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GREEN-LOOP

Sustainable manufacture systems towards novel bio-based materials

**WP2 – Sustainability and Circularity by design**

## **D2.3 – Energy, exergy, LCA, SLCA and LCC assessments**

Version 1.0

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## GREEN LOOP Key Facts

|                        |                                                                                                                                 |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Project title          | Sustainable manufacture systems towards novel bio-based materials                                                               |
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| Consortium             | 17 organizations: 15 from EU Member States + 2 from UK                                                                          |

## GREEN LOOP Consortium Partners

|    | Partner                                                                                    | Acronym | Country |
|----|--------------------------------------------------------------------------------------------|---------|---------|
| 1  | IDENER RESEARCH & DEVELOPMENT                                                              | IDE     | ES      |
| 2  | NATIONAL INSTITUTE OF CHEMISTRY                                                            | NIC     | SI      |
| 3  | SLOVENIAN NATIONAL BUILDING AND CIVIL E. I.                                                | ZAG     | SI      |
| 4  | FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V                       | FHF     | DE      |
| 5  | GUALA CLOSURES                                                                             | GUALA   | IT      |
| 6  | MIXCYCLING SRL                                                                             | MYX     | IT      |
| 7  | NERO SU BIANCO                                                                             | NSB     | IT      |
| 8  | GERACE MARIA CRISTINA - TERRE DI ZOE'                                                      | TDZ     | IT      |
| 9  | IRIS TECHNOLOGY SOLUTIONS, SOCIEDAD LIMITADA                                               | IRIS    | ES      |
| 10 | GLOWNY INSTYTUT GORNICTWA                                                                  | GIG     | PL      |
| 11 | AACHEN UNIVERISTY: PROCESS CONTROL ENGINEERING / AACHEN UNIVERISTY: INSTITUTE OF SOCIOLOGY | AAU     | DE      |
| 12 | AUSTRIAN STANDARDS INTERNATIONAL                                                           | ASI     | AT      |
| 13 | INSTITUTO DE SOLDADURA E QUALIDADE                                                         | ISQ     | PT      |
| 14 | AXIA INNOVATION UG                                                                         | AXIA    | DE      |
| 15 | ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE                                       | AIMEN   | ES      |
| 16 | NATIONAL COMPOSITE CENTER                                                                  | NCC     | UK      |
| 17 | UNIVERSITY OF BRISTOL                                                                      | UBRIS   | UK      |

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## Executive Summary

The present document, deliverable **D2.3 – Energy, exergy, LCA, SLCA and LCC assessments** compiles the results of GREEN-LOOP’s tasks **T2.2 – Energy and Exergy analysis of the systems** and **T2.3 – Tools and methodology for LCA, LCC, and Social LCA assessments**. The results included focused on the value chains developed within the activities of WP6, continuing the analyses of **D2.2 – Energy, exergy, LCA, SLCA and LCC assessments** under WP2, evaluating the improvement in both the saving and quality of energy and the environmental impact of the manufacturing process. These two tasks were carried out for D2.3 in order to achieve the objectives of the project, which are: to develop the three innovative bio-based materials (bio-rubber, bio-plastic and wood composites); to implement circular business models; to promote sustainable manufacturing; and to accelerate market adoption by reducing manufacturing costs and improving the sustainability of products.

For this purpose, the value chains carried out in WP3, 4, and 5 by the corresponding partners have been upgraded to more consolidated technology levels (i.e., to industrial scales) within the scope of tasks **T6.2, T6.3** and **T6.4**, which are related to the three manufacturing products considered in GREEN-LOOP (bio-rubber, bio-plastic and wood composites, respectively). Moreover, this deliverable (DV) consists of the conclusion of the findings at laboratory scale presented in D2.2, after scaling up to industrial levels at the final of the project (M36); the discussion about these upgrades includes the analysis of the energy transformation in terms of quantity and quality and the assessment of the environmental impact and costs of the different products manufactured at industrial scales.

In order to achieve the assessment of the project at TRL6, IDE and AIMEN (as leaders of tasks T2.2 and T2.3, respectively) have adhered to the same standardised **methodology** applied in the previous DV, outlined in **section 2**. This methodology encompasses the following steps: gathering process data via questionnaires, illustrating the process steps in Process Flow Diagrams (PFDs), computing the inventory rate equations, and conducting the results analysis. This approach ensures consistency and comparability across the different process developments within the project. Regarding the Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) evaluations, AIMEN adhered to established standards, specifically, the LCA was conducted in accordance with ISO 14040, while the LCC followed the UNE-EN 60300 guidelines.

Regarding the energy and exergy analysis, these evaluations have been similarly carried out in the present DV compared to D2.2, analysing the processes from an efficiency performance perspective, comparing not only the amount of energy required for the machinery to operate, but also the mass-energy rate that characterizes the successful of the manufacture to produce an unit of product mass with the minimal energy consumption and the quality of the energy -i. e., the exergy involved within the process-. The exergy analysis helps to understand the

irreversibilities that take place throughout the steps of the processes and allows for the comprehension of their mechanisms by determining the potential of energy to optimally be used, which is related to the energy losses through the efficiency of the equipment and the heat exchange that comes from the materials' mass flows.

The Life Cycle Assessment (LCA) and the Life Cycle Costing (LCC) have been successfully completed; moreover, the Social Life Cycle Assessment (SLCA) has also been considered in the present DV, which was not included in D2.2 since the project was still at laboratory scale to study the social impact of the project. These evaluations played a critical role in identifying key environmental impacts, economic implications, and potential social effects of the developed manufacturing processes. The inclusion of industrial-scale data in this final analysis provides a more realistic view of the sustainability and cost-efficiency of the technologies, supporting informed decision-making for future implementation and scaling.

Throughout the duration of the project, ongoing assessments have enabled process optimisation and supported project partners in scaling up their manufacturing solutions. This final deliverable reflects the cumulative work carried out over the project's lifetime, offering a complete and integrated analysis of the energy, environmental, economic, and social performance of the GREEN-LOOP technologies at an industrial scale.

In conclusion, the studies carried out under T2.2 and T2.3 have successfully conducted up to the final state of the project at TRL6, leading to the comprehension of the efficiency in the machinery used for the value chains and the circularity of the materials used within their manufacturing processes, achieving thus the upscaling to obtain TRL6 under the objectives of WP6 as well as the assessments of circular economy established in GREEN LOOP project. The improvements of manufactures are also proposed at the end of the document, regarding the energy and exergy analysis, as well as the LCA and LCC, presenting potential upgrades in the value chains for future upscaling.

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## Abbreviations and Acronyms

|           |                                                   |
|-----------|---------------------------------------------------|
| CM        | Compression Moulding                              |
| D/DV      | Deliverable                                       |
| DR        | Discount rate                                     |
| EF        | Environmental Footprint                           |
| E-LCA     | Environmental Life Cycle Assessment               |
| EoL       | End-of-Life                                       |
| EwS       | Europe without Switzerland                        |
| FEED      | Front-End Engineering Design                      |
| HDPE/LDPE | High-Density or Low-Density Polyethylene          |
| IRR       | Internal Rate of Return                           |
| ISO       | International Organisation for Standardisation    |
| LCA       | Life Cycle Assessment                             |
| LCA FE    | LCA for Experts                                   |
| LCC       | Life Cycle Costing                                |
| LCI       | Life Cycle Inventory                              |
| LCIA      | Life Cycle Impact Assessment                      |
| LCSA      | Life Cycle Sustainability Assessment              |
| LCT       | Life Cycle Thinking                               |
| M         | Month                                             |
| MM        | Metallic Mix                                      |
| MP        | Microplastics                                     |
| mrh       | Medium risk hours                                 |
| MRIO      | Multi-Regional Input/Output                       |
| MW        | Microwave                                         |
| NCC       | Naphtha Cracking Centre                           |
| NPV       | Net Present Value                                 |
| OEF       | Organisation Environmental Footprint              |
| PFD       | Process Flow Diagram                              |
| PHA       | Polyhydroxyalkanoates                             |
| PHBH      | 3-hydroxybutyrate-co-3-hydroxyhexanoate           |
| PLA       | Poly lactide Acid                                 |
| RP        | Rubber Panel                                      |
| T         | Task                                              |
| TRL       | Technology Readiness Level                        |
| VC        | Value Chain                                       |
| WP        | Work Package                                      |
| WPL       | Work Package Leader                               |
| PBP       | Petroleum-Based Polymer                           |
| PEF       | Product Environmental Footprint                   |
| PHA       | Polyhydroxyalkanoates                             |
| PHB       | Poly-3-hydroxybutyrate                            |
| PHBH      | Poly-(3-hydroxybutyrate-co-3-hydroxyheanoate)     |
| PLA       | Poly lactic acid                                  |
| PRP       | Performance Reference Point                       |
| PSILCA    | Product Social Impact Life Cycle Assessment       |
| SETAC     | Society of Environmental Toxicology and Chemistry |

|       |                                    |
|-------|------------------------------------|
| S-LCA | Social Life Cycle Assessment       |
| SKU   | Stock-Keeping Units                |
| TDP   | Tyre Derived Polymer               |
| TIN   | Nominal Interest Rate              |
| UK    | United Kingdom                     |
| UN    | United Nations                     |
| UNEP  | United Nations Environment Program |
| USA   | United States of America           |
| VC    | Value chain                        |
| VOC   | Volatile Organic Compounds         |
| WH    | Worker Hours                       |
| WP    | Work package                       |



## 1. Introduction

This document, named **D2.3 – Energy, exergy, LCA, SLCA and LCC assessments**, extends the analysis carried out in previous deliverable (D2.2), considering the updated data of process in upscaling of tasks **T2.2 - Energy and Exergy analysis of the systems** and **T2.3 - Tools and methodology for LCA, LCC, and Social LCA assessments**: these tasks were performed under scope of WP3, 4 and 5 to determine both the environmental impacts of the value chains and the energy and exergy balances at TRL5.

Furthermore, to determine the performance of the value chains (VC) evaluated within this project at TRL5 (bio-rubber, bio-plastic and wood composites manufactures) in scaling up to TRL6, partners and manufactures involved in these VC have collaborated to develop the manufacturing processes in this state of the project. The manufacture partners have given support to the analysis of the mass, energy and exergy balances by updating the process flow diagrams (PFDs) and by providing the corresponding updated data (estimations in case of lack of the information needed to carry out calculations).

### 1.1. Objectives

The objective of this deliverable (DV) is to update the processes performed in previous state of the project, which was focused on a laboratory scale, and determine the major changes and improvements introduced through the tasks T2.2 and T2.3 in scaling up to TRL6. In this statement, the main objectives pursued by the project that are also contemplated in WP6 are listed below:

- **Environmental sustainability:** The project prioritizes environmentally friendly production, reducing the environmental footprint from sourcing to recycling.
- **Circular economy:** All processes are designed to keep materials in circulation as long as possible, maximizing reuse and minimizing waste through optimal recycling and in-depth audits of waste streams.
- **Interdisciplinary innovation:** GREEN-LOOP integrates diverse expertise from engineering, chemistry, biology, materials science, and data science, fostering collaborative development and replicable results.
- **Continuous improvement:** Plans are constantly evaluated and improved based on monitoring, feedback, and audits to ensure ongoing optimization and adaptation to new knowledge and technologies.

The **analysis of mass, energy and exergy balances and the assessments about the life cycle of the value chains** provides valuable insights about the development of the project compared to the results in D2.2. The main points of the objective to study the improvements are the following:

- Coordination with AIMEN with regard to the LCI and LCA updates at TRL6 and their inclusion in the present DV.

- Close communication with the rest of consortium partners to gather the novelties introduced at TRL6 (under statements established in WP6) in the value chains analysed in GREEN LOOP in WP3, 4 and 5, making a comparison to the results obtained at a lab scale.
- Regarding the previous point, partners must notify about any modification in PFDs during scale up of the value chains and complete the questionnaires available to facilitate the analysis of the processes with the available data.
- Update of the rate equations used in the analysis of energy and exergy balances and validation of the results by partners.

To develop the study regarding the sustainability of GREEN-LOOP, an environmental, economic, and social assessment of the three value chains (VCs) developed within the project has been proposed.

The objective of this study is to assess the manufacturing of each case of use based on the data obtained during the project's life in every technical task in WP6: bio-rubber panels in Task T6.2, bioplastic closures in T6.3, and wood composites from T6.4. For the sake of comparison, the environmental and social impacts will be presented along with the current manufacturing process (state-of-the-art) to contextualise the values within the current situation.

The Life Cycle Sustainability Assessment (LCSA) was initially proposed by Klöpffer and Renner in 2008 [1] as a holistic combination of three separate life cycle analyses, which include the three dimensions of sustainability:

- Environmental Life Cycle Assessment (E-LCA),
- Life Cycle Costing (LCC),
- and Social Life Cycle Assessment (S-LCA).

This document aims to study the scope of the transition of the project up to TRL6 from a lab scale (TRL5) and analyse the main changes introduced during the process, focusing on the environmental impact considered in LCI and LCA and the mass, energy and exergy balances carried out in the processes of the three VC developed by partners in GREEN-LOOP.

## 1.2. Scope

The scope of subtask T2.2 was defined in **D2.2**, which considered the energy and exergy analysis of the processes involved in the project, which are bio-rubber (NCC), bio-plastic (GUALA) and wood composites (FHF) manufacturing. In line with the assessments in D2.2 regarding this analysis, the final exergy costs of these three value chains (VCs) will be determined to comprehensively analyse the upscaling of the process. The properties of components used within each manufacture and the characteristics of the corresponding final products are provided by the WPLs, which have been contacting to rest of consortium to gather the information and include it in the datasheets -filled templates are present in **Annex 1: Process**

**datasheets for mass, energy and exergy balance-**, so that IDE can perform the mass, energy and exergy balances of the VCs. The next table shows the VCs that are considered under the scope of the project, including the associated tasks, WP and the partners involved in their development:

*Table 1. Manufacturing processes developed within GREEN LOOP up to TRL6*

| Value chain            | Task | Partners                        | Final product               |
|------------------------|------|---------------------------------|-----------------------------|
| <b>Bio-Rubber</b>      | T6.2 | <b>NCC</b> , UBRIS, NIC and ZAG | Rubber panels               |
| <b>Bio-Plastic</b>     | T6.3 | <b>GUALA</b> , MIX and TDZ      | Limoncello / olive oil caps |
| <b>Wood Composites</b> | T6.4 | <b>FHF</b> and GUALA            | Wood composite plates       |

In addition, whereas in D2.2 only LCA and LCC for the three VCs were included under the scope of the task T2.2, in the task T2.3 AIMEN has also carried out the social LCA (s-LCA). The analysis of the impacts of the project aims to include the three pillars of sustainability (environment, economic, and social) within one versatile, coherent, and holistic framework based on the comprehensive 4-step process proposed by ISO 14044:2006 [2], that supports the principles of Life Cycle Thinking (LCT), *i.e.*, creating a tool designed to evaluate the sustainability of products, goods, or services throughout their whole life cycle. The holistic point of view states that all the properties of a system cannot be determined or explained only individually by the parts that compose it. Therefore, full integration of all aspects is needed and can only be achieved by considering the three dimensions of sustainability and the whole life cycle.

The first methodological guidance for LCSA was published in 2011 by the United Nations Environment Programme (UNEP) in collaboration with the Society of Environmental Toxicology and Chemistry (SETAC) and Life Cycle Initiative [3]. The document includes instructions and examples about how to perform LCSA and a conceptual definition of LCSA: “*Life Cycle Sustainability Assessment refers to the evaluation of all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle.*”

In the following sections, a comprehensive review of the Life Cycle Assessment (LCA) methodology and its application to various dimensions will be provided. The data and diagrams with regard to this analysis are present in **Annex 2: Supplementary material from the LCA** and **Annex 3: Supplementary material from the s-LCA**. The results of both types of analysis -on the one hand, the energy and exergy; on the other hand, LCA/LCC- are discussed through both the **sections 3 and 4** according to the scope of D2.3, and the conclusions about the results are

present at the end of the document, in **section 5**; nonetheless, the established goals have successfully been achieved during upscaling, such as introducing more environmental friendly species and recycled materials, or improving the efficiency of manufacturing machinery in the processes.



## 2. Methodology

### 2.1. System definition

Similarly to the methodology followed in D2.2, all WP leaders of each VC have been contacted and requested information to assess the modifications and upgrades implemented during the upscaling of their manufacturing processes towards TRL6 to create a series of process flow diagrams (PFDs) based on the ones developed at TRL5.

The PFDs follow the following structure:

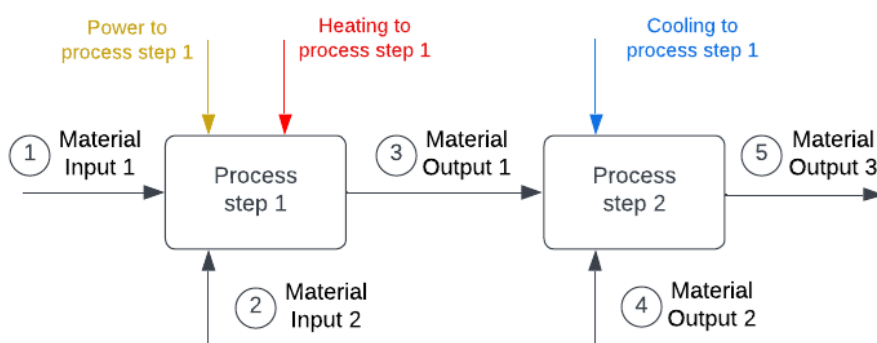


Figure 1. Example of a hypothetical PFD following the structure developed in T2.2

After the creation of the PFDs for each of the manufacturing processes, IDE has validated with each of the responsible partners within the consortium to start preparing the process technical datasheets of the manufacturing processes, requesting project partners to provide the information contained within the files. Then, IDE contacted the partners again for further validation and refinement of the data, whenever necessary to solve potential deviations or minor incongruencies found. Finally, validated questionnaires are obtained. The WP leaders responsible for the WP6 tasks related to each VC are listed next, including the rest of consortium partners: **WP3 and T6.2** (bio-rubber), leaded by **NCC** with the support of **UBRIS, NIC and ZAG**; **WP4 and T6.3** (bio-plastic), leaded by **GUALA** and supported by **MYX and TDZ**; and **WP5 and T6.4** (wood composites), by **FHF** in collaboration with **GUALA**.

The complete iterative data gathering protocol for task T2.2 is described in the following figure:

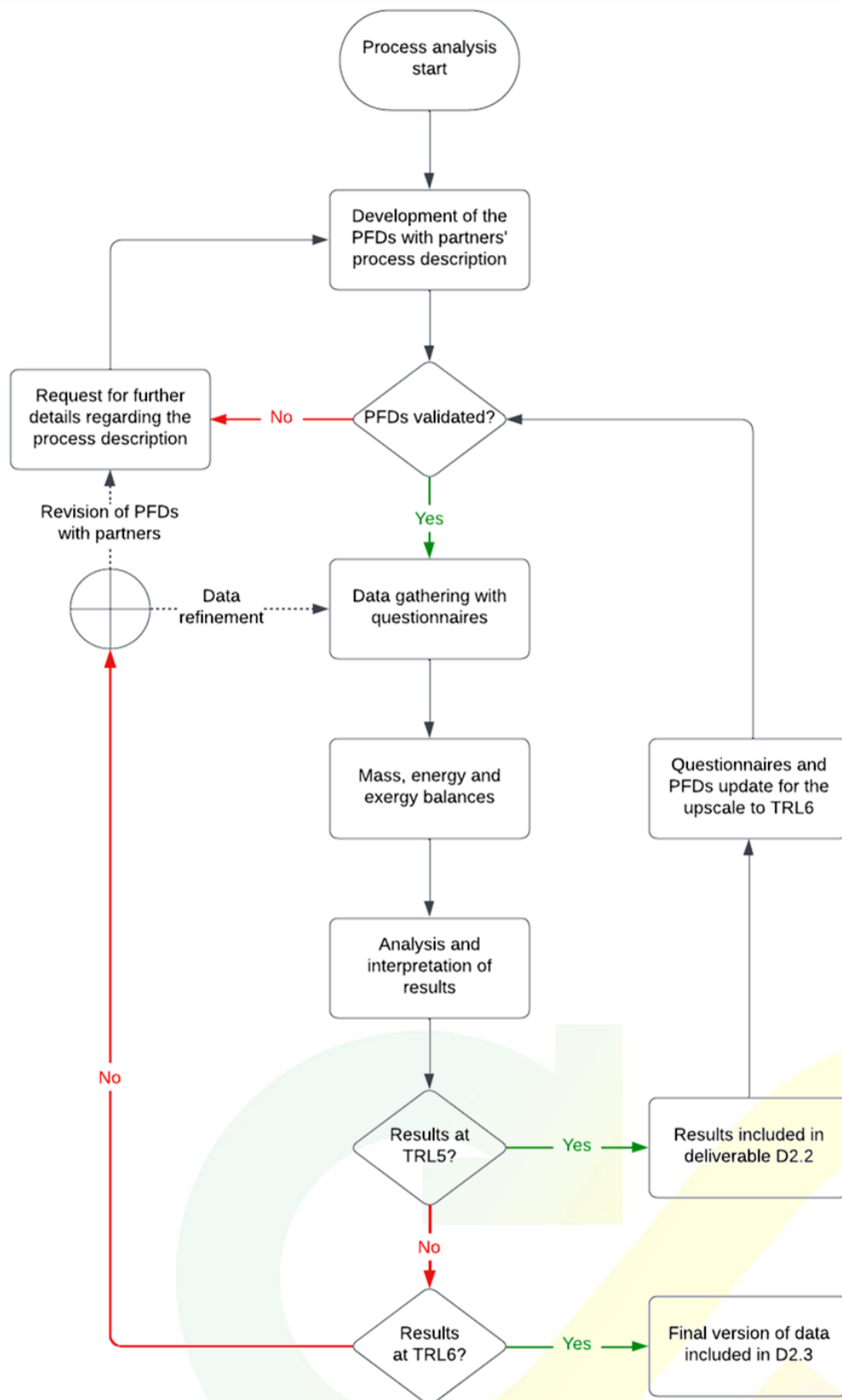


Figure 2. Data gathering protocol used in task T2.2

## 2.2. Energy and exergy analysis

To perform mass and energy analysis of industrial processes, it is necessary to develop inventory rate equations for each of the process steps in the system [4] using the laws of conservation of mass, energy or momentum and additional physics laws.

All inventory rate equations are comprised of the following terms:

$$\left( \frac{\text{Rate of}}{\text{input of } i} \right) - \left( \frac{\text{Rate of}}{\text{output of } i} \right) + \left( \frac{\text{Rate of}}{\text{generation of } i} \right) = \left( \frac{\text{Rate of}}{\text{accumulation of } i} \right) \quad (1)$$

Whereas "i" represents the variables that is being analysed, usually its mass, energy, exergy, or momentum. To define and solve the equations, several aspects of the manufacturing processes developed within GREEN-LOOP must be assessed with these next steps:

- 1) Definition of the systems, including components and limits, provided by the manufacturing partners.
- 2) List the assumptions used for the analysis: in order to perform the manufacturing system evaluation, the process is represented to a mathematically simple form through reasonable assumptions to enable a faster analysis.
- 3) Develop the proper inventory rate equations for each basic element in the system.
- 4) Use empirical correlations if necessary to evaluate transfer coefficients if they are not available.
- 5) Solve the algebraic and differential equations depending on the assumptions made for the system and using the initial conditions for the differential equations provided by manufacturing partners whenever necessary.

After all the inventory rates equations have been solved in a process, the analysis of mass flows and energy flows can be performed and represented in a Sankey diagram, which serves as a powerful visual tool not only by shedding light on any possible enhancements of the process, but also quantifying where it would be more efficient to do so.

Furthermore, to support the upscaling of the manufacturing processes analysed in the previous DV, IDE has created a series of process engineering datasheets -the structure of datasheets is described in **section 2.2.3**- that in addition to this purpose, enhance the presentation of results and reduce the time necessary for data collection to perform the analysis of energy and exergy balances.

## 2.2.1. Heuristics followed during the analysis

Following the same approach adopted in D2.2 methodology, usual standards in process engineering have been applied within the assumptions carried out in the task to facilitate the analysis in the current project stage, TRL5. A list with the assumptions followed in this DV is provided:

- The total enthalpy of a system cannot be measured directly because the internal energy contains components that are unknown, not easily accessible, or are not of interest for the thermodynamic problem at hand. Therefore, when performing an energy analysis is paramount to define a reference temperature  $T_{ref}$  and state of matter to properly assess changes in the energy of a system.
- Although the specific heat capacities of components and mixtures vary with temperature, at small changes of temperature a mean value between both range values can be used without significant deviations (e.g., in the designing of heat exchangers)
- Accumulated values of parameters are considered instead of rates since processes consists of batches, so that the balances have a base calculus linked to their specific process. Therefore, absolute units replace rate units in datasheets: g, dm<sup>3</sup> and kJ instead of g/h, dm<sup>3</sup>/h and kWh/h, respectively.
- A “Notes” section is included in datasheets in order to include considerations related to variables or other kind of statements, e. g. the balances are evaluated in their specific process in terms of the amount of substrate coated (dm<sup>3</sup>).

Furthermore, some of the parameters needed for process balances are only accessible to manufactures (e.g. the efficiency of a motor of a specific potency), for this reason a series of heuristics common across process engineering from literature have been applied in analysis:

- Energy efficiency of heating systems that are not fully detailed is considered as 85% [5].
- As well as heating systems, the energy efficiency of cooling systems is assumed to be 70% [6].
- Energy efficiency of evaporator and compressor systems is considered as 70% in both cases [7].
- Every device driven by a motor (such as power supply devices) is assumed to have an energy efficiency of 85% [8].
- Energy efficiency of pumps is estimated to be 90% of the power required [7].

## 2.2.2. Inventory rate equations development

The same development process described in **Mass balances, Energy balances and Exergy balances** from **section 2.2.2 of D2.2** has been followed for this DV, therefore no additional information is presented. The expressions of these equations throughout the states of the processes have been used to calculate both the

energy and exergy balances within their steps. equations have been used from a general perspective,

## 2.2.3. Process technical datasheets development

In process engineering, process technical datasheets are widely used by engineering companies in their Front-End Engineering Design (FEED) and detailed engineering designs by different departments, especially process engineers, to model, simulate, size, and design process equipment and plant utilities (e.g., cooling water, electricity consumption, etc.).

For GREEN LOOP, IDE has developed a series process technical datasheets (**Annex 1: Process datasheets**) to be used in as the mass as the energy and exergy balances of the system, and divided them into the following categories:

- **BM-1 (Balances):** These are the process datasheets in which the main material data are included, as well as the properties of the streams.
- **BM-2 (Compositions):** The compositions of the streams present in the process are included here.
- **PPUU-1 (Cooling demand):** These datasheets include the cooling needs of the system using cooling water or other utilities.
- **PPUU-2 (Cooling water):** These datasheets include the cooling water needed by the processes.
- **PPUU-3 (Heating demand):** These datasheets include the heating needs of the system using electricity or the combustion of fuels to create the heat.
- **PPUU-4 (Fuel consumption):** These datasheets include the fuel consumption of the system.
- **PPUU-5 (Electricity):** These datasheets include the electricity consumption of the system.
- **W-1 (Solids), W-2 (Liquids) & W-3 (Gases and Vapours):** These datasheets include all the wastes generated during the processes, being solids, liquids or gases/vapours.

Moreover, in the case of bio-rubber production, BM has been divided into several datasheets, which correspond to each of the sub-processes involved in the VC: lignin extraction and rubber panels production.

For the purpose of traceability and data consistency, if the value of one of the variables represented in the system does not apply (e.g., the % of water vapor in a gaseous stream without water), instead of leaving empty the row, a “-” will be added so future process engineering working with these datasheets will consider it during their own assessments; in contrary, in the cases a chemical involved in the process does not participate in a consider step (e. g., the mass percentage of a component in a mixture after it has been removed), their lack will be indicated through a “0” value. Furthermore, if there are some variables which are unknown

(e.g., the amount of minor gases generated during a process), it will be marked as “Unknown” in the datasheets, and considerations taken during analysis such as estimations in calculus will be included in the “Notes” section at the bottom of the datasheets.

## 2.3. Life Cycle Analysis

The first phase of the LCA is where the assessment is conceptually planned. Defining the goal implies clarifying what product system will be assessed with what objective. The objectives could vary depending on the dimensions and the stakeholders. Still, it is important to describe a system that could be representative from an environmental, economic, and social point of view. Therefore, all the decisions taken during the Goal and Scope phase of LCSA must be applied transversely across the E-LCA, LCC, and S-LCA. This scope will be discussed later in the sections dedicated to the Objective and Scope of each of the analyses covered in this document.

Analyses of Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA) are aligned with the project's objectives, as each addresses key dimensions of the project's sustainability. The LCA focuses on assessing recyclability, as well as waste reduction and greenhouse gas emissions. It is complemented by other relevant impact categories, providing a comprehensive view of the environmental effects of the product's life cycle. The LCC, meanwhile, will estimate capital and operating costs, possible cost reductions, and indirect economic impacts derived from environmental externalities. It will also include the residual value of the asset at the end of its useful life. This will enable an assessment of its long-term economic viability. Finally, the SLCA will focus on various social indicators related to social impact categories, beginning with raw materials and resources in the initial stages of the project (WPs 3 to 5) and expanding in the validation phase to incorporate industrially relevant data (WP6), thus ensuring a thorough and contextualised social evaluation.

The scope collects the information provided in the goal and delineates it by defining the following elements:

- The functional unit, which describes a representative physically meaningful quantity of a product, good, or service linked to its end-use application. Inside the study, it enables objective comparison throughout the life cycle.
- The reference flow, which represents the quantity of materials needed to produce the functional unit.
- The system boundaries that identify which parts of the product system will be considered in the assessment.
- The methodological framework, including data quality requirements, data collection strategies, allocation procedures, assumptions required, and impact indicators. The methodology framework varies depending on the type of LCA as

well as the impact indicators selected; hence, it will be discussed in the specific sections.

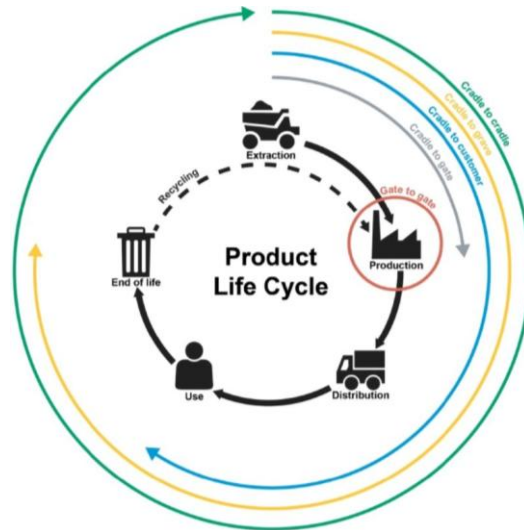


Figure 3. Different scopes for LCA [9]

While defining the system boundaries, some problems must be tackled. The first is the necessity to decide what life cycle stages will be included within the assessment. In cases where the entire life cycle (*i.e.*, the extraction and processing of raw materials or basic components, the manufacture of the final product, the use phase, and the recycling or final disposal/management) is considered, a “Cradle-to-Grave” scope is used. If the End-of-life (EoL) scenario proposes recycling some of the materials in a closed loop, *i.e.*, reusing them as a raw material, then the scope is named “Cradle-to-Cradle”. Conversely, in other cases of study, not all the life cycle is within the system boundaries. When the analysis stops as soon as the product is on the market (right after de manufacturing step) is referred to as “Cradle-to-Gate” scope, while when only the manufacturing stage is included, it is denominated “Gate-to-Gate” scope.

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The second issue is deciding how to allocate the impacts among the different products obtained. Allocation is defined as the method to split up the contribution of individual constituents of the product system between the different outputs based on different criteria, depending on the scope of the LCA (mass, cost/value, other physical properties, ...). Although selection and allocation criteria above the other are subjective, it is necessary to provide insights about how the choice was made, ensuring the transparency of the assessment.

### 2.3.1. Steps from Life Cycle Methodology description

According to UNEP guidelines, the three dimensions of LCSA could be evaluated following the same four-step framework, originally proposed for E-LCA in the ISO 14044:2006 (Figure 4). These four steps are:

- Objective and Scope definition, that encompasses the description of the system under assessment and the definition of the objective (or goal) and intended use of the study.
- Life Cycle Inventory (LCI), focused on collecting all the information that describes the system under assessment.
- Life Cycle Impact analysis (LCIA), in which the LCI is transformed into real or potential impacts by different methodologies depending on the dimensions.
- Interpretation, in which the results are analysed concerning the objective and scope to extract conclusions and recommendations.

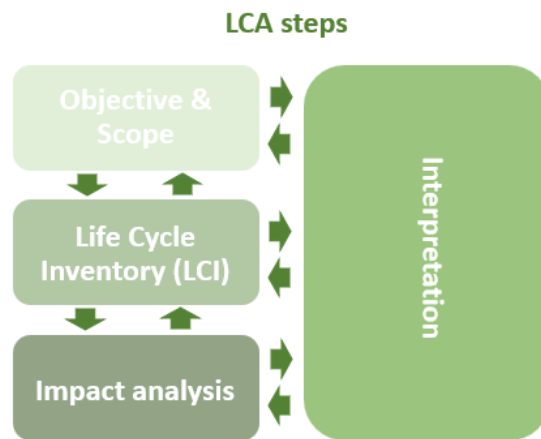


Figure 4. ISO 14040:2006 4-step framework for the Life Cycle Assessment (LCA).

As it can be seen in Figure 4, all the phases are interconnected since assessment is expected to be refined once more data is acquired. This leads to an iterative process in which communication between practitioners, policymakers, and professionals is key.

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## Goal and scope

Each of the following sub-section will define their respective goal and scope of the analyses, as well as the functional units for each value chain studied. Even though the framework is common, the slight differences between the dimensions make it necessary to describe their application individually. However, in all the cases, the practitioner who performs a Life Cycle Assessment (LCA) must:

- Understand the system under assessment, set an objective, define what parts of the system are relevant, and decide representative impact indicators.
- Collect all the foreground data (environmental, economic, or social) of the product system within the system boundaries previously defined.
- Analyse these data to extract the impact values supported by databases and impact calculations methodologies.
- Present the conclusions as positive or negative (environmental, economic, or social) impacts, organised in a coherent manner that permits establishing strategies for their reduction.

## *Dataset selection and data collection for Life Cycle Inventory (LCI)*

Typically, the product system is defined by a series of unit processes, each represented as a “step” within the overall system. During the LCI step, the focus is on collecting representative information about all the unit processes in the form of flows. Depending on their interaction with the unit system, two types of flows could be described:

- **Inputs:** use of raw materials, parts or products; transport; electricity; energy requirements, equipment costs, social aspects, etc., which are used in each unit process/phase of the system.
- **Outputs:** emissions to air, water, and soil; wastes and by-products that are considered in each process/phase of the system.

All the information provided by these flows is considered the foreground system, *i.e.*, the primary data that specifically embodies and describes the system under assessment. Usually, these data are not enough to translate the flows into impacts, requiring support from more generic data that fills the gaps, composing the background system (also named secondary data). The large datasets collected in the background data not only provide an overview of the supply chains but also allow the results to be broken down by product category, brand, or individual stock keeping units (SKUs). This granular analysis can help consumers make more informed purchasing decisions and guide companies on how to prioritize sustainability improvements in their product portfolios.

LCA is a data-intensive methodology that requires information from primary sources. However, the access to these data is limited for the practitioners, either owing to confidentiality restriction or immature value chains. Therefore, the three dimensions of LCSA usually need to rely on background data to conduct the analysis. For instance, in the case of environmental dimension, the background system is able to link the flows with elementary flows, *i.e.* direct exchanges between your product system and the environment in both directions, such as extraction of raw materials or emissions of contaminants. In the economic and social dimensions, background systems make use of other strategies to link the flows with the impacts, that will be discussed in the following sections.

Additionally, it must be pointed out that impacts related to auxiliary processes such as transport, storage or distribution should be collected in the LCI providing they are part of the system boundaries.

## *Elaboration of Life Cycle Inventory (LCI)*

The collection of all input/output flows is the basis for the third phase of LCA, the impact analysis, where the Life Cycle Impact Analysis (LCIA) is carried out. This is calculated using characterisation factors, which represent the contribution of any flow to a given impact category relative to a reference unit or value. For instance,

the CO<sub>2</sub> is the reference substance for the environmental impact category “*climate change*” with the reference unit “*kg of CO<sub>2</sub> equiv.*”. Thus, emitting 1 kg of CO<sub>2</sub> is equivalent to 1 kg of CO<sub>2</sub> equiv. in “*climate change*”. However, methane has a global warming potential 34 times greater than CO<sub>2</sub>, so the emission of 1 kg of CH<sub>4</sub> equals to 34 kg of CO<sub>2</sub> equiv., since methane characterisation factor is 34.

## Calculation of results

The subsequent LCIA implies the translation of the input/out flows into the environmental, economic or social impacts of interest for the value chains under assessment. To ease the process, software like SIMAPRO, OpenLCA or LCA For Experts is used. After completing the mandatory steps, there are optional steps that can be carried out depending on the objective and intended scope. These are as follows:

- **Normalisation:** Conversion of the characterisation results to global neutral units, dividing each by a normalisation factor. These factors represent the degree of contribution of each impact category to the local environmental problem.
- **Grouping:** Classification of impact categories into other groups encompassing impact categories with similar effects.
- **Weighting:** Conversion of the results of the characterised values into a common and summable unit (in case the methodology includes a normalisation, from the normalised values), by multiplying them by their weighting factor. They are then summed to obtain a single total score for the environmental impact of the system.

## Interpretation

The first matter that must be pointed out about the interpretation phase is that it must be performed transversely throughout the other three phases. Owing to the iterative and interconnected nature of the 4-step methodology (Figure 4), the interpretation is the phase where the framework is cautiously revised while the objective, the scope, the model and assessment is carried out.

According to the ISO14044, this phase should include:

- Identification of significant issues based on the LCI and the LCIA phases
- Evaluation of the sensitivity and robustness of the study itself
- Conclusions, suggestions and recommendations to mitigate the impacts.

To conclude, it must be reminded that the final aim of a LCA is to support the decision-making processes, so its final output should be aligned with this idea.

### 2.3.2. Environmental Life Cycle Assessment

The first dimension of LCSA is the environmental life cycle assessment (E-LCA). The principles to this methodology were laid down in the early 1990s by the SETAC.

Later, in 2006, the International Organisation for Standardisation (ISO) established a framework for the standardisation of the LCA methodology in the context of environmental assessment [2]. Concretely, two ISO standards are relevant to the E-LCA:

- **UNE EN ISO 14.040:2006:** Environmental Management. Life Cycle Analysis. Principles and reference framework.
- **UNE EN ISO 14.044:2006:** Environmental Management. Life Cycle Analysis. Requirements and guidelines. According to the standardisation carried out, four phases can be distinguished in an LCA study (Figure 4).

Within this normative, the E-LCA is defined as “compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle”. In the case of the GREEN-LOOP project, E-LCA is expected to support the decision-making process in the three VCs from an environmental perspective.

During the Objective and Scope phase of E-LCA, it is necessary to define the impact categories of interest and the methodology that will be used to calculate the impacts. These categories represent the environmental impacts of interest (either at mid- or an endpoint) to which the results of the LCIA will be assigned. In other words, the environmental impacts for which results are searched. There are several environmental impact categories, and the choice will depend on the objective of the study, the target audience and the level of precision of the results required.

The Product Environmental Footprint (PEF) is an impact assessment scientific tool designed to quantitatively translate the LCI data into contributions to environmental impacts of concern of products, goods or services [10]. Along with the Organisation Environmental Footprint (OEF) methods, the PEF is collectively known as Environmental Footprint (EF) methodology. The development of the method, that was originally proposed in 2013 [11], has been coordinated by the European Commission and has been carried out through an extensive international consultation process with experts, stakeholders and the public with the aim of harmonising EU methodologies to calculate and mitigate environmental impacts taking into account the supply chain activities (from extraction of raw materials to the End-of-Life) [12]. Currently, the EF method addresses 16 impact categories selected with the criteria of covering a broad range of relevant environmental issues, providing for each of them a scientific based characterization model.

During the second phase, the LCI the foreground data is collected as physical flows like raw material masses, energy consumption, transport distances, emissions or wastes. The background data is provided by databases like ecoinvent 3.11. The EF methodology also gives guidelines to model the product system considering the cut-off criteria, electrical use or the transport distances, among others.

During the third phase, environmental impacts could be presented as midpoint or endpoint indicators. Midpoint indicators focus on single environmental issues, not addressing how they will ultimately affect the stakeholders, while endpoint indicators focus on aggregating the midpoint indicators in three categories: effect on human health, biodiversity and resource scarcity. Endpoint indicators require weighting and aggregating the impacts, increasing the uncertainty but simplifying the interpretation phase.

Table 2. Environmental Impact Categories considered in EF 3.0 for E-LCA

| Environmental impact category      |                                                                                                                                                                                                                   | Reference unit          | Indicator                                                |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|----------------------------------------------------------|
| Climate change, total <sup>1</sup> | The potential of a greenhouse gas to trap extra heat in the atmosphere over time. The enhanced heat trapping is caused by the absorption of infrared radiation by a given gas                                     | kg CO <sub>2</sub> eq   | Radioactive forcing as Global Warming Potential (GWP100) |
| Ozone depletion                    | Destruction of the protective ozone layer in the polar regions of the Earth's stratosphere brought about by interaction of gaseous (e.g. CFCs) emissions with NOX and UV radiation                                | kg CFC-11 <sub>eq</sub> | Ozone Depletion Potential (ODP)                          |
| Human toxicity, cancer             | The toxicity impacts to humans posed by the system processes (waste/pollutant/emissions) which have potentially carcinogenic effects. The level will depend on estimates of environmental fate and human exposure | CTUh                    | Comparative Toxic Unit for humans                        |
| Human toxicity, non-cancer         | The toxicity impacts to humans posed by the system processes (waste/pollutant/emissions) which have not carcinogenic effects. The level will depend on estimates of environmental fate and human exposure         | CTUh                    | Comparative Toxic Unit for humans                        |
| Particulate matter formation       | The release of fine particulates at ground level, which can have a negative impact on human health                                                                                                                | Disease incidences      | Human health effects associated with exposure to PM2.5   |
| Ionising radiation, human health   | Impact indicator for all the emissions of radioactive elements, which have potentially carcinogenic effects                                                                                                       | kBq U <sup>235</sup>    | Human exposure efficiency                                |

<sup>1</sup> The indicator "Climate Change, total" is constituted by three sub-indicators: "Climate Change, fossil"; "Climate Change, biogenic" and "Climate Change, land use and land use change".

| Environmental impact category               | Reference unit        | Indicator                                                     |
|---------------------------------------------|-----------------------|---------------------------------------------------------------|
| Photochemical ozone formation, human health | kg NMVOCeq            | relative to U235<br>Tropospheric ozone concentration increase |
| Acidification                               | mol H <sup>+</sup> eq | Accumulated Exceedance (AE)                                   |
| Eutrophication, terrestrial                 | mol N <sub>eq</sub>   | Accumulated Exceedance (AE)                                   |

| Environmental impact category | Reference unit     | Indicator                                                     |
|-------------------------------|--------------------|---------------------------------------------------------------|
| Eutrophication, freshwater    | kg P <sub>eq</sub> | Fraction of nutrients reaching freshwater end compartment (P) |
| Eutrophication, marine        | kg N <sub>eq</sub> | Fraction of nutrients reaching marine end compartment (N)     |
| Ecotoxicity, freshwater       | CTU <sub>e</sub>   | Comparative Toxic Unit for ecosystems (CTU <sub>e</sub> )     |
| Land use                      | Soil quality index | Soil quality index                                            |

| Environmental impact category     |                                                                                                                                                                                                                                                                  | Reference unit                                                                           | Indicator                                                                                     |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Water use                         | It takes into account the length of time over which such use is sustained, and the degree to which the land can be restored to its original condition after the use has ceased                                                                                   | Kg biotic production<br>Kg soil<br>m <sup>3</sup> water<br>m <sup>3</sup> of groundwater | Biotic production<br>Erosion resistance<br>Mechanical filtration<br>Groundwater replenishment |
|                                   | This impact quantifies the water withdrawal-to-availability ratio of the system under consideration. "Withdrawal" refers to all off-stream water use which excludes water extracted and subsequently returned to the environment unpolluted (e.g. cooling water) | m <sup>3</sup> world eq. deprived water                                                  | User deprivation potential (deprivation-weighted water consumption)                           |
| Resource use, minerals and metals | The cumulative extraction of non-living, non-renewable resources such as minerals and metals                                                                                                                                                                     | kg Seq                                                                                   | Abiotic resource depletion (ADP ultimate reserves)                                            |
| Resource use, fossil              | The cumulative extraction of non-living, non-renewable resources such as fossil fuels                                                                                                                                                                            | MJ                                                                                       | Abiotic resource depletion-fossil fuels (ADP-fossil)                                          |

### 2.3.3. Life Cycle Costing

The Life Cycle Costing is the second dimension of LCSA. The principles to this methodology were laid down in the standard UNE-EN 60300-1:2015 [13]. Despite being oriented towards the analysis of reliability, safety, maintainability, maintenance, support and requirements of operations, it was chosen to describe the economic dimension of Green Loop since the other standards (UNE-EN 15643-4:2012 [14], UNE-EN 16627:2016 [15], or ISO 15686-5:2017 [16]) are intended to be used for LCC of buildings.

The LCC is used to calculate the economic impacts, in shape of direct or indirect cost, identify cost hotspots and define strategies to mitigate these negative impacts. UNE-EN 60300 defines LCC as: "Methodology that evaluates the total

*cost of a product, system or service throughout all the stages of its life cycle, from acquisition to final disposal"*

Therefore, LCC is not a business costing tool, but expresses the monetary value of an asset taking into account the internal costs associated with its life cycle. LCC quantifies the relationship between economic and environmental optimisation of the system under consideration to understand how economic activities affect environmental activities and vice versa. LCC is ideally suited for application to products and building components, as it facilitates cost savings and quantifies the economic value of environmental improvements of these products and services. In the case of GREEN-LOOP project, LCC is expected to facilitate the integration of the economic aspects as pillars in three VC. The UNE-EN 60300 guidelines for calculation of LCC defines a complete road map that could be aligned with the 4-steps LCA methodology (Figure 4):

- Define the objectives and scope in line with the decision-making process for which the analysis will be used. In the case of the LCC, this phase includes identifying and estimating the resources and elements that will contribute the most to the costs.
- Develop or select the most appropriate LCC model more adequate for the objective of the assessment, considering aspects like selectivity and sensibility.
- Collect the cost data (foreground system) to describe the product system, subsystems and supportive infrastructure based on the LCC model proposed in the previous step.
- Perform the cost analysis of product operational scenarios defined in the objective and scope.

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Once the cost analysis is finished, the interpretation phase compares the results to the initial model to see whether the assessment meets the objective requirements and determines the most significant impacts. Additionally, to enhance the robustness of the assessment, the practitioners could refine the results by:

- Quantifying the differences in product performance, availability and other relevant constraints between the alternatives considered, unless these differences are directly reflected in the results of the LCC model.
- Performing sensitivity analyses to examine the impact of assumptions and uncertainties about cost elements on the results of the LCC model, paying particular attention to key cost drivers and assumptions about product usage and the time value of money.

Finally, to present the conclusions and support the decision-making process, results are grouped and summarised according to a logical grouping (recurring or

non-recurring costs, acquisition, ownership or disposal costs, etc.) that may be relevant to the stakeholders.

## 2.3.4. Reference values and environmental externalities

To develop the LCC, several values related to the economy have to be calculated and used in this latter analysis, which are defined in terms of the Net Present Value (NPV), which is the sum of discounted future cash flows (i.e., discounted at a discount rate), including both costs and revenues.

Another thing to consider in the LCC are the environmental externalities, i.e. cost associated with the palliation of an affection achieved on the environment. For example, the energy consumption causes a series of emissions that have impacts on the environment. These costs have an impact on the global economy of the process. To calculate the environmental externalities, the “European Environmental Prices (2015)” [17] is used. This method consisted of five steps:

1. Updating monetary values of the endpoint categories based on literature, General SCBA Guidelines, and Discount Rate Working Group.
2. Updating the impact pathway analyses, which specify the relationship between emissions in the Netherlands and impacts on endpoints.
3. Valuation of 15 pollutants based on inputs from the previous steps and literature,
4. Allocation of those pollutants to midpoint impact categories in EF v3.1.
5. Deriving the weighted average value for damage to midpoint categories to calculate the damage cost for each substance characterised in EF v3.1 and midpoint damage factors.

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## 2.3.5. Social Life Cycle Assessment (S-LCA)

The Social Life Cycle Assessment (S-LCA) is considered the third, and less mature, dimension of LCSA. In 2009 UNEP in collaboration with SETAC took a step forward in standardising S-LCA by publishing the first version of “*Guidelines for Social Life Cycle Assessment of Products*”, a voluntary-use document that provides guidance to conduct a social life cycle assessment (S-LCA). Lately, in 2020, the guidelines were updated in collaboration with the Social Life Cycle Alliance, publishing a new document entitled “*Guidelines for Social Life Cycle Assessment of Products and Organizations*” [18]. The new version of the guidelines, that was widely referenced in the social LCA scientific literature, proposes to carry out the assessment following the same comprehensive 4-step methodology (Figure 4) in coherence with the other two dimensions of sustainability.

S-LCA aims to assess the social performance or risks of products, goods and services. According to Benoît Norris *et al.*: “*Social performance refers to the principles, practices, and results of a company’s interactions with stakeholders, including individuals, organisations, institutions, communities, and society. It*

*encompasses both intentional business actions and unintended side effects, assessed against established standards.” [19]*

On the other hand, social risk refers to the likelihood of adverse social effects due to companies or business-related activities in a given sector within a country. Therefore, contrary to the environmental or economic dimensions, S-LCA's results does not provide information about whether a product should or should not be produced, but evaluates the social quality of the supply chains, providing a consistent view of social hotspots and potential social impacts along the life cycle of the products and promoting Corporate Social Responsibility (CSR).

As in the other two dimensions, during the objective and scope phase it is necessary to describe the methodology that will be used to guide the data collection strategies (LCI) and the impact analysis (LCIA). For this, the guidelines propose two different options, depending on the availability of primary data:

- The Reference Scale Approach (Type I or Reference Scale S-LCA), that assess the **social performance** or **risks** based on performance reference points (PRP). The PRPs are calculated by establishing social risks and lead to obtaining potential social impacts that could arise from the company activities but does not provide enough evidence to affirm these impacts are really occurring.
- The Impact Pathway Approach (Type II or Impact Pathway S-LCA), that predicts the real consequences of the product system based on establishing causal relationships between the social performance of organizations and the **social impacts**.

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During the LCI phase, it must be pointed out the additional complexity of translating qualitative data into quantitative indicators in S-LCA [20]. Currently, qualitative foreground data (that is scarce and difficult to collect from primary sources) is portrayed as working hours, a value that measures the number of labour hours necessary to complete a unit process. Although other activity variables were proposed (such as added value), worker hours are the most meaningful and, therefore, preferred option, since a large number of hours working at a given unit process implies the stakeholders are exposed to the social impacts related to the process for a longer time. In order to determine the worker hours for each unit process, it is possible to ask the different value chain actors, a time-consuming process, or to calculate it using hypotheses and estimations, a less reliable alternative

In the case of the LCIA, UNEP guidelines suggest 6 stakeholder categories that represent all the social actors potentially affected by S-LCA outcomes: workers, value chain actors (companies or suppliers), local communities, society, customers or children. The stakeholder categories are, in turn, divided into 40 subcategories, each of them represented by at least one inventory indicator. Inventory indicators are simple variables that provide the status of a certain topic, life cycle stage or

process. Currently, UNEP guidelines give examples of inventory indicators in their Methodological Sheets for Subcategories in S-LCA, but not a closed list [21]. Owing to the complexity that some researchers have found to select representative inventory indicators [22], it is recommended to use supportive social databases like PSILCA [23].

The results of S-LCA are difficult to interpret because data aggregation could mislead the conclusions or hide hotspots. As in the other cases, sensitivity analysis is recommended to check the quality of the assumptions.

### 2.3.6. Datasets and computational tools used

Within this project, the practitioners have used two different LCA software:

- SIMAPRO, a software developed by PRé Sustainability, that is compatible with databases like Ecoinvent or PSILCA.
- LCA For Experts (LCA FE), a software developed by Sphera Solutions GmbH, that is compatible with Ecoinvent and several Sphera sectorial databases. LCA For Experts will be used in the E-LCA of T6.4.

For developing the E-LCA, firstly, the required primary data will be collected in collaboration with technical partners, following that the primary data will be completed with background data provided by two possible environmental databases combined with sustainability assessment software:

- Ecoinvent 3.11 database with SIMAPRO software
- LCA for Experts database with LCA For Expert software

Finally, the LCIA phase is carried out with the software and the impact assessment method EF 3.0. For developing the LCC, the same primary data collected in the E-LCA will be used. The technical partners have provided information about the equipment, operational and labour cost. Following that, the market prices will be updated using global prices databases, like **EU Comtrade**, or wholesale trading webpages, like **Alibaba.com**, to predict the future raw materials costs. Thus, the economic impacts will be calculated using an Excel document.

And finally, to perform the S-LCA we will rely on the costs calculated during the LCC transformed to USD (average currency exchange from the past 5 years). Then, data will be supported with social database PSILCA and SIMAPRO to calculate the social impacts. In the following sections, the three background databases used within the project will be described.

#### *Environmental LCA Database: Ecoinvent 3.10*

Ecoinvent is a E-LCA database developed by the Ecoinvent Centre, firstly released in 2003, that contains high-quality environmental data about processes, materials and products across various sectors such as energy, manufacture of products or goods, transport, agriculture and construction activities. The database is described

as comprehensive, consistent and transparent, updated frequently with new entries and compatible with several LCA software. Currently, it contains over 25000 unique datasets modelling human activities or processes, and impact calculation methodologies such as EF 3.0, supporting a broad range of sustainability assessments.

The database contains by three different datasets, all of them related to physical flows like mass, volume or energy:

- Elementary flows, the basic unit that composes all ecoinvent processes, containing the characterisation factors to translate the physical flows into environmental impacts aligned with the characterisation model of LCIA methods like ReCiPe2016 or EF3.1.
- Transformation activities, that represent human activities to transform inputs into different outputs. These datasets contain raw materials, energy consumptions, emissions and wastes, altogether modelling the environmental impacts related to the activity based on primary data or literature.
- Market activities, that represent the consumption mix of a product, good or service at a given region, including the transport distance and possible product losses happening during them. Although market datasets do not transform the product, they include the transformation activities too and, therefore, their use is recommended over transformation activities when modelling the LCI. To calculate transport distances, if not primary data is available, ecoinvent has published reference scales to calculate freight distances [24].

Additionally, the market and transformation activities are geographically located, allowing the assessment of different countries' environmental practices. During the LCIA phase Ecoinvent provides two different ways to present the results: system and unit:

- System describes the impacts by normalising and aggregating them into transformation or market activities, e.g. all the ozone depletion (kg CFC-11<sub>eq</sub>) caused by the elementary flows included in the datasheet “Chlorine gaseous | market for chlorine gaseous | System”.
- Conversely, unit describes the impacts as a list of all the elementary flows included within the product system. E-LCA is a data intensive methodology in which collecting up to date primary data from companies and experts is key. However, this data carries sensitive information that must be treated confidentially. In this context, some datasheets are modelled and later presented as unit processes even for the database user.

Based on this complex structure, ecoinvent is used in collaboration with software like SIMAPRO, Open LCA or LCA For Experts, that enable modelling unitary processes by linking foreground data into representative datasets. The information within these datasets is a complex supply chain, ultimately decomposed on a list of elementary flows containing the environmental impact equivalences (i.e.

characterization factors). Finally, during the LCIA phase the results are aggregated or weighted and presented either as system or unit processes depending on the confidentiality requirements.

During GREEN-LOOP project, Ecoinvent 3.10 database will be used in combination with SIMAPRO to carry out the E-LCA of T6.2, T6.3 and T6.4.

## *Environmental LCA database: LCA for Experts*

LCA for Experts databases were designed to be compatible with the sustainability software LCA For Experts (previously named LCA for Experts), providing up to 15000 plans and processes built as a combination of many unitary processes or flows and mainly based on primary data collected from around 500 companies worldwide. They even provide the user with impact calculation methodologies such as EF 2.0 and 3.0.

The database is compliant with ISO 14040 and ISO14044 and was originally released in 1989 and is updated annually since 2013.<sup>2</sup> Structurally talking it is composed by three different datasets:

- Flows, that work similarly to Ecoinvent elementary flows, referred to different raw materials and providing a list of characterisation factors to translate physical quantities into environmental impacts following the conclusions of LCIA methodologies.
- Processes, created from the primary data collected from the industrial experts. They represent human activities to transform raw materials by combining different flows.
- Plans, that combine different processes to create product systems in the same way as unitary processes are used to describe the system under assessment in LCA.

Additionally, processes are geographically located, allowing the assessment of different countries' environmental practices. LCA for Experts databases pay special attention to confidentiality, describing all the processes as a list of flows in the same way as unit processes in Ecoinvent. During GREEN-LOOP project, the basic version of LCA for Experts database will be used in combination with LCA For Experts to carry out the E-LCA of T6.4.

## *S-LCA Database: PSILCA*

Product Social Impact Life Cycle Assessment (PSILCA) is a comprehensive database developed by Green-Delta GmbH that provides regionalised background information about representative supply chains, social risks and average worker hours per USD from 187 countries and 15909 industrial sectors. The database was originally designed for OpenLCA, but is compatible with SIMAPRO as well. PSILCA

<sup>2</sup> LCA for Experts Databases. <https://ghgprotocol.org/LCA-for-Experts-databases>

is built following the Reference Scale (Type I) S-LCA described in the UNEP guidelines and the EORA Multi-Regional Input/Output (MRIO) database, a model that reflects the world’s economy structure and uses monetary flows in USD to link processes across different sectors and countries [25]. Thus, the database used USD as input flows [26].

In order to transform the monetary flows into impacts, PSILCA established two PRP scales, one for positive social impacts (opportunity level) and other for negative social impacts (risk level). The scale for positive social impacts is composed by 4 levels of social risks that apply positive (1, 10) or negative (0.1, 0) scaling factors to the inventory indicator. It is represented by the PRPs “*High Opportunity (x10)*”, “*Medium Opportunity (x1)*”, “*Low opportunity (x0.1)*” and “*No opportunity (x0)*”.

The scale for negative impacts is composed by 5 levels of social risks that use negative (1, 10 or 100) or positive (0.1 or 0.01) scaling factors to the inventory indicator. It is represented by the PRPs “*Very High Risk (x100)*”, “*High Risk (x10)*”, “*Medium Risk (x1)*”, “*Low Risk (x0.1)*” and “*Very Low Risk (x0.01)*” (Table 3). In the cases in which there is no information, the PRP is represented as “*No data*” and multiplied by the scaling factor 0.1 (Table 3). The two PRP scales was established based on international conventions and standards, expert opinions or database developers’ experience.

Table 3. Performance Reference Point used in PSILCA database.

| <i>Performance Reference Point (PRP) –<br/>Negative social impact</i> | <i>Scaling factor</i> |
|-----------------------------------------------------------------------|-----------------------|
| <i>Very Low Risk</i>                                                  | x0.01                 |
| <i>Low Risk</i>                                                       | x0.1                  |
| <i>Medium Risk</i>                                                    | x1                    |
| <i>High Risk</i>                                                      | x10                   |
| <i>Very High Risk</i>                                                 | x100                  |
| <i>No data</i>                                                        | x0.1                  |
| <i>Performance Reference Point (PRP) –<br/>Positive social impact</i> | <i>Scaling factor</i> |
| <i>No opportunity</i>                                                 | x0                    |
| <i>Low Opportunity</i>                                                | x0.1                  |
| <i>Medium Opportunity</i>                                             | x1                    |
| <i>High Opportunity</i>                                               | x10                   |

Structurally talking, the database is composed by three different entries:

- **Commodities**, that represent an average for the provision of a certain good within a country from different industries, *i.e.* the supply chain necessary to provide that good in a specific country.

- **Industries**, that represent an industrial sector within a country able to provide more than one commodity, *i.e.*, the supply chain of this industry in a specific country combined with an average value of worker hours per USD.
- **Social aspects**, that represent a list of inventory indicators linked with PRP, different for each industry and country.

UNEP guidelines, in their aim not to constrict the evolution of S-LCA, does not provide a closed list of inventory indicators but recommendations to create or choose them for each subcategory. As an alternative approach for it, PSILCA provides a list of 70 qualitative and quantitative inventory indicators for a set of four stakeholders, divided into 20 subcategories [23]. The four stakeholders are: *workers, local communities, society and value chain actors* (not including the stakeholders children and consumers described by the UNEP) and the 20 subcategories are described in Error! Reference source not found. The 70 inventory indicators, or social aspects, are clearly defined and linked to PRPs, providing information about how they were calculated.

Thus, with this large and organised background structure it is possible to overcome the weak data availability problems of S-LCA and build LCI. The foreground data is introduced in the database as monetary flows (USD) and each social aspect is linked with a PRP that defines qualitatively its social risk within this sector and country. Following that, the unit processes are proxied, combining the monetary flows with the average value of worker hours per USD and the social aspects contained in the most representative industry within the company's country. Finally, the upstream impacts are modelled using commodities whenever it is possible, as GreenDelta GmbH recommends.

The social impacts are presented in medium risk hours (mrh), a weighting unit that is calculated by aggregating the impacts for a given social impact of all the unitary processes that form the product system. Depending on the type of inventory indicators, a higher number of mrh could represent a positive or negative impact. The type of PRP selected (opportunities or risks) for each indicator provides information about this. The formula to calculate the medium risk hours (mrh) of the inventory indicator  $j$  on PSILCA based on the WH/Unit process  $i$  and the PRP of the inventory indicator  $j$ .

$$mrh(h)_j = \sum_{i=1}^n [WH_i / \text{Unit process} \times PRP_j (\text{Opportunity or risk})]$$

$j$  = inventory indicator

$n$  = total number of unit process

$i$  = unit process

During the GREEN-LOOP project, the PSILCA database will be used in combination with SIMAPRO to carry out the S-LCA of T6.2, T6.3 and T6.4.

Table 4. Description of the 20 subcategories included in four stakeholder categories in PSILCA

| Stakeholder               | Subcategory                                      | Inventory indicators                                                                                                                                                                                                                                                           |
|---------------------------|--------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Workers</b>            | Child labour                                     | Children in employment – female, male or total                                                                                                                                                                                                                                 |
|                           | Forced labour                                    | Frequency of forced labour<br>Good produced by forced labour<br>Trafficking in persons                                                                                                                                                                                         |
|                           | Fair salary                                      | Living wage, per month<br>Minimum wage, per month<br>Sector average wage, per month                                                                                                                                                                                            |
|                           | Working time                                     | Weekly hours of work per employee                                                                                                                                                                                                                                              |
|                           | Discrimination                                   | Gender wage gap<br>Men in the sectoral labour force<br>Women in the sectoral labour force                                                                                                                                                                                      |
|                           | Health and safety (Workers)                      | DALYs due to indoor and outdoor air and water pollution<br>Presence of sufficient measures<br>Rate of fatal accidents at workplace<br>Rate of non-fatal accidents at workplace<br>Violations of mandatory health and safety standards<br>Workers affected by natural disasters |
|                           | Social benefits, legal issues                    | Evidence of violation of laws and employment regulations<br>Social security expenditures                                                                                                                                                                                       |
|                           | Freedom of association and collective bargaining | Right of association<br>Right of collective bargaining<br>Right to strike<br>Trade union density                                                                                                                                                                               |
|                           | Fair competition                                 | Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation                                                                                                                                                                                     |
|                           | Corruption                                       | Active involvement of enterprises in corruption and bribery<br>Public sector corruption                                                                                                                                                                                        |
| <b>Value Chain Actors</b> | Promoting Social Responsibility                  | Social responsibility along the supply chain                                                                                                                                                                                                                                   |

## 3. Technical analysis development

### 3.1. Energy and exergy analysis

The following modifications compared to their TRL5 counterparts have been made to the manufacturing process developed within GREEN LOOP: Next, A discussion about the modifications introduced in the three value chains (VC) compared to their TRL5 counterparts is shown, including the improvements of the equipment regarding the balances of mass, energy and exergy in upscaling. Moreover, the process flow diagrams (PFDs) corresponding to these processes are included for a better understanding of the performance and equipment involved in each VC.

#### 3.1.1. Bio-rubber manufacture (WP3)

In D2.2, the process was divided into three processes: lignin extraction, rubber functionalisation and their introduction as inputs among the chemicals used to produce the rubber panels (RPs). However, in the current document only two processes are analysed, the lignin extraction and the RPs production, so the functionalisation of rubber is no longer considered in the analysis of the process. Note that in the next sub-sections, the steps involved in the lignin extraction are denoted with “a” whereas them corresponding to rubber panel production are denoted with “b”, since these are the first and second manufacturing sub-processes of the VC, respectively.

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#### Mass balance

The mass flows are separately analysed in both sub-processes, lignin extraction (“a” in the PFDs and the technical datasheets in **Annex 1: Process datasheets for mass, energy and exergy balance**) and the rubber panel production (“b” in the PFDs and the datasheets).

#### Lignin extraction

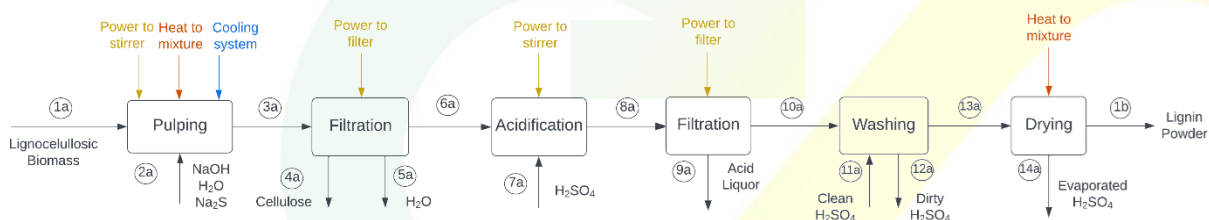


Figure 5. PFD of the lignin extraction within the bio-rubber manufacture

The lignin extraction presents no major changes regarding the manufacturing process, i. e., the PFD of this sub-process is the same as in the previous deliverable

(DV); the novelties regarding the flows of mass and energy are analysed throughout this section.

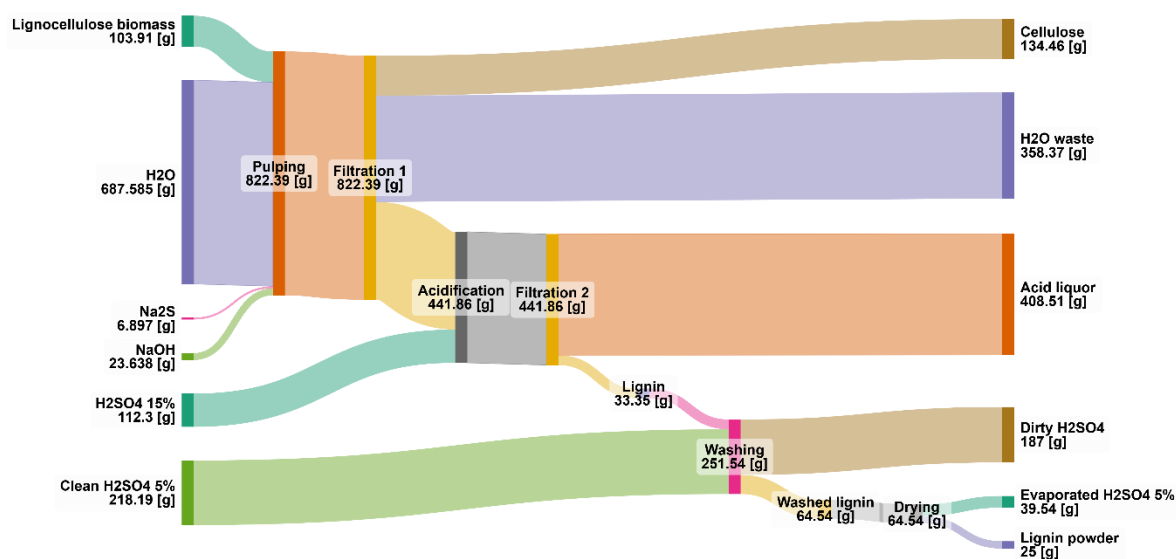


Figure 6. Sankey diagram of the mass flow for lignin extraction

In the previous state of the project, lignocellulose biomass was converted into three compounds (cellulose, hemicellulose and lignin) throughout the introduction of water,  $\text{Na}_2\text{S}$  and  $\text{NaOH}$  during pulping. Then, the cellulose was removed alongside a fraction of the water, and sulfuric acid ( $\text{H}_2\text{SO}_4$  15 %) is introduced in acidification hydrolysing the hemicellulose, which is totally converted into sugars. Finally, during filtration the acid liquor of mixture was removed from the system ( $\text{H}_2\text{O}$ ,  $\text{Na}_2\text{S}$ ,  $\text{NaOH}$  and sugars), only remaining the lignin, which was washed with  $\text{H}_2\text{SO}_4$  at 5 % to prepare it for the production of the RPs. In this case, the amount of lignocellulose biomass introduced as inlet has been reduced, so a fraction of the materials used during the manufacture have been saved compared to the previous DV. Moreover, after the removal of acid liquor, part of water remains alongside the lignin -it represents a 20 % of the mixture-, which is removed within washing through the application of  $\text{H}_2\text{SO}_4$  5 % and their later vaporisation in the drying oven.

## Rubber panel production

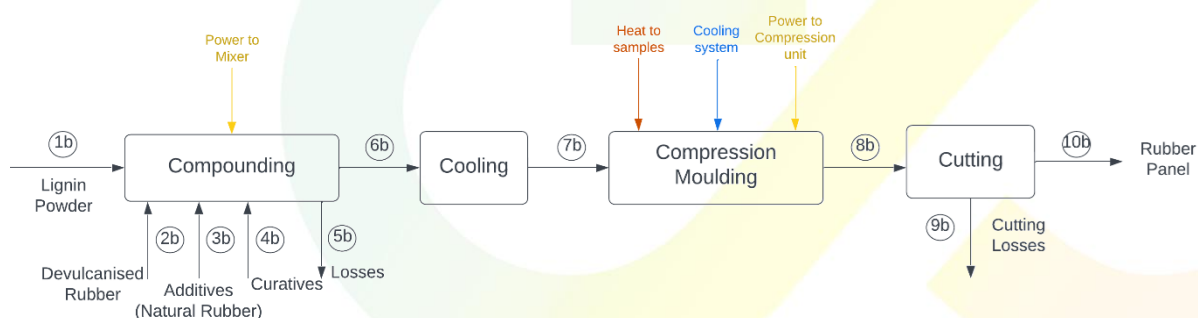


Figure 7. PFD of the rubber panel production within the bio-rubber manufacture

The PFD has been reordered, introducing some changes throughout the involved steps: the cutting, which was originally placed between the compounding and the cooling of the mix, has been shifted toward the end of the process in the current state, replacing the machining.

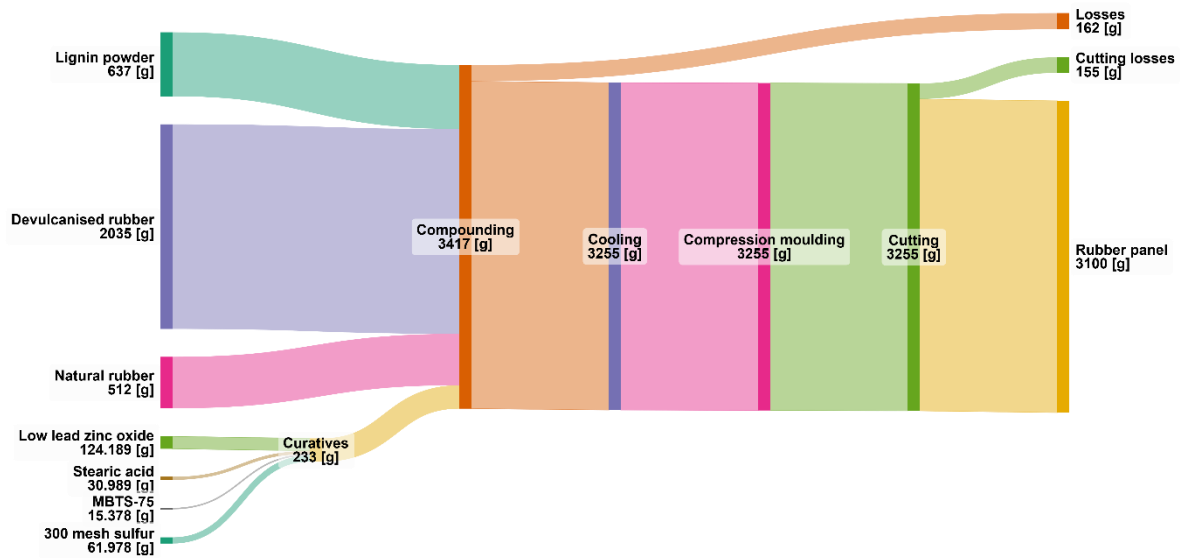


Figure 8. Sankey diagram of the mass flow for rubber panel production

At TRL6, a major inlet mass is used in a batch: whereas at TRL5 only the amount of lignin and devulcanised rubber produced during a manufacturing batch were considered as input (25 g and 80 g, respectively), now 637 g of lignin and 2035 g of devulcanised rubber are introduced during compounding, i. e., the amount of cured rubber has been increased from 115 g to 3100 g in a batch. The composition of chemicals in the mixture remains approximately the same, in contrary to the process at TRL5 no losses are taken into account during moulding in this case, but they are all carried out in compounding and cutting.

## Energy balance

The consumption of energy is simultaneously discussed for both sub-process in contrary to the mass balance since the mechanisms of energy demand occur in parallel and they all contribute to the total energy consumption of the manufacture.

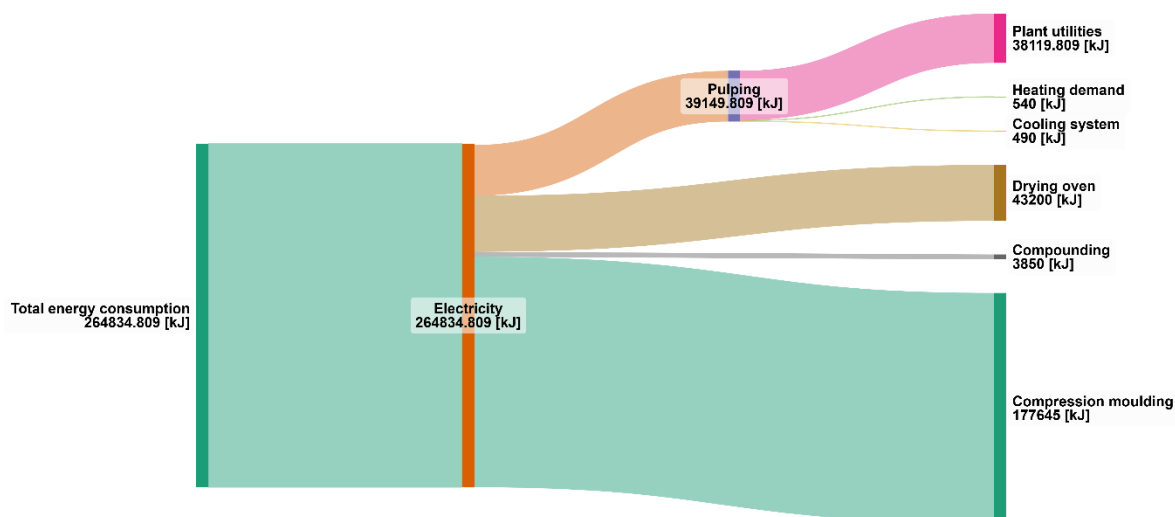


Figure 9. Sankey diagram of the energy flow for bio-rubber manufacture

The energy consumption of both processes involved in the manufacture of bio-rubber are simultaneously analysed in Figure 9 since the total energy of the whole process gathers several types of machinery electrical demand that are divided into parallel end-use consumptions.

The electrical consumptions in both the filtration and acidification performed during the extraction of lignin are negligible compared to the corresponding values in the oven and the compounding  $\sim 10^3$  kJ compared to  $\sim 10^4$  kJ, so these components are excluded from the analysis. Compared to the process state in D2.2, consumption related to heating and cooling are available, whereas the mechanical demand during pulping of components is unknown. For this reason, an estimation of the mechanical consumption has been made taking into account the calculus of previous DV, considering energy consumed per unit of mass in pulping. On the other hand, the heating demand of the oven used to dry the lignin and remove  $H_2SO_4$  is 43200 kJ, whereas the heat exchange to the lignin was 83.47 kJ at TRL5; since the oven is entirely used to heat the product, this mismatch could be due to the efficiency of power-to-heat conversion, and to the specific heat of remaining components ( $H_2SO_4$  and water), which only need a fraction of the heating to evaporate and exit the system.

Within the panels production, only the compounding and compression moulding (CM) present energy consumption, since cutting is done manually. From these two components, the CM represents the major consumption of the whole process, which includes pressing, heating and cooling.

## Exergy balance

Similarly to the energy balance, the exergy is simultaneously analysed in all the steps to divide the losses of energy into the irreversibilities present in the manufacturing process.

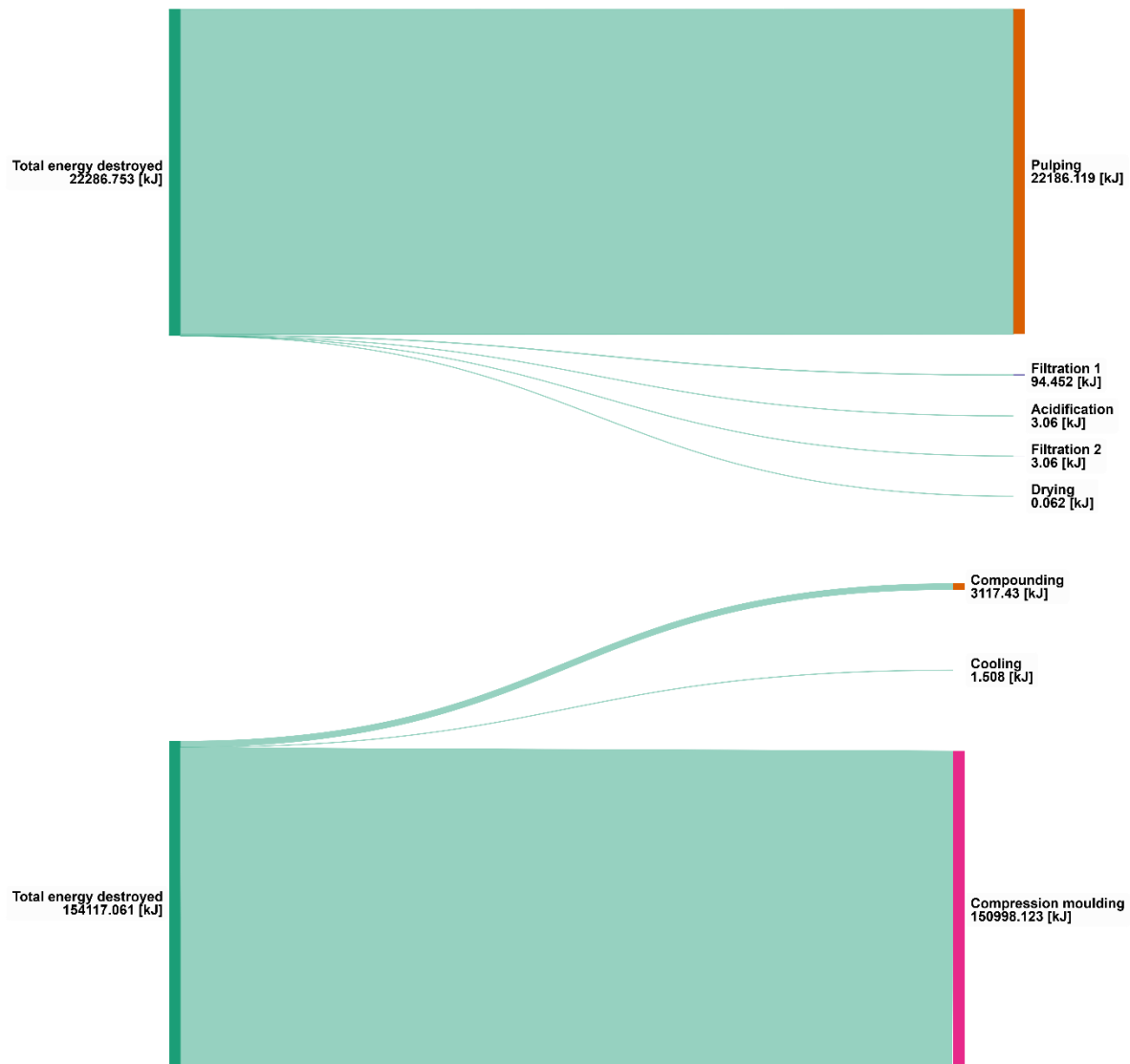


Figure 10. Sankey diagram of the exergy flow for bio-rubber manufacture. Lignin extraction at the top, rubber panel production at the bottom

In contrary to energy consumption, in the exergy analysis both sub-processes (lignin extraction and rubber panel production) are separately showed in the Figure 10 since the scale of destruction of energy (also known as irreversibility) is different in both diagrams and thus the results can be better discussed:

- In lignin extraction, the pulping in the high-pressure batch reactor represents the significant irreversibilities, due to both mechanical consumption during pulping and the heating demand, which leads to the increasement of temperature of inlet up to 448.15 K. The mixture is cooled in the filtration 1, leading to a loss of energy in the outlet mass flow through the heat exchange with the surroundings, i. e., the destruction of energy that could have been used. During the acidification and the filtration 2 the destroyed energy only is due to the shaft work since there are no changes

in the temperature of species, and finally only heating demand is present in drying, which means a minor fraction of the irreversibility during the whole process.

- In rubber panel production, the destruction of energy mostly comes from the compression moulding, since this step requires high amounts of energy consumption -for heating, cooling and mechanical work- to press the mixture, which simultaneously leads to a major loss of useful energy. The increase in temperature during compounding due to both heating and shaft work leads to irreversibilities that are still present within manual cooling, where species give their heat to the surroundings up to reach the room temperature.

### 3.1.2. Bio-plastic manufacture (WP4)

The bio-plastic manufacturing process has been tested for two separated products of bio-plastic: limoncello and olive oil caps. The formulations for these two products are the same, although the machinery applied during manufacture is different in the two processes, leading to a different energy consumption. In addition, two kind of formulations -compounded by 80 % of polyhydroxyalkanoates (PHA) and 20 % of rice husk- have been tested in both products; nevertheless, the official tests have been conducted for the 3-hydroxybutyrate-co-3-hydroxyhexanoate (PHBH) modified MFI formula, so the analysis have been carried out for this kind of composition.

#### Mass balance

The mass flows are the same in both productions (limoncello and olive oil), since the official tested compositions present no differences in formulations (80 % PHBH modified formula and 20 % rice husk) during the whole process.

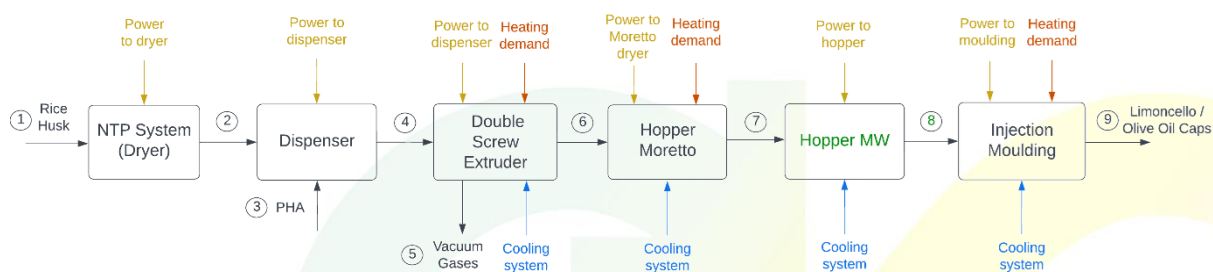


Figure 11. PFD of the bio-plastic manufacture

Compared to D2.2, an extruder has been introduced within the process and the hopper is considered separately from the dispenser, before the injection moulding; hopper MW is also included in the production of olive oil caps. Moreover, a dryer is included at the beginning of the process to remove the humidity of the inlet materials.

Depending on the manufacture -either limoncello or olive oil caps-, different machines have been used for the moulding: in limoncello manufacture a “Baby

Pressa” have been used, whereas olive oil caps are processed within a JSW55 moulder. These two equipment components require different amounts of electricity, which will lead to different consumptions in the energy analysis (**section Energy balance**).

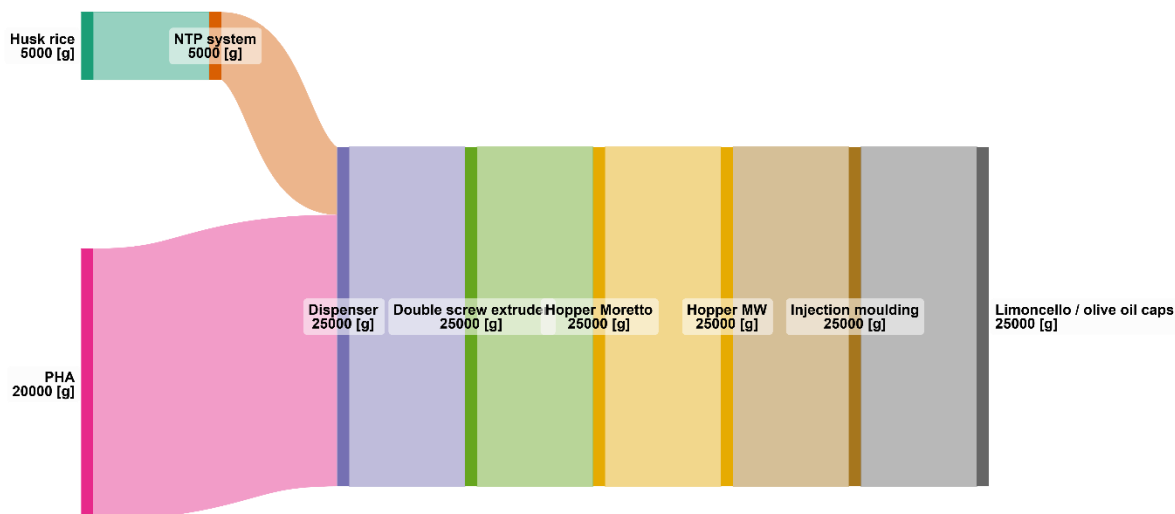


Figure 12. Sankey diagram of the mass flow for bio-plastic manufacture

Both the polylactide acid (PLA) and the cork have been replaced by rice husk, which is the element that is introduced within the dryer of the NTP system. An unknown amount of gases are generated during drying in the NTP system, whereas the rest of materials correspond to 5 kg of rice husk that are combined to the PHA (PHBH modified) within the dispense; with this regard, only the 5 kg of husk rice are considered in the analysis and is supposed that no wastes are present during this step, as they are neglectable compared to the rest of materials. In the extruder, the gases are removed remaining a mixture composed by 5 kg of rice husk and 20 kg of PHA.

The compound passes through the hopper Moretto, although only in case of olive oil also passes through the hopper MW -the step corresponding to olive oil manufacture is marked in green in Figure 11-. Nonetheless, the mass flows are the same in both manufactures, so only properties of final product change between them due to the differences in composition.

## Energy balance

The equipment is different for both kind of bio-plastic manufactures, so two parallel energy flows have been analysed with this regard. In addition, due to the increment of machinery involved at TRL6 compared to TRL5, the energy consumption of both limoncello and olive oil is over the consumption analysed in D2.2.

## Limoncello production

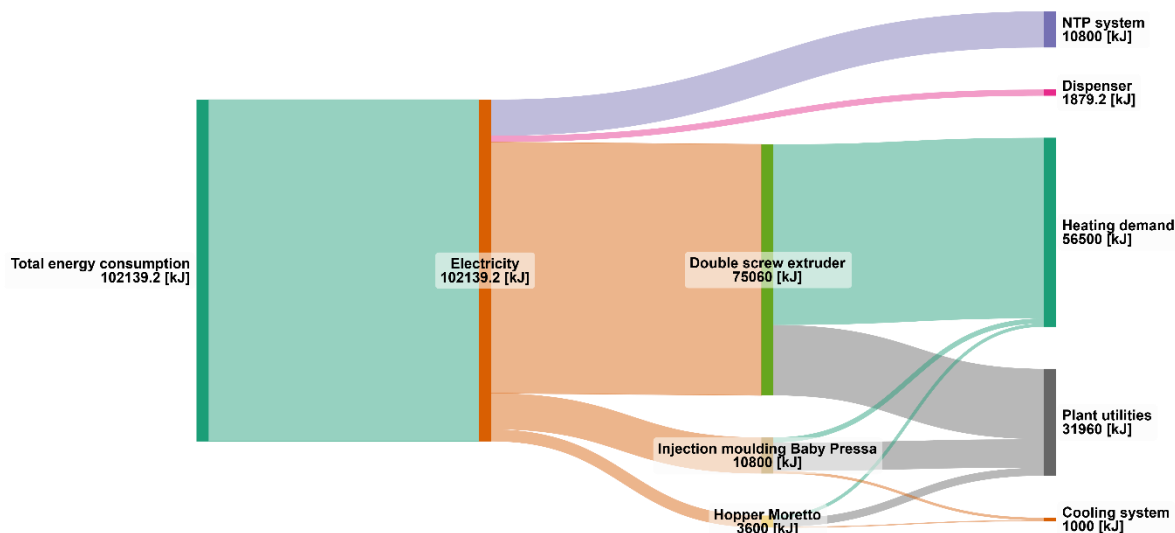


Figure 13. Sankey diagram of the energy flow for limoncello production

Both the NTP system and the dispenser only consumes mechanical power. The rest of the components also requires energy to heat the species and a system to cool and keep the equipment at temperature set point. In case of the extruder the cooling demand is unknown, so it is divided into plant utilities and heating demand consumptions.

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## Olive oil production

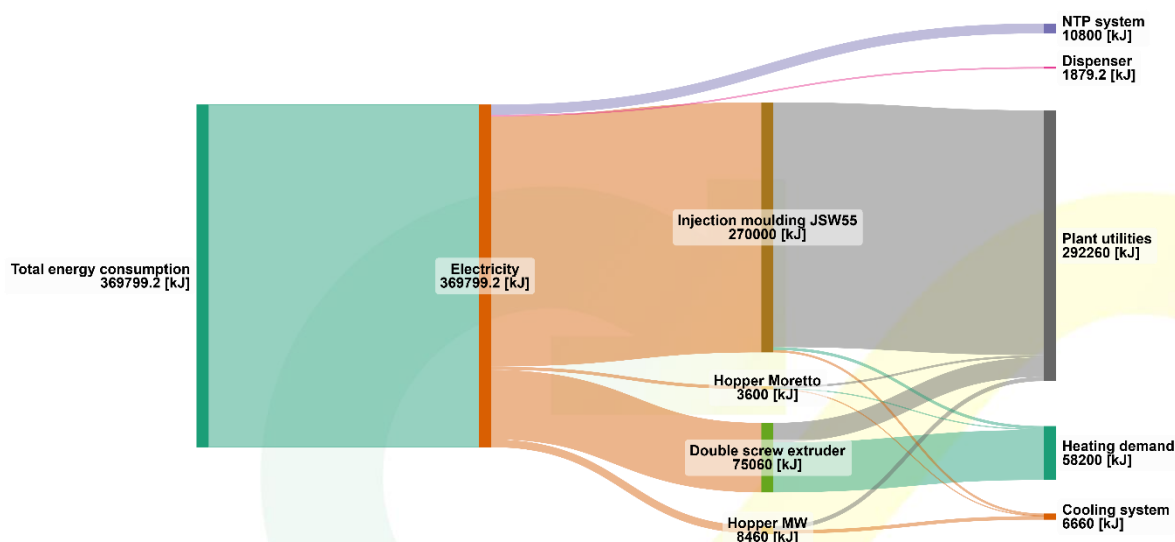


Figure 14. Sankey diagram of the energy flow for olive oil production

This manufacture presents a similar energy flow to limoncello, except to the machinery used during injection moulding (JSW55 instead of Baby Pressa) and the introduction of hopper MW between the hopper Moretto and the moulding steps.

Regarding this last change, the hopper MW only consumes mechanical energy and uses a closed-loop chiller that maintains the temperature at the set point, so no water flow is needed.

## Exergy balance

Since the equipment is different for both manufacturing processes, the energy consumption also leads to different irreversibilities in some steps of the process, so the exergy balance depends on the product.

## Limoncello production

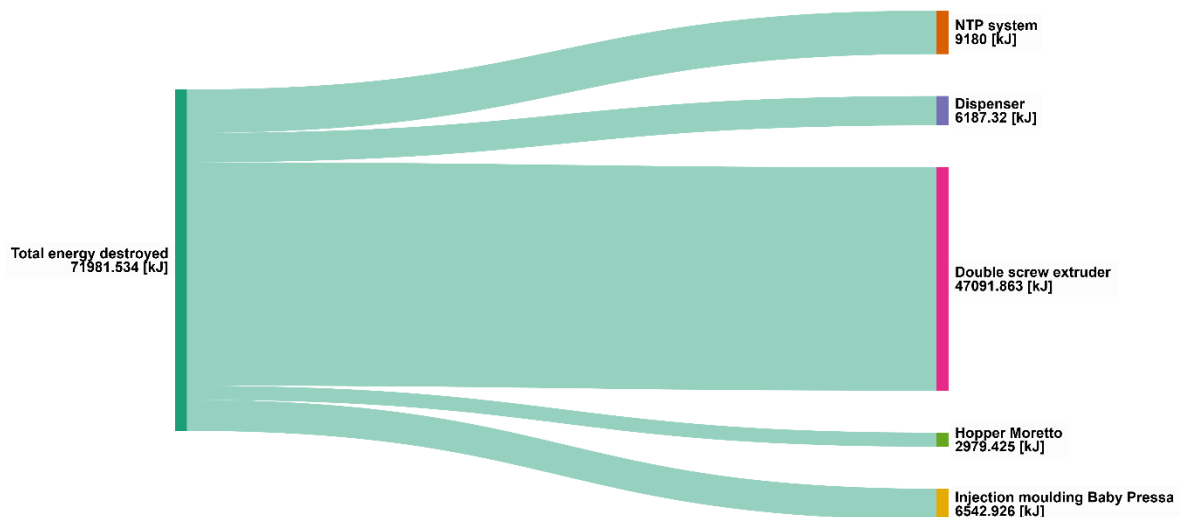


Figure 15. Sankey diagram of the exergy flow for limoncello production

The first two steps (the NTP system and the dispenser) only require mechanical consumption, so the irreversibilities only come from the shaft work related to plant utilities. Next, the formulations are subjected to continuous changes of temperature through the process due to heat exchanges during the steps: the outlet mass reaches 408.15 K in the extruder; then it is cooled up to 333.15 K in the hopper Moretto; and finally, the compound is newly heated up to 448.15 K within the Baby Pressa during the injection moulding.



Figure 16. Sankey diagram of the exergy flow for olive oil production

The process is similar to limoncello's, but in this case the hopper MW is introduced, and the Baby Pressa is replaced by the JSW55 machine. The hopper MW heats the mixture from the 333.15 K at the output of hopper Moretto up to 433.15 K, and the destroyed energy represents a minimum fraction since the energy is effectively used to heat the materials; the JSW55 heats the mixture up to 448.15 K alongside a high mechanical consumption, which leads to the major fraction of destroyed energy in the process.

### 3.1.3. Wood composites manufacture (WP5)

#### Mass balance

In contrary to the other two value chains, in the wood composites production there are not several PFDs depending on either the product or the treatment, so a single PFD is considered in this process and, therefore, only the corresponding flows of materials are analysed in the mass balance.

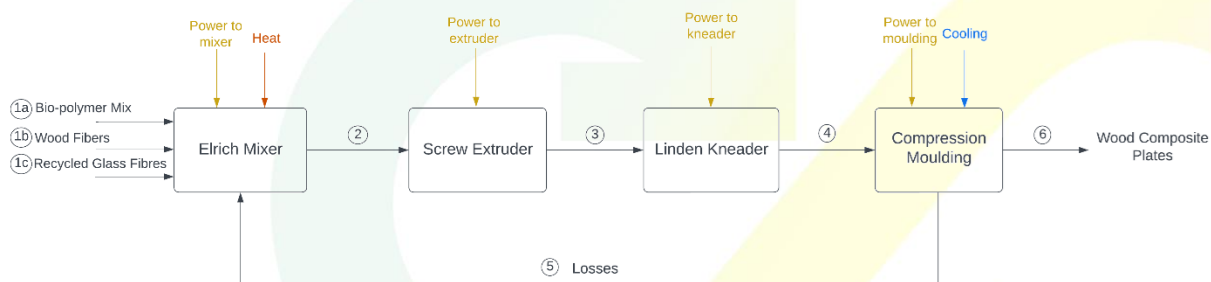


Figure 17. PFD of the wood composites manufacture

During the production of wood composites at TRL5 there were no chemical reactions nor accumulations and no components were wasted, so the input mass of components in all steps equals the exit mass. Bio-polymer and wood fibres were

mixed in the elrich mixer, resulting in a batch of 1560 g of wood composites. Then, the solutions were processed throughout extruder alongside the application of microwaves.

From the total composition, a bath mass of 60 g was used to produce a test sample in the kneader. Nevertheless, 5 g of mass flow was wasted during moulding: this amount was reused for next test samples. Therefore, this step could be interpreted from two perspectives: on the one hand, for each 60 g sample from the original 1560 g of solutions, a 5/60 fraction was applied for the next sample up to 28 times, resulting in a waste of 19.8 g that can be reused in the inlet of the next whole process; on the other hand, a 5/60 fraction is saved in each moulding step, saving a total of 130 g after the production of 26 samples, and reusing that quantity to save materials in the next batch. For the analysis of the process in D2.2, the second assessment was considered during the analysis of the process -the results remain the same, this consideration only affects the way the process is discussed-.

In D2.3, recycled glass fibres are included in the mixer to produce the wood composites, so the total mass of product has increased (1430 g from to 1995 g). Also, a 10/60 fraction of samples is now wasted during moulding, and the same assessment as in D2.2 regarding the saving of materials is considered -i. e., a 1/6 ratio of total mass is saved for the batch in the next whole process-. Last but not least, the machining has been removed, so there is no manual reduction of temperature from operating value (478 K) to room temperature at the end of the process.

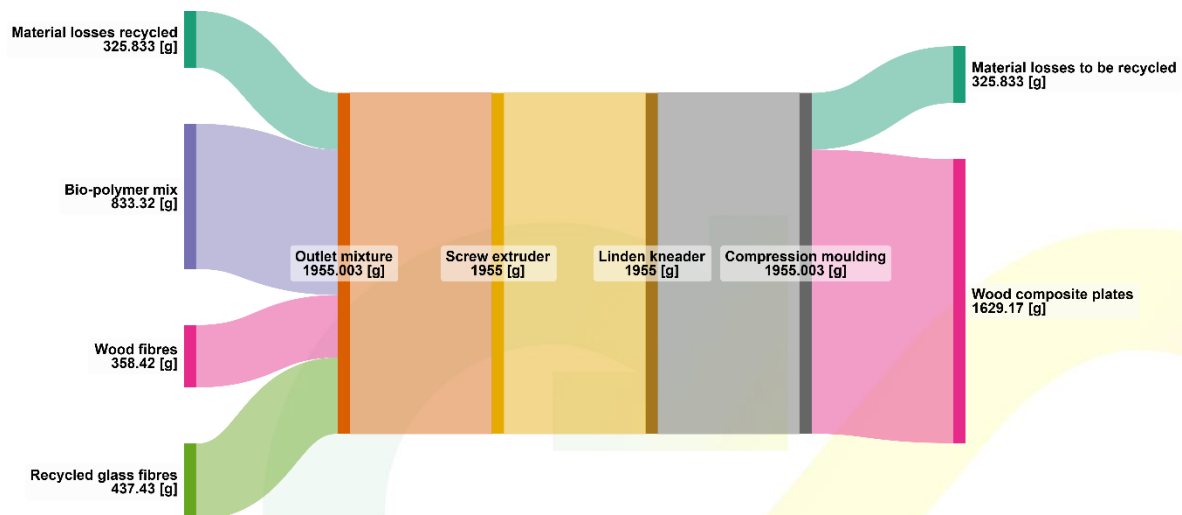


Figure 18. Sankey diagram of the mass flow for wood composites manufacture

Whereas the composition of both wood and glass fibres are available -ARBOCEL C400 (100 % cellulose fibre) and FG 400/100 (100 % glass fibre), respectively- the bio-polymer mix is based on ARBOBLEND® 2241X, whose component weights are unknown (mixture of PMA polymer, lignin, etc): for this reason, all three main

components - ARBOCEL C400, FG 400/100 and ARBOBLEND® 2241X- are considered as an unique material while their chemicals have been indicated in the “Notes” section of the datasheets, located in the **Annex 1: Process datasheets for mass, energy and exergy balance**.

## Energy balance

In this section, the energy required for the operation of machinery involved in the manufacture of the wood composite plates is discussed.

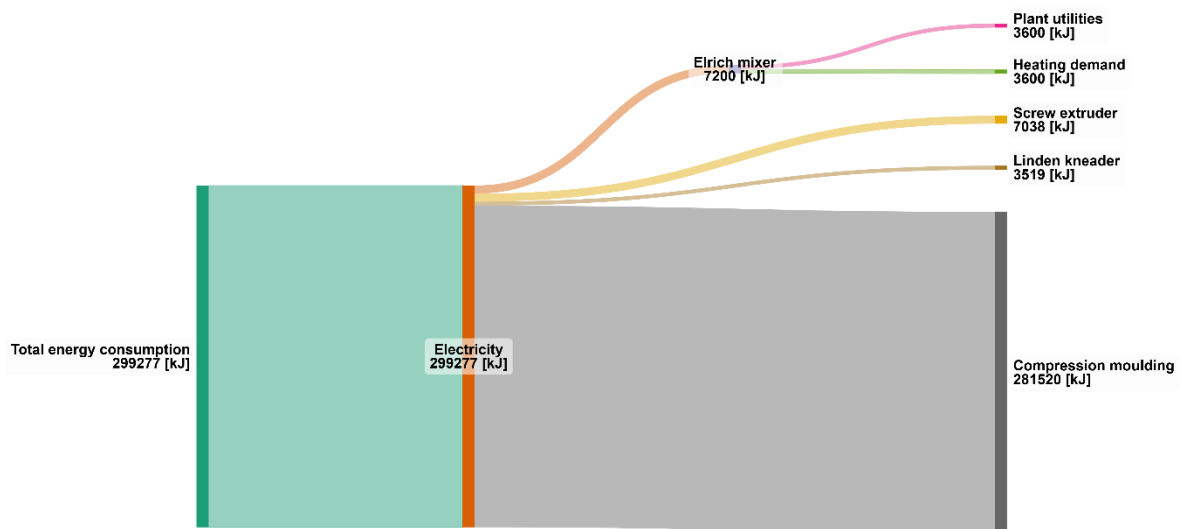


Figure 19. Sankey diagram of the energy flow for wood composites manufacture

The Elrich mixer produces mechanical energy for mixing of components and heating to reach 473 K in the mixture, which is maintained during the process. Both the extruder and the kneader have similar consumptions compared to TRL5, representing the minor percentage of the manufacturing process. Finally, during the compression moulding (CM) the wood composite plates are compressed whereas an unknown fraction of energy is consumed to cool the system. The consumption in CM has the major percentage of electrical demand in the process and has increased in the last update of PFD.

## Exergy balance

The energy consumed within the process is used to determine the irreversibilities that are present within the wood composites manufacture.

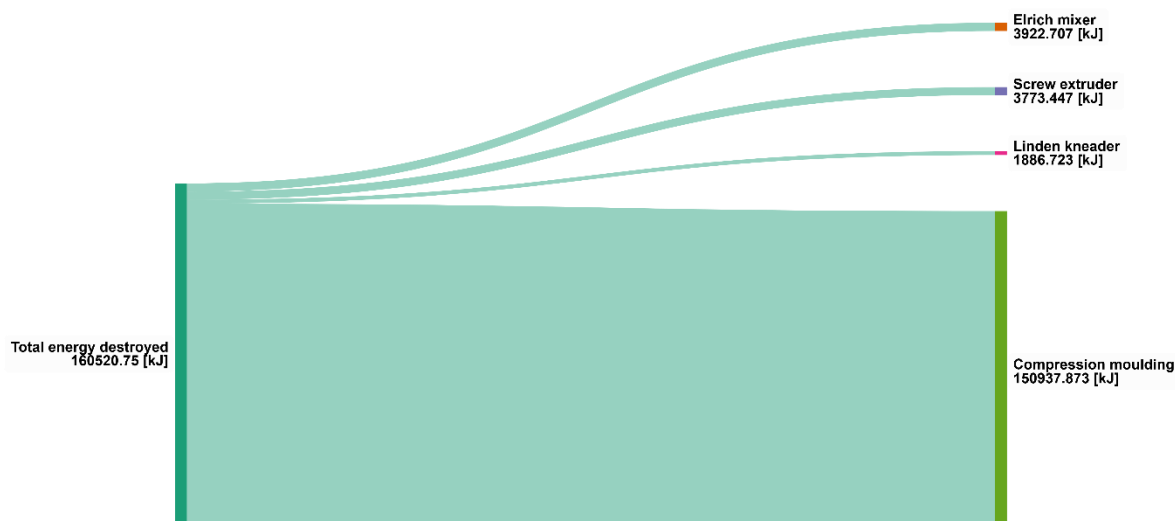


Figure 20. Sankey diagram of the exergy flow for wood composites manufacture

Within the elrich mixer, the inlet mixture is heated from the dead state temperature (the room temperature, 298.15 K) to 473.15 K, and it is maintained at that temperature throughout the whole process. Therefore, the irreversibility comes from the work done by machinery in the remaining steps. The consumed energy is effectively used to maintain the temperature at 175 K so the process presents low irreversibilities except in the compression moulding, which requires high amounts of energy to mould an unit of product mass.

## 3.2. Life Cycle Analysis

### 3.2.1. Bio-rubber manufacture (WP3)

The final demonstrator of the WP3 is a bio-rubber panel of 50cm x 50cm x 1cm that weighs 3.1 kg and includes a series of recovered products such as: lignin, from the kraft process to prepare cellulose paper pulp, and devulcanized rubber, obtained from rubber waste via an innovative devulcanization process catalysed by a eutectic solvent (Ramezani, et al., 2024) . Subsequently, the final product includes, at least, a significant 13.6% of natural rubber.

The lignin is a complex highly heterogeneous polymer composed by aromatic styrene-containing monomers named lignols. The lignin is part of the wood, providing strength and rigidity but is commonly treated as a residue of the kraft process to extract the cellulose and use as an internal fuel within the process. Their introduction in the GREEN-LOOP value chains opens the possibility to source the manufacturing process with the waste of another industrial process. However, this possibility was not yet explored. During GREEN-LOOP, lignocellulose biomass is treated with white liquor mixture to break the cross-linking bonds, and the lignin

is separated as a powder from the cellulose and the hemicellulose using an aqueous acid solution.

Tyres are composed of about 40-50% of rubber and about 20-30% of reinforcing fillers like carbon black or silicon oxide. Usually, the rubber consists of a mixture of natural and synthetic rubber, being the first one more abundant since it provides stronger mechanical resistance and thermal stability compared to the synthetic one (Zerin, Rasul, Jahirul, & Sayem, 2023). After the use-phase of tyres, there is a large percentage of these materials that still could be functional if it is recovered. Thus, some recycling plants collect used tyres to shred and grid them after removing the metallic components. The obtained granulate is the crumb rubber, a material that is used as a filler for asphalt or rubberised concrete, and to produce new tyre rubbers and or any other rubber goods. Recent studies have underlined the possibility of using rubber crumb as a filler in the production of composites, one of the objectives of this project (Medina, et al., 2018). The rubber crumb contains a mixture of natural and synthetic rubber and fillers like black carbon and silica.

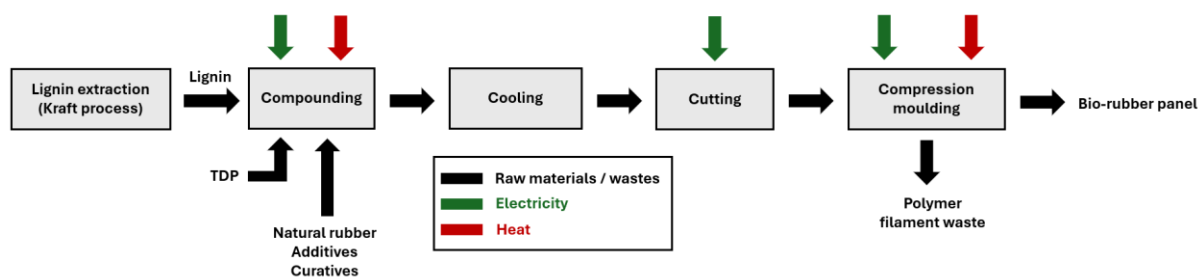


Figure 21. PFD for bio-rubber panel manufacture process

Recycling the rubber crumb involves a devulcanization process, in which the cross-linking S-S bond within the rubber crumbs are cleaved, recovering the original properties of the rubber. Vulcanised rubber is a thermoset polymer with high heat resistance, being difficult to reshape them into new rubber products [27]. Thus, the devulcanization process renders an easier-to-handle material that could be blended into new composites, for example. In GREEN-LOOP the devulcanization process is carried out by sonication of the tyre shreds with a eutectic solvent that is recovered and reused afterwards. Alternatively, some companies are currently carrying out processes to recycle the tyres and recover the valuable rubber to be sold as tyre derived polymers (TDP).

The devulcanized rubber obtained after recycling the tyres, rich in natural rubber, is used as raw materials in the production of the multifunctional panel combined with more virgin natural rubber, additives and curatives. In the process, other materials like carbon black and silica sand are blended into the final demonstrator. During the bio-rubber panel manufacture, the materials are blended in a compounding phase. Then, after cooling the materials, it was cut in a solid filament

and transformed in the final demonstrator in a compression moulding step in which some of the filament is discarded as a waste (Figure 21).

The use of recycled materials without compromising the functionality also opens the possibility of installing circularity within the value chain by recycling the old panels to recover the rubber and filling materials or reusing the polymer off-cuts.

### 3.2.2. Bio-plastic manufacture (WP4)

Two final demonstrators were manufactured within this demo case: an olive oil cap with a dispenser and a limoncello (Italian alcoholic drink) cap with a stem pourer. In both cases, the final demonstrators were made of a biodegradable composite containing an 80% of poly-3-hidroxybutirate (PHB), a biopolymer, and a 20% of rice husk, the hard outer covering of rice grains that is obtained during the milling process.

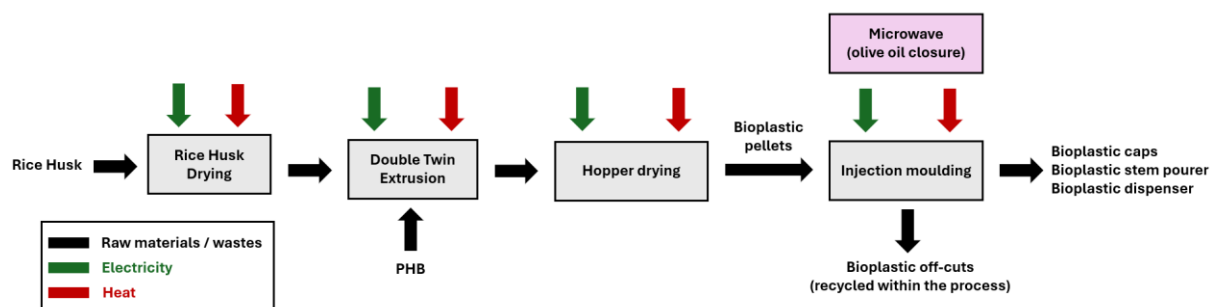


Figure 22. PFD for bioplastic closure manufacture process.

The production process of the caps and dispensers/pourers starts with the desiccation of the rice husk during 15 h at 30 °C using a fibre drying machine. Following that, the dried rice husk is combined with the PHB in a double twin extrusion process. The blended material undergoes a second drying process for 3 h at 65 °C using a Hopper Dryer obtaining bioplastic pellets. Finally, the material is shaped in the final form using an injection moulding process that operates in different conditions depending on the final demonstrator. During the process to prepare the olive oil closure, a microwave system is included to enhance the process.

Although no real wastes are generated during the processes, between 5 and 10% of the pellets introduced in the injection moulding process are not incorporated in the final products, being recycled in the same step.

### 3.2.3. Wood composites manufacture (WP5)

The final demonstrator of WP5 is a 50 g test plate of 100x100x5 mm (length x width x height) made of a mixture of three materials: a biopolymer mixture, wood fibres and glass fibres. This material will be the base of the wood-composite sliding bearings. The process starts with a compounding step in which the three raw

materials were mixed in a Eirich Mixer for 30 minutes at temperature of 200 °C. The resulting product undergoes an extrusion process followed by an extrudate cutting step with a Linden Kneader, in which the granulate wood composite is obtained in a scale of 2 kg. None of these processes is expected to produce significant residues unless.

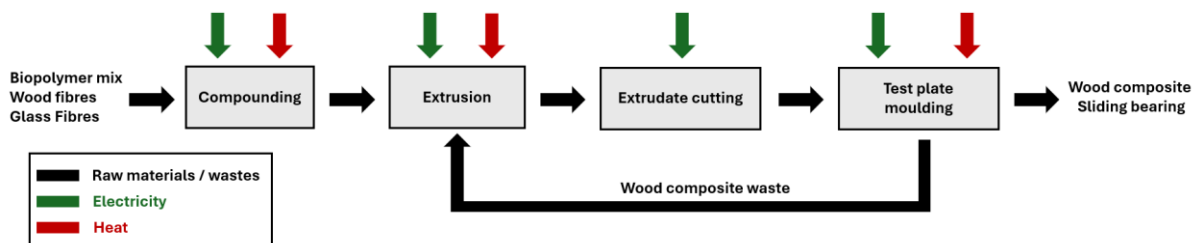


Figure 23. PFD for wood composite manufacture process.

Finally, the wood-composite granulate is moulded into the final demonstrator using a Warm Press Machine Vogt. The process uses 60 g of wood-composite, from which 10 g are not included in the final demonstrator. However, this wood composite waste is recirculated into the extrusion process and reused, closing the circular value chain (Figure 23).

### 3.2.4. Environmental Life Cycle Assessments (E-LCA) of GREEN-LOOP value chains

To perform the E-LCA of GREEN-LOOP, representative examples of bio-rubber, bioplastic and wood composites have been selected as use cases. The system boundaries of these PFDs were established in close collaboration with technical partners, deciding to focus the assessment only on the manufacturing processes, not the whole value chain, including transports to the end user, use phase or EoL. Thus, the “Cradle-to-Gate” scope has been selected, including the extraction and transformation of raw materials, their transport to the facility gate and the manufacturing process. The waste generated during each manufacturing scenario of the project has been categorised into two types: benchmark waste will undergo direct treatment in a linear chain, while bio-based waste will be recycled to ensure a circular system.

As the entire value chain, including the use phase and end-of-life (EoL) stage, has not been considered, it has not been possible to carry out these analyses in relation to reuse and refurbishment. However, it has been possible to do so based on waste or greenhouse gas reduction. The considered value chains for each use case are described in Figure 21 for bio-panels (T6.2), Figure 22 for bioplastic closures (T6.3), and Figure 23 for the wood composites (T6.4).

During the following E-LCA, the main intention will be to assess separately the environmental burdens of the three use cases herein described and compare the

results with benchmark scenarios that represent the state-of-the-art. Finally, the results obtained will be analysed along with the socioeconomic data (LCC and S-LCA) to extract conclusions that will support the decision-making process.

For three value chains, the functional unit (FU) defined is 1 kg of bio-based manufactured material:

- 1 kg of bio-rubber for the VC1
- 1 kg of bioplastic for VC2
- and 1 kg of wood composite for the VC3

Using this value as the functional unit, the partners were asked to provide an inventory scaled to 1 Kg of output, including the materials, energies, emissions and wastes that represent the reference flow, *i.e.* the primary or foreground data. Later, these data are combined with the background datasets from Ecoinvent or LCA for Experts database, modelling the Life Cycle Inventories (LCI), and translated into environmental impacts using the EF 3.0 methodology. The indicators selected will be, therefore, the 16 categories included within the EF methodology. Allocation was not required since within the three demo cases only one product is obtained after the manufacture process. Additionally, the assumptions made during the assessments will be further discussed in the following sections.

During the bio-rubber and bioplastic cases of use, the Ecoinvent database was used as background data, while in the wood composite case of use it was decided to compare the results obtained with Ecoinvent and LCA for Experts database. The selection of the background data is a crucial part of the environmental assessment, providing the tools to translate the primary data into elementary flows. Therefore, it is legit to ask whether the results could be influenced by using one database or another, and it is planned to test it in this GREEN-LOOP value chain.

## *Definition of comparison scenarios*

In order to evaluate whether GREEN-LOOP value chains are reducing the environmental footprint, it is necessary to compare them with the current state-of-art. The state-of-art for the three value chains are described within these sections and later modelled into LCI.

### *Bio-rubber benchmark scenario*

Natural fibre-reinforced thermoset or thermostable composites are a current matter of study by researchers and the industrial community to ensure real-time service, exhibiting promising results in terms of energy absorption and vibration damping [28]. Herein, in this case of study, GREEN-LOOP wants to test the possibility of obtaining fire-retardant and vibrational properties by combining natural fibres of lignin (considered a waste of the kraft process) with recycled and natural rubber. However, such technology is not yet in the market, having achieved

only TRL4, choosing a benchmark a serious challenge. The most likely product in the market could be an anti-vibrational pad made of rubber and/or ethylene-vinyl-acetate (EVA foam). However, this kind of material is not intended to be fire-retardant, so the comparison would not be accurate since the utility of both products is clearly different.

Thus, it was decided to propose a hypothetical benchmark material that provides the same functionality of the final product but does not rely that much on recycled or natural raw materials. Considering the current tendencies of the global market, it is possible to suppose that some companies less familiarised with recycling processes would prefer to use virgin raw materials, with which they have more experience. With the aim of comparison, the quantities of these additives would be the same, while the mass of devulcanized rubber and natural rubber will be substituted with the equivalent quantity of synthetic rubber and black carbon. Additionally, the wastes generated within the benchmark current scenario will not be recycled but incinerated.

*It must be pointed out that using synthetic non-recycled rubber is very likely to obtain different properties and composition compared to using recycled devulcanized rubber. The vulcanisation process introduces cross-linking between the long polymer chains by heating them in the presence of sulphur or other additives. Therefore, even after the devulcanization process, it is possible to retain some degree of crosslinking or some additives in the formulation. To check the extent of these differences, it would be necessary to prepare the rubber panel following both approaches and test them. However, for the sake of comparison, this benchmark will be considered good enough to assess the impacts related to introducing recycled and renewable raw materials and circularity.* The different scenarios of the first value chain (VCI) have been established with the help of NCC to evaluate the most characteristic ones. The current scenario consists of the use of virgin synthetic rubber, while the lignin developed in the project remains as an additive to be purchased if it is a key factor and a hotspot in the project, as mentioned above in deliverable D2.2, since the two scenarios to be evaluated within the framework of the GREEN-LOOP Project are: bio-based rubber with 20% lignin and bio-based rubber with 0% lignin.

This first section presents the inventory of the development process for a lignin-based additive, intended for use in construction panel manufacturing. Lignin, obtained as a by-product from the pulp and paper industry, represents a promising renewable resource for developing sustainable building materials. The objective of this inventory is to provide a detailed account of the material inputs, energy requirements, processing steps, and outputs involved in transforming biomass into a lignin functional additive. This information is collected in *Table 5*. This lignin

is used in the current scenario and the manufacturing of the Bio-Rubber Panel 1 (BRP1).

Table 5. LCI for the manufacture of 1 kg of lignin using lignocellulose biomass.

| <b>BENCHMARK Synthetic rubber panel production</b> |                       |
|----------------------------------------------------|-----------------------|
| <b>Material</b>                                    | <b>Quantity (Kg)</b>  |
| Distilled water                                    | 39.21                 |
| Sodium sulfide                                     | 0.28                  |
| Sodium hydroxide                                   | 0.94                  |
| Lignocelullose Biomass                             | 5.56                  |
| Sulfuric Acid 98%                                  | 1.89                  |
| <b>Energy</b>                                      | <b>Quantity (KWh)</b> |
| High-pressure batch reactor                        | 856.8                 |
| <b>Waste</b>                                       | <b>Quantity (Kg)</b>  |
| Acid Liquor                                        | 43.50                 |
| Cellulose-rich waste                               | 3.56                  |
| <b>Output</b>                                      | <b>Quantity (Kg)</b>  |
| Lignin powder                                      | 1.0                   |

The inventory for the remaining stages of manufacturing the current material for the panel is listed in *Table 6* below. This LCI includes inputs (raw materials, energy), outputs (current rubber), and waste (polymer filaments) generated during the Compounding and Compression Moulding stages.

Table 6 collects all the data about this benchmark.

## Bio-plastic benchmark scenario

Before commenting on the benchmark for this value chain, it should be highlighted that a benchmark has been established for each of the scenarios evaluated in this value chain: olive oil and limoncello closures. The current materials that have been established for comparison with the new materials developed in value chain 2 (VC2), related to T6.3, have been agreed internally with GUALA, ensuring first-hand the most widely used material at an industrial level.

The use of low-density polyethylene (LDPE) for olive oil bottle closures is justified by its excellent chemical resistance and flexibility, which allows for an airtight seal that protects the product from oxidation and prevents leaks, even in applications where there may be prolonged contact with fats and oils [29]. On the other hand, polypropylene (PP) is widely used in closures for alcoholic beverage bottles such as limoncello due to its high thermal resistance, rigidity and low moisture absorption, making it ideal for containing liquids with high ethanol content without degrading or altering its mechanical properties [30]. Furthermore, PP allows for easy manufacturing through injection moulding and good compatibility with security

systems such as tamper-proof closures, which are essential in alcoholic products. These specific properties of each polymer make their selection for these particular uses technically and economically appropriate.

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## Wood composites benchmark scenario

Currently, sliding bearings are made of different materials. Metallic sliding bearings are supposed to contain metals such as copper alloys, cast irons, tin alloys, zinc or aluminium.<sup>3</sup> Conversely, petroleum-based sliding bearings could be made of different rigid plastics such as polyamide (PA), polyether ether ketone (PEEK), polyether sulphone (PES), polyoxymethylene (POM) or high-density polyethylene (HDPE) [31].<sup>4</sup> In both cases, the selection of the material is dependent on the final use and is very difficult to predict without specific industrial data. Hence, it was decided to create two proxies, one with a metallic mix (MM) and the other with three common petroleum-based polymers (PBP).

The two current benchmark scenarios that will be analysed in the wood composite scenario are:

- A MM sliding bearing represented by copper, cast iron, zinc and aluminium in similar proportions.
- a PBP sliding bearing proxied as a mixture of three common plastic materials in similar proportions, polyamide (PA), polyoxymethylene (POM) and LDPE.

Both current benchmark scenarios will rely on mature technology, far more optimised than the current GREEN-LOOP scenario. Concretely, the metallic bearing would probably require reforging the virgin metal into the final shape, while the PBP would probably require polymerising a monomer to obtain a granulate polymer and moulding it. As a realistic comparison would be challenging and could mislead the conclusions, it was proposed to focus it only in the substitution of non-renewable raw materials by mainly biobased raw materials,

<sup>3</sup> Materials described in the grant agreement. Not an exhaustive list.

<sup>4</sup> Plastic sliding bearings – various types & sizes. <https://bbs-industrie.com/bearing-technology/sliding-bearings/plastic-bearings/>

considering the same processes for both benchmarks and GREEN-LOOP wood composites.

## Life Cycle Inventory

Geographic location could make a significant difference in terms of environmental impact. Owing to this, ideally, it would be better to locate each process within the country in which it is carried out. However, in most of the inventory entries, the database only differentiates between European (*RER*) and non-European (*GLO*). Thus, unless other thing is noted, the processes will be modelled as they were carried out inside Europe, “{*RER*}”, or globally, “{*GLO*}”, if a specific European dataset that fits with the process does not exist. Additionally, in all the cases, the energy consumptions are represented as electricity consumption.

## Bio-rubber scenario

The different scenarios of the first value chain (VCI) have been established with the help of NCC to evaluate the most characteristic ones. The current scenario consists of the use of virgin synthetic rubber, while the lignin developed in the project remains as an additive to be purchased if it is a key factor and a hotspot in the project, as mentioned above in deliverable D2.2, since the two scenarios to be evaluated within the framework of the GREEN-LOOP Project are: bio-based rubber with 20% lignin and bio-based rubber with 0% lignin.

This first section presents the inventory of the development process for a lignin-based additive, intended for use in construction panel manufacturing. Lignin, obtained as a by-product from the pulp and paper industry, represents a promising renewable resource for developing sustainable building materials [32]. The objective of this inventory is to provide a detailed account of the material inputs, energy requirements, processing steps, and outputs involved in transforming biomass into a lignin functional additive. This information is collected in *Table 5*. This lignin is used in the current scenario and the manufacturing of the Bio-Rubber Panel 1 (BRP1).

Table 5. LCI for the manufacture of 1 kg of lignin using lignocellulose biomass.

| <b>BENCHMARK Synthetic rubber panel production</b> |                       |
|----------------------------------------------------|-----------------------|
| <i>Material</i>                                    | <b>Quantity (Kg)</b>  |
| <i>Distilled water</i>                             | 39.21                 |
| <i>Sodium sulfide</i>                              | 0.28                  |
| <i>Sodium hydroxide</i>                            | 0.94                  |
| <i>Lignocelullose Biomass</i>                      | 5.56                  |
| <i>Sulfuric Acid 98%</i>                           | 1.89                  |
| <i>Energy</i>                                      | <b>Quantity (KWh)</b> |
| <i>High-pressure batch reactor</i>                 | 856.8                 |
| <i>Waste</i>                                       | <b>Quantity (Kg)</b>  |

|                      |                      |
|----------------------|----------------------|
| Acid Liquor          | 43.50                |
| Cellulose-rich waste | 3.56                 |
| Output               | <b>Quantity (Kg)</b> |
| Lignin powder        | 1.0                  |

The inventory for the remaining stages of manufacturing the current material for the panel is listed in *Table 6* below. This LCI includes inputs (raw materials, energy), outputs (current rubber), and waste (polymer filaments) generated during the Compounding and Compression Moulding stages.

*Table 6. Benchmark LCI for the manufacture of 1 kg of rubber panel using virgin synthetic rubber. The process to obtain lignin powder is the same in the GREEN-LOOP bio-rubber value chain.*

| <b>BENCHMARK Synthetic rubber panel production</b> |                       |
|----------------------------------------------------|-----------------------|
| <i>Material</i>                                    | <b>Quantity (Kg)</b>  |
| Virgin synthetic rubber                            | 0.785                 |
| Lignin power                                       | 0.196                 |
| Low Lead Zinc Oxide                                | 0.038                 |
| Stearic acid                                       | 0.009                 |
| MBTS-75                                            | 0.0048                |
| 300 Mesh Sulphur                                   | 0.019                 |
| <i>Energy</i>                                      | <b>Quantity (KWh)</b> |
| Compounding                                        | 0.313                 |
| Compression Moulding                               | 15.16                 |
| <i>Waste</i>                                       | <b>Quantity (Kg)</b>  |
| Polymer off-cuts                                   | 0.103                 |
| <i>Output</i>                                      | <b>Quantity (Kg)</b>  |
| Virgin rubber panel                                | 1.0                   |

For the first bio-based scenario, BRP1, the virgin synthetic rubber has been replaced by a Tyre-Derived Polymer (TDP) and Natural Rubber. With the help of the bibliography, it has been possible to establish an approximation for introducing TDP as an input into the system, as there is currently no such input in Ecoinvent. As this is an end-of-life material, no environmental impact will be attributed to it, so the energy consumption associated with shredding tyres to obtain 1 kg of TDP will be attributed to it.

The amount of electricity required to shred **1 kilogram of rubber from a tyre** depends on several factors, including:

- **Type and size of shredder used**
- **Configuration of the shredding process** (single stage vs. multi-stage)
- **Condition of the tyres** (e.g., clean vs. contaminated with steel or fibre)
- **Desired output size** (e.g., chips, crumb rubber, powder)

This analysis will only take into account particle size. As this is a specific material, TDP-B, it will be associated with a particle size of approximately 0.585 mm, assuming that it will be a very energy-intensive process, so an energy consumption of 1 kWh/kg will be selected.

The inventory for the complete BRP1 scenario is shown in Table 7. The lignin inventory has not been included because it is the same process as for the current material manufacturing system.

*Table 7. LCI for the manufacturing of 1 kg of bio rubber panel with 20% lignin. The process to obtain lignin powder is the same in the current scenario.*

| <b>BRP1 rubber panel production</b> |                |
|-------------------------------------|----------------|
| Material                            | Quantity (kg)  |
| TDP-B                               | 0.625          |
| Lignin powder                       | 0.218          |
| Natural rubber                      | 0.158          |
| Low Lead Zinc Oxide                 | 0.038          |
| Stearic acid                        | 0.010          |
| MBTS-75 (accelerator)               | 0.004          |
| 300 Mesh Sulphur                    | 0.019          |
| Energy                              | Quantity (KWh) |
| Compounding                         | 0.313          |
| Compression Moulding                | 15.16          |
| Waste                               | Quantity (Kg)  |
| Polymer off-cuts                    | 0.10           |
| Output                              | Quantity (Kg)  |
| BRP1 material                       | 1.0            |

Finally, the second bio-based scenario – BRP2 – will be similar to BRP1, but without the lignin from lignocellulosic biomass. The percentage of the other compounds remains unchanged. The data related to BRP2 are summarised below in Table 8.

*Table 8. LCI for the manufacturing of 1 kg of bio rubber panel with 0% lignin. The process to obtain lignin powder is the same in the current scenario.*

| <b>BRP2 rubber panel production</b> |                |
|-------------------------------------|----------------|
| Material                            | Quantity (kg)  |
| TDP-B                               | 0.732          |
| Natural rubber                      | 0.185          |
| Low Lead Zinc Oxide                 | 0.045          |
| Stearic acid                        | 0.011          |
| MBTS-75 (accelerator)               | 0.006          |
| 300 Mesh Sulphur                    | 0.022          |
| Energy                              | Quantity (KWh) |
| Compounding                         | 0.313          |

## BRP2 rubber panel production

|                      |                      |
|----------------------|----------------------|
| Compression Moulding | 15.16                |
| Waste                | <b>Quantity (Kg)</b> |
| Polymer off-cuts     | 0.10                 |
| Output               | <b>Quantity (Kg)</b> |
| BRP2 material        | 1.0                  |

## Bio-plastic scenario

Bioplastics are biosynthesised by many microorganisms as carbon feedstock that can be transformed into energy. Over the past decades, the bioplastics polyhydroxyalkanoates (PHAs) have received increasing attention as a substitute for the conventional fossil-based plastics since they are biocompatible and biodegradable. Currently, companies like the **Helian Polymers**, located in Netherlands, are able to provide huge amounts of PHAs like the poly-3-hydroxybutyrate (PHB) or the poly-(3-hydroxybutyrate-co-3-hydroxyheanoate) (PHBH) via different biosynthetic routes protected by industrial secret.

Unfortunately, these materials have not been included yet in the databases. Thus, it will be necessary to either select a representative dataset within the Ecoinvent 3.10 database or create a proxy. Finally, the most representative entry has been, and the only bioplastic dataset contained in the Ecoinvent 3.10 database is one starch-based polyester, which represents a biopolymer produced from starch modified by complexation with polyesters, intended as a biodegradable alternative to conventional plastics.

Consequently, the market process "*Polyester-complexed starch biopolymer {RER}/ polyester-complexed starch biopolymer production | Cut-off, U*" was selected to represent the PHA. This dataset contains life cycle inventory data for the production of 1 kg of starch-based biopolymer modified with polyesters, based on aggregated data derived from the environmental declaration of the bioplastic Mater-Bi [33].

The following tables show the inventories for four different scenarios related to VC2. The FU selected for these analyses is again 1 kg of bio-based material produced. For the closures manufactured for olive oil with the current scenario, the inventory is collected in Table 9.

Table 9. Benchmark LCI for the manufacturing of 1 kg of LDPE olive oil closures.

## Benchmark for olive oil closures

|                                           |                       |
|-------------------------------------------|-----------------------|
| <i>Material</i>                           | <b>Quantity (Kg)</b>  |
| <i>LDPE</i>                               | 1                     |
| <i>Energy</i>                             | <b>Quantity (KWh)</b> |
| <i>NTP</i>                                | 1.5                   |
| <i>Extruder</i>                           | 1.273                 |
| <i>Hopper - Dryer</i>                     | 0.18                  |
| <i>Hopper Loader</i>                      | 1                     |
| <i>MW preheating system</i>               | 1                     |
| <i>Injection Moulding - Caps</i>          | 5.5                   |
| <i>Injection Moulding - Pourer</i>        | 5.5                   |
| <i>Output</i>                             | <b>Quantity (Kg)</b>  |
| <i>Current Olive oil closure material</i> | 1                     |

On the other hand, the inventory for the development of bio-based closures for olive oil is shown in the following Table 10. In this case, as mentioned above, an input as similar as possible has been chosen for PHA, while a proxy has been developed for rice husk.

Table 10. LCI for the manufacturing of 1 kg of Bio-based olive oil closures.

| <b>Bio-based olive oil closures</b>  |                       |
|--------------------------------------|-----------------------|
| <i>Material</i>                      | <b>Quantity (Kg)</b>  |
| <i>PHA</i>                           | 0.80                  |
| <i>Rice Husk</i>                     | 0.20                  |
| <i>Energy</i>                        | <b>Quantity (KWh)</b> |
| <i>NTP</i>                           | 1.5                   |
| <i>Extruder</i>                      | 1.273                 |
| <i>Hopper - Dryer</i>                | 0.18                  |
| <i>Hopper Loader</i>                 | 1                     |
| <i>MW preheating system</i>          | 1                     |
| <i>Injection Moulding - Caps</i>     | 5.5                   |
| <i>Injection Moulding - Pourer</i>   | 5.5                   |
| <i>Output</i>                        | <b>Quantity (Kg)</b>  |
| <i>BB Olive oil closure material</i> | 1                     |

On the other hand, for limoncello closures, the benchmark material will not be the same; in this case, it is polypropylene - PP. In addition, energy consumption will also be different because it is a different process with fewer stages than the previous one. All of this is shown in Table 11 below.

Table 11. Benchmark LCI for the manufacturing of 1 kg of PP limoncello closures.

## Benchmark for limoncello closures

|                                            |                       |
|--------------------------------------------|-----------------------|
| <i>Material</i>                            | <b>Quantity (Kg)</b>  |
| <i>PP</i>                                  | 1                     |
| <i>Energy</i>                              | <b>Quantity (KWh)</b> |
| <i>NTP</i>                                 | 1.5                   |
| <i>Extruder</i>                            | 1.273                 |
| <i>Hopper - Dryer</i>                      | 0.18                  |
| <i>Injection Moulding - Caps</i>           | 5.5                   |
| <i>Injection Moulding - Pourer</i>         | 5.5                   |
| <i>Output</i>                              | <b>Quantity (Kg)</b>  |
| <i>Current Limoncello closure material</i> | 1                     |

Unlike the benchmark, in the case of the BB limoncello closures, these will be made of the same material as BB olive oil closures: the mix of PHA and Rice Husk. This information is collected in Table 12.

Table 12. LCI for the manufacturing of 1 kg of Bio-based limoncello closures.

| <b>Bio-based limoncello closures</b>  |                       |
|---------------------------------------|-----------------------|
| <i>Material</i>                       | <b>Quantity (Kg)</b>  |
| <i>PHA</i>                            | 0.80                  |
| <i>Rice Husk</i>                      | 0.20                  |
| <i>Energy</i>                         | <b>Quantity (KWh)</b> |
| <i>NTP</i>                            | 1.5                   |
| <i>Extruder</i>                       | 1.273                 |
| <i>Hopper - Dryer</i>                 | 0.18                  |
| <i>Injection Moulding - Caps</i>      | 5.5                   |
| <i>Injection Moulding - Pourer</i>    | 5.5                   |
| <i>Output</i>                         | <b>Quantity (Kg)</b>  |
| <i>BB limoncello closure material</i> | 1                     |

## Wood composites scenario

Within this value chain, the LCI were modelled in the Ecoinvent and LCA for Experts (LCA FE) databases. One of the main differences between these two databases is that, unlike the market activities of ecoinvent, LCA FE does not include the transport distances in the datasets. Therefore, it is necessary to calculate them based on literature such as the manuscript from Borken-Kleefeld and Weidema [24]. The freight processes were geographically located as "{GLO}" since the raw materials could be transported from outside Europe. Additionally, the manuscript categories set to proxy the transport distances were reported within each LCI in the supporting material, along with the PFD processes modelled with LCA for Experts.

Table 14 collects the inventory data for preparing 1 kg of the wood composite SBS2, while Table 60 and Table 65 included the Ecoinvent and LCA FE datasets, respectively. Within this experiment, three raw materials were used: the

biopolymer mixture ARBOBLEND 2241x, natural wood fibre and glass fibre filler. The energy consumed during the manufacture was provided by the partners and represented in kWh per Kg of output. In this case, the only wastes are obtained after the test plate moulding step (Figure 23). However, this waste, wood composite granulate, could be directly reintroduced into the warm press machine, so it was not considered in the final assessment.

Table 13. LCI for the manufacture of 1 kg of SBS1, the wood composite test plate of 100x100x5 mm (without glass fibre).

| <b>SBS1: Wood composite without Glass Fibre</b> |                       |
|-------------------------------------------------|-----------------------|
| <i>Material</i>                                 | <b>Quantity (Kg)</b>  |
| ARBOBLEND 2241x                                 | 0.839                 |
| Natural Wood Fibre                              | 0.361                 |
| <i>Energy</i>                                   | <b>Quantity (KWh)</b> |
| Eirich mixer (Compounding)                      | 1.0                   |
| Extruder (Extrusion)                            | 1.0                   |
| Linden Kneader (Extrudate cutting)              | 0.5                   |
| Warm press Machine (Test plate moulding)        | 20.0                  |
| <i>Waste</i>                                    | <b>Quantity (Kg)</b>  |
| Wood composite off-cuts                         | 0.20                  |
| <i>Output</i>                                   | <b>Quantity (Kg)</b>  |
| Wood composite test plate                       | 1                     |

The experiment SBS1 (Table 13) collects the data for a hypothetical process to prepare the wood composite, removing the glass fibre filler from the composition, to see how the glass fibre filler affects the environmental impact.

Table 53 and

Table 64 included the Ecoinvent and LCA for Experts datasets, respectively.

Table 14. LCI for the manufacture of 1 kg of SBS2, the wood composite test plate of 100x100x5 mm (with glass fibre).

| <b>SBS2: Wood composite with Glass Fibre</b> |                       |
|----------------------------------------------|-----------------------|
| <i>Material</i>                              | <b>Quantity (Kg)</b>  |
| ARBOBLEND 2241x                              | 0.614                 |
| Natural Wood Fibre                           | 0.264                 |
| Glass Fibre Filler                           | 0.322                 |
| <i>Energy</i>                                | <b>Quantity (KWh)</b> |
| Eirich mixer (Compounding)                   | 1.0                   |
| Extruder (Extrusion)                         | 1.0                   |
| Linden Kneader (Extrudate cutting)           | 0.5                   |
| Warm press Machine (Test plate moulding)     | 20.0                  |
| <i>Waste</i>                                 | <b>Quantity (Kg)</b>  |

|                           |                      |
|---------------------------|----------------------|
| Wood composite off-cuts   | 0.20                 |
| Output                    | <b>Quantity (Kg)</b> |
| Wood composite test plate | 1.0                  |

ARBOBLEND 2241x is a 100% biodegradable thermoplastic that contains unspecified quantities of polyhydroxyalkanoates (PHA), lignin, polyesters, starch, cellulose, natural waxes and polylactic acid (PLA), along with organic additives. Representing such a complex material with the current environmental assessment databases seems to be very challenging, especially considering that its formulation is protected by industrial secrecy. After screening the ecoinvent 3.10 database, the dataset “*Polylactic acid, granulate {GLO} | market for | Cut-Off, U*” was selected, since PLA, already present in the biopolymer, is a biodegradable polymer prepared from starch. In the case of the LCA FE database, the process “*Ingeo Polylactide (PLA) biopolymer production*” was chosen following the same logic.

Wood fibres are obtained after treatment of the wood chips at high temperatures or pressures to obtain a valuable material to reinforce composites. During this assessment, wood fibres will be represented as “*Bark chips, wet, measured as dry mass {EwS} | market for fibreboard, hard | Cut-off, U*” in the ecoinvent 3.10 database, since the hard fibreboard is made of wood fibres. In the case of the LCA FE database, the process “*RER: Lightweight wood fibre panel (EN15804 A1-A3)*” was chosen following the same logic.

Finally, the glass fibre filler was represented by the dataset “*Glass fibre {GLO} | market for | Cut-off, U*” in Ecoinvent 3.10, and the process “*DE: Glass fibres*” in LCA FE database.

In all the cases, the energy requirements and represented by the ecoinvent dataset “*Electricity, medium voltage | market for | Cut-Off, U*”<sup>5</sup> or the LCA FE dataset “*Electricity grid mix 1 kV -60kV*”, selecting in both cases the country in which the processes took place.

In the case of the benchmarks, Table 15 represents the data for the copper benchmark and Table 16 the data for the petroleum-based polymer (PBP) benchmark. In both cases, the process is supposed to be the same that was previously described for the wood composites (i.e. same kWh and geographic location of electricity mix or same amount of wastes), with the difference of considering that the wastes of the test plate moulding step (Figure 23) were incinerated in a municipal incineration plant located in Germany.

<sup>5</sup> Within Europe, medium voltage ranges from 1kV to 36-52 kV.

During the metallic benchmark, four different materials frequently used in sliding bearings were selected. In the Ecoinvent database, copper is represented by the dataset “Copper, cathode {GLO}| market for copper, cathode | Cut-off, U”<sup>6</sup>, cast iron by “Cast iron {GLO}| market for cast iron | Cut-off, U”, zinc by “Zinc {GLO}| market for zinc | Cut-off, U” and aluminium by “Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| market for aluminium, primary, ingot | Cut-off, U”. In LCA FE database, copper is represented by the dataset “GLO: Copper (99.99% cathode) ICA”,<sup>6</sup> cast iron by “DE: Cast iron component (EN15804)”, zinc by “RER: Special high grade zinc only from Zn” and aluminium by “RER: Aluminium ingot mix Sphera”.

During the PBP benchmark, it was necessary to find three plastic materials that were used in the sliding bearings and included in both databases. Two of them, PA and LDPE, were included in the Ecoinvent database as “Nylon 6-6 {RER}| market for nylon 6-6 | Cut-off, U” and “Polyethylene, high density, granulate {GLO}| market for | Cut-off, U”, respectively, and in the LCA FE database as “RER: Polyamide 6.6” and “RER: polyethylene high density granulate (HLDPE/PE-HD)”. Nevertheless, the third one, POM, is only included in the LCA FE database as “RER: Polyoxymethylene (POM)”.

Table 15. LCI for the manufacture of 1 kg of the current metallic scenario, the copper alloy sliding bearing.

| Metallic benchmark sliding bearing       |                |
|------------------------------------------|----------------|
| Material                                 | Quantity (Kg)  |
| Copper                                   | 0.30           |
| Cast iron                                | 0.30           |
| Zinc                                     | 0.30           |
| Aluminium                                | 0.30           |
| Energy                                   | Quantity (KWh) |
| Eirich mixer (Compounding)               | 1.0            |
| Extruder (Extrusion)                     | 1.0            |
| Linden Kneader (Extrudate cutting)       | 0.5            |
| Warm press Machine (Test plate moulding) | 20.0           |
| Waste                                    | Quantity (Kg)  |
| Metallic off-cuts                        | 0.20           |
| Output                                   | Quantity (Kg)  |
| Metallic sliding bearing                 | 1.0            |

Polyoxymethylene (POM) is a thermoplastic with excellent mechanical properties manufactured via polymerisation of formaldehyde, catalysed either by acids (cationic polymerisation) or organometallic initiators (anionic polymerisation). A

<sup>6</sup> These datasets were selected since the Copper ASTM B152 has at least 99.9% purity.

fine powder is the output of this process, which is mixed with stabilisers and other additives to prevent degradation and improve its physical properties. Then, it is fed into a melt extruder to obtain pellets that are later used in injection moulding machines to process the final products. Based on this process, it was decided to create a proxy of POM in the Ecoinvent database. As it was recommended Hischier *et. al.*, the stoichiometry of the polymerisation process was collected from the Ulmann's Encyclopaedia of Industrial Chemistry [34] supposing a 95% yield, the energy consumptions were included as average values reported by 12 German companies from the chemical sector in 2001 (Industrial Park Werk GENDORF) and the infrastructure use was proxied as a production capacity of 50.000 tones/year and a plant lifetime of 50 years, obtaining  $4 \cdot 10^{-10}$  units/Kg of chemical produced [35].

Transport distances were included based on chemicals average freight values published by Borken-Kleefeld and Weidema. Finally, only air emissions are considered, as 0.5% of fugitive losses, and the other residues are treated as spent solvent and proxied by the dataset "Spent solvent mixture {CH}| treatment of spent solvent mixture, hazardous waste incineration | Cut-off, U". To represent the monomer, the process "Formaldehyde {RER}| formaldehyde production, methanol oxidation | Cut-off, U" was selected, since formaldehyde is primarily produced through catalytic oxidation of methanol. Boron trifluoride was selected as an acid catalyst for the cationic polymerisation and represented by the process "Boron trifluoride {GLO}| market for | Cut-off, U".

Regarding the additives and stabilisers, it is difficult to find which ones are added to the POM during the compounding process since they totally depend on the intended final use. Additionally, according to the literature, plastic additives have not received much attention in terms of environmental concerns, and therefore, only about 25% of them have had their environmental properties studied [36]. Owing to this, and although they could represent between 0.001% to 50% of the total weight of the final product, it was decided not to consider them in the proxy due to weak data availability.

Table 16. LCI for the manufacture of 1 kg of current petroleum-based polymer (PBP) scenario, the plastic sliding bearing.

| PBP benchmark sliding bearings     |                |
|------------------------------------|----------------|
| Material                           | Quantity (Kg)  |
| PA                                 | 0.40           |
| POM                                | 0.40           |
| HDPE                               | 0.40           |
| Energy                             | Quantity (kWh) |
| Eirich mixer (Compounding)         | 1.0            |
| Extruder (Extrusion)               | 1.0            |
| Linden Kneader (Extrudate cutting) | 0.5            |

## PBP benchmark sliding bearings

|                                          |                      |
|------------------------------------------|----------------------|
| Warm press Machine (Test plate moulding) | 20.0                 |
| Waste                                    | <b>Quantity (Kg)</b> |
| Polymer off-cuts                         | 0.20                 |
| Output                                   | <b>Quantity (Kg)</b> |
| Plastic sliding bearings                 | 1.0                  |

To see further information about the benchmarks, check Table 61, Table 62, **Error! Reference source not found.** (supplementary material).

### 3.2.5. Life Cycle Costing (LCC) of GREEN-LOOP Value Chains

Across the life of the GREEN-LOOP Project, the LCC will take into account the main aspects that affect the costs of the bio-based components during their entire life cycle. In this case, a "Cradle-to-Gate" scope was selected, including only the manufacturing process, considering the raw materials purchased to develop the bio-based components. It has been considered:

- Raw materials (including the auxiliary).
- Direct manufacture costs: energy consumption and labour (hours).
- Indirect manufacture costs: equipment purchases, waste management and other costs (5% of direct cost).
- Manufacture profits: 7% of raw materials, direct and indirect manufacturing costs.
- Environmental externalities.

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This Life Cycle Costing (LCC) aims to evaluate the economic viability of three bio-based material value chains in the construction, beverage and appliance sectors. By systematically evaluating the costs associated with the entire product life cycle, the LCA provides insight into the economic performance of these bio-based solutions, comparing them with conventional fossil- or non-renewable-origin alternatives.

Against the backdrop of a transition towards more sustainable production models, the LCC seeks to pinpoint critical cost points, pinpoint opportunities for improvement, and determine the conditions necessary to ensure the competitiveness of these new bioeconomic models. The analysis also aims to provide strategic information for designing public policies, private investments and innovation initiatives that develop more sustainable products and processes. The analysis covers all stages of each value chain, including biomass production (from agricultural raw materials, organic waste and other renewable sources), industrial transformation, manufacturing and distribution processes, and the end use and end-of-life management of the product. In particular:

- In the construction sector, the use of bio-rubber for structural elements, insulation and cladding is being analysed.
- In the beverage sector, the use of bioplastic materials for different kinds of closures is under consideration.
- The appliance sector is focusing on components made from bio-based polymers, modular parts, and sustainable casings, evaluating durability and recyclability.

The analysis considers direct costs (e.g. raw materials, energy, processing, transport) and indirect costs (e.g. R&D, regulatory compliance, environmental management), using a comparative approach to evaluate the economic performance of these solutions against their traditional equivalents.

Overall, this LCC provides a solid basis for making informed decisions about developing and implementing bio-based products in key economic and sustainable sectors.

## *Life Cycle Inventory*

As the Life Cycle Cost (LCC) inventory was based directly on the existing Life Cycle Assessment (LCA) inventory, it was not necessary to collect additional data for its development. As both methodologies share a common structure based on processes, materials, and energy flows, the same value chain modelling could be reused, thus facilitating consistency between the economic and environmental analyses. This methodological integration provides a more consistent and efficient overview of the implications of each evaluated alternative.

The unit prices used to calculate the costs of each process, input or technology were provided by the project's technical partners and are based on real data or updated estimates according to their areas of expertise. This has enabled the construction of a robust economic model aligned with the specific technological and operational conditions of each value chain and adapted to the realities of the sector in which bio-based materials are used.

### **3.2.6. Social Life Cycle Assessments (S-LCA) of GREEN-LOOP Value Chains**

The objective of the S-LCAs in GREEN-LOOP is to determine the **potential social impacts** of the three novel value chains developed within the project and compare them with the potential social impacts of the current state-of-art.

The scope of the three demo cases will be from the extraction of raw materials to the end of the manufacture process, not the whole value chain including the transports to the end user, the use phase or the End-of-Life. Thus, a “Cradle-to-gate” scope has been chosen (as in the previous dimensions) in order to evaluate the potential social impacts of every manufactured component by state-of-art or

novel processes. These boundaries have been decided based on the goals and results of the project.

*Table 17. Stakeholder, subcategories and inventory indicators assessed during the S-LCA of GREEN-LOOP.*

| <b>STAKEHOLDER: Workers</b>                             |                                                                                                  |
|---------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| <i>Subcategory</i>                                      | <b>PSILCA Inventory Indicator</b>                                                                |
| <i>Child labour</i>                                     | Children in employment, total                                                                    |
| <i>Fair salary</i>                                      | Living wage, per month<br>Sector average wage, per month                                         |
| <i>Working time</i>                                     | Weekly hours of work per employee                                                                |
| <i>Discrimination</i>                                   | Gender wage gap<br>Women in the sectoral labour force                                            |
| <i>Health and safety (Workers)</i>                      | Rate of fatal accidents at workplace<br>Rate of non-fatal accidents at workplace                 |
| <i>Social benefits, legal issues</i>                    | Violation of employment laws and regulations<br>Social security expenditures                     |
| <i>Freedom of association and collective bargaining</i> | Right of association<br>Right of collective bargaining<br>Right to strike<br>Trade union density |
| <i>Subcategory</i>                                      | <b>PSILCA Inventory Indicator</b>                                                                |
| <i>Corruption</i>                                       | Active involvement of enterprises in corruption and bribery<br>Public sector corruption          |

The analysis will be performed using a Reference Scale Approach S-LCA with the support of the **PSILCA** database and **SIMAPRO** software. The primary data will be collected from the expert partners (NCC for VC1, GUALA for VC2 and FHF for VC3) as physical flows that will be translated into monetary flows (USDs) to be introduced in the database. PSILCA includes four stakeholder categories: workers, value chain actors, society and local communities. The practitioners have decided that only **workers** and **value chain actors** are relevant stakeholders within the GREEN-LOOP system boundaries. The criteria, that was extended to the selection of subcategories (and impact indicators), were focused on analysing the potential social impacts within the value chains that concern the workers' rights during the process and the value chain actors' responsibility.<sup>7</sup>

The 8 selected subcategories and the 16 inventory indicators, in agreement with experts' opinion, are listed in Table 17. While in general the target of the inventory indicators is clear, some of them are not very straightforward, like “*Women in*

<sup>7</sup> Other **Value Chain Actors** subcategories, such as “Promoting social responsibility” or “Fair competition”, considered relevant were excluded due to lack of data in the corresponding datasets.

*sectoral labour force*”, which represents the percentage of women employed related to the total employed population in the same sector. The other stakeholders will be assessed in future S-LCA, with the large-scale supply chain already established. Further description of these subcategories is provided in Table 4.

Allocation, in case of being necessary, will be managed using the cost/value of coproducts, since the social impacts in PSILCA scale with the monetary value. The defined FU for the S-LCA is the raw material, operational and labour costs (in USD) to manufacture 1 Kg of each bio-based material, *i.e.*:

- 177.02 USD of BRP1 and 59.99 USD for BRP2 for T6.2;
- 93.73 USD of Olive Oil BB and 50.75 USD of Limoncello BB for T6.3;
- 214.74 USD of SBS1 and 224.06 of SBS2 USD for T6.4.

To fulfil the Reference Flow, the three LCIs in USD will be scaled to manufacture 1 Kg of the product. In the case of the benchmarks, their functional unit will be the raw material, operational and labour cost (in USD) to manufacture 1 Kg of benchmark material, *i.e.*:

- 177.02 USD of BRP1 and 59.99 USD for BRP2 for T6.2;
- 88.59 USD of Olive Oil current and 45.19 USD of Limoncello current for T6.3;
- 214.74 USD of MM benchmark and 213.67 USD of PBP benchmark for T6.4.

To fulfil the Reference Flow, the LCI in USD will be scaled to manufacture 1 Kg of the different products.

## Assumptions

Medium-low TRL innovative projects present a significant challenge when modelling a S-LCA, since the large-scale supply chains are not yet established. Consequently, to complete and create the LCI based on the reference flow, it is necessary to formulate a series of general assumptions that will affect the three value chains.

For GREEN-LOOP, expert partners were only using small-scale suppliers with higher prices per kg. Under these circumstances, it is legitimate to ask whether these providers would be able to supply large-scale chemicals or materials once the process is up-scaled to several kg. Additionally, the practitioners do not have access to sufficient data from pilot-scale production processes. In this section, we will present our approach to fulfil these data gaps.

In the case of the providers, we have decided to consider the **small-scale providers' country**, supposing they would be able to supply the company in case of an increasing demand for the chemicals/materials. Indeed, suggesting an alternative country for the large-scale supply chain would require a deep market analysis with so many variables.

Conversely, in the case of the prices, we suggest using **industrial prices** provided by webpages like **UN Comtrade** or **Alibaba.com** instead of the small-scale prices/kg provided by the partners. The justification for this decision relies on how the sLCA impacts are calculated. The preferred activity variable, worker hours (WH) is largely dependent on the material price, and it is clear to the practitioners that prices will be significantly reduced once large-scale supply chains are established. Therefore, there is little reason to believe that the results obtained with the small-scale supply chain values would be close to reality. Seeking coherence with the LCC, we have decided to use the same monetary inputs, transforming the euros into USD based on the average five-year currency equivalence (2021 to 2025, 1 euro = 1.098 USD).

Finally, the PRP are based on the countries in which the company or the supply chain actors are located, according to the PSILCA transparent criteria to assign these indicators.

For the benchmarks, all the primary data was sourced from existing literature. Therefore, industrial market prices were used while providers were selected based on global supply chains or key industries. It is widely known that European Union (EU) is actively promoting sustainability within its supply chains, and the selection of providers largely affects the social impacts. Owing to this, researchers like Koese et al. have performed sensibility assessment within their S-LCA considering supply chain located both inside and outside Europe [37]. Following the same strategy, this study decided to adopt a strategy in which two supply chains per benchmark scenario were considered: one inside Europe (**EU**) and another outside Europe (**Non-EU**). The manufacturing process was assumed to take place in the same countries as those considered by the GREEN-LOOP scenarios owing to limited reliable industrial data for non-European regions.

Some authors consider PSILCA *commodities* precise enough to carry out the entire assessment [38]. However, in GREEN-LOOP the primary data provided by the partners were used to geographically locate the raw materials and link them with the most representative PSILCA *commodities* (that were preferred over *industries* according to GreenDelta GmbH recommendations) in order to create the upstream flows. The manufacture process was represented by the social impacts (inventory indicators with PRPs) of the most representative *industries* within the database considering this geographical location. For the activity variable, the worker hours / USD provided by PSILCA will be used in combination with the input/output prices. These methodological decisions are aligned with some literature examples [39] [40].

## Definition of comparison scenarios

The tree benchmark processes that represent the current state-of-art technologies were selected in accordance with experts’ opinion: the rubber panels (T6.2), the Aluminium-LDPE plastic closures (T6.3) and the metallic or plastic sliding bearings (T6.4). The assumptions made to decide the **Non-EU** and the **EU** scenarios of the benchmarks are discussed based on the largest worldwide producers of each raw material outside and inside Europe, respectively.

### Bio-rubber benchmark scenario

The benchmark for natural fibre-reinforced rubber composites substitutes the natural and recycled tyre rubber by synthetic rubber. Chemically talking, synthetic rubber is an elastomer synthesized from petroleum byproducts, while natural rubber is 1,4-isoprene linear polymer (2-methyl-1,3-butadiene), therefore their providers are supposed to differ. However, some products like the vehicle tyres contain different proportions of both.<sup>8</sup>

Nowadays China is the world’s largest producer of synthetic rubber due to the significant market presence of two companies: Sinopec and PetroChina, that together account for approximately 14.4% of total market share.<sup>9</sup> For this social life cycle assessment, the PSILCA process “*Commodities - Manufacture of rubber products - CHN*” has been selected to represent the synthetic rubber production in the **Non-EU** scenario.

European biggest synthetic rubber manufacture actors are Versalis and Synthos S.A., both out of the top ten worldwide producers. Concretely, **Synthos S.A.** is a Poland company that has produced more than 4 millionth ton of synthetic elastomeric styrene-butadiene rubber (ESBR).<sup>10</sup> Based on this capacity, the PSILCA process “*Commodities - Manufacture of rubber and plastic products - POL*” was selected to represent the synthetic rubber production in the **EU** scenario.

Table 18. Countries selected to represent the raw material production of the bio-rubber benchmark scenarios.

| Non-EU scenario  |         |
|------------------|---------|
| Material         | Country |
| Synthetic rubber | China   |
| EU scenario      |         |
| Material         | Country |
| Synthetic rubber | Poland  |

<sup>9</sup> Global synthetic rubber production Q1 2024, by country – Statista. <https://www.statista.com/statistics/1288280/distribution-of-global-synthetic-rubber-production-by-select-country/>

<sup>10</sup> Synthos – 4 millionth ton of rubber. <https://www.synthosgroup.com/en/4-millionth-ton-of-rubber/>

All other chemicals, materials and processes included in the current scenario will be modelled consistently with the GREEN-LOOP scenarios, focusing the comparison on the substitution of the synthetic rubber. The manufacturing process is assumed to take place in the United Kingdom, where NCC is located.

## Bio-plastic benchmark scenario

Olive oil closures are currently made from either aluminium and low-density polyethylene (LDPE) or combination of both in different proportions. However, during this study, only LDPE will be considered as the benchmark material.

PE is produced through high-pressure and temperature polymerisation of ethylene. Between 2019-2021, the United States was the largest producer of PE with 820000 tonnes manufactured by companies such as Chevron Phillips Chemicals, Dow or ExxonMobil Corporation.<sup>11</sup> Consequently, the PSILCA process "Commodities - Plastics material and resin manufacturing - USA" has been selected to represent the **Non-EU** scenario. Conversely, the Dutch company LyondellBasell Industries is the largest PE produced within Europe, so the PSILCA process "Commodities - Manufacture of rubber and plastic products - NLD" has been chosen to represent the **EU** scenario.

Table 19. Countries selected to represent the raw material production of the bioplastic benchmark scenarios.

| Non-EU scenario |             |
|-----------------|-------------|
| Material        | Country     |
| LDPE            | USA         |
| PP              | USA         |
| EU scenario     |             |
| Material        | Country     |
| LDPE            | Netherlands |
| PP              | Portugal    |

In the case of the Limoncello closures, the material selected for the benchmark is polypropylene (PP). The PP is produced through a polymerisation process using propylene as raw material, high temperatures and pressures and catalysts. The largest producer of PP is the American company LyondellBasell Industries N.V. Consequently, the PSILCA process "Commodities - Plastics material and resin manufacturing - USA" was selected to represent the Non-EU scenario. Inside Europe, the Portuguese factory of Repsol is the biggest polypropylene producer.

<sup>11</sup> Statista - New production capacity of HDPE worldwide between 2019 and 2021 by country (in 1000 metric tons). <https://www.statista.com/statistics/1120465/global-high-density-polyethylene-production-distribution-by-region/>

Thus, the PSILCA process “*Commodities - Manufacture of rubber and plastic products - PRT*” was selected to represent the EU scenario.

All other processes included in the current olive oil closure and Limoncello closure scenarios were modelled consistently with the GREEN-LOOP scenarios (T6.3). The manufacturing processes are assumed to take place in Italy, where MIX and LBRT are located.

## Wood composites scenario

Commercially available sliding bearings are generally manufactured from metals or plastics. Metallic sliding bearings are composed of a wide variety of metals such as copper, cast iron, zinc and aluminium, while plastic sliding bearings could be made of different rigid plastics such as polyamide (PA), polyether ether ketone (PEEK), polyether sulphone (PES), polyoxymethylene (POM) or high-density polyethylene (HDPE). The selection of the material is totally dependent on the final application and, therefore, very difficult to predict specifically in this case of use.

Some researchers who had similar issues in selecting their supply chain opted for creating representative mixes to account for the potential social risk occurring within different plausible supply chains. Based on this, it was decided to represent the metallic and plastic benchmarks as a material mix in agreement with the E-LCA benchmarks previously established.

Consequently, the two current scenarios proposed for this S-LCA are:

- a metallic mix sliding bearing (MM) proxied as a mixture of copper, cast iron, zinc and aluminium in similar proportions (Benchmark **A**).
- a petroleum-based polymer mix sliding bearing (PBP) proxied as a mixture of three common plastic materials in similar proportions: polyamide (PA), polyoxymethylene (POM) and HDPE (Benchmark **B**).

For both scenarios, the **Non-EU** and **EU** scenarios were proposed, obtaining 4 different benchmarks to analyse. In the following paragraphs, the materials will be analysed individually to decide where to locate them.

**Copper** production outside Europe is led by South American countries. Chile is the world’s largest producer with 5 million tonnes per year, followed by Peru, which produces 2.6 million tonnes annually.<sup>12</sup> Consequently, the PSILCA process “*Commodities - Basic products of nonferrous metals - CHL*” has been selected to represent the copper alloy production in the **Non-EU** scenario. Within Europe, the German company Aurubis AG is the leader in the production of non-ferrous metals.<sup>13</sup> Therefore, the PSILCA process “*Commodities - Basic non-ferrous metals -*

<sup>12</sup> Statista – Copper production by country. <https://www.statista.com/statistics/264626/copper-production-by-country/>

<sup>13</sup> <https://www.aurubis.com/en/>

*DEU*” has been selected to represent the copper alloy production in the **EU** scenario.

**Cast iron** is produced through melting a combination of pig iron, steel scrap, carbon coke and other additives. It is produced worldwide, although China currently leads the global market with companies such as China Baowu Group.<sup>14</sup> Consequently, the PSILCA process “*Commodities - Alloy iron smelting - CHN*” has been selected to represent the cast iron production in the **Non-EU** scenario. Inside Europe, the Luxembourgish company ArcelorMittal leads the market, with the largest steel plant in Europe located in Italy [39]. Therefore, the PSILCA process “*Commodities - Manufacture of basic metals - ITA*” has been chosen to represent the cast iron production in the **EU** scenario.

33% of **Zinc** alloys produced from mining activities is accounted by China, followed from afar by Peru with an 11.7%. Consequently, the PSILCA process “*Commodities - Metal Products - CHN*” has been selected to represent the zinc production in the **Non-EU** scenario. Within Europe, Sweden produces 1.8% of the total share with companies such as Boliden. Therefore, the PSILCA process “*Commodities - Manufacture of basic metals - SWE*” has been selected to represent the **EU** scenario.<sup>15</sup>

Aluminium market share has already been discussed beforehand. During this discussion, the PSILCA process “*Commodities - Nonferrous metal processing - CHN*” has been selected to represent the production of primary virgin aluminium in the **Non-EU** scenario, while the PSILCA process “*Commodities - Manufacture of basic metals - NOR*” has been selected to represent the **EU** scenario.

**PA** is prepared through the polymerisation reaction of nitrogen-containing molecules with carboxylic acid monomers. Outside Europe, China is one of the main producers of PA-6 and PA-6,6 but specifically providing the textile sector. The USA is another big actor within the PA industry, with companies such as Celanese that manufacture a wide variety of polyamide compounds. Consequently, the PSILCA process “*Commodities - Plastics material and resin manufacturing - USA*” has been selected to represent the PA in the **Non-EU** scenario. Inside Europe, Germany leads the market, with companies such as BASF. Therefore, the PSILCA process “*Commodities - Manufacture of plastic products - DEU*” has been selected to represent the PA in the **EU** scenario.<sup>16</sup>

<sup>14</sup> <https://www.metalbook.com/blogs/top-10-largest-steel-producing-companies-in-the-world/>

<sup>15</sup> Statista: Distribution of zinc mine production worldwide in 2023, by country. <https://www.statista.com/statistics/604618/distribution-of-zinc-production-from-mines-worldwide-by-country>

<sup>16</sup> European Polyamide Market. <https://www.mordorintelligence.com/industry-reports/europe-polyamide-market>.

**POM** is obtained by direct polymerisation of formaldehyde. According to Plastic Insights, China leads the world production of this polymer, with companies such as China BlueChemical Ltd.<sup>17</sup> Consequently, the PSILCA process "*Commodities - Manufacture of plastic products - CHN*" has been selected to represent the **Non-EU** scenario. The German company BASF is again the main European producer. Therefore, the PSILCA process "*Commodities - Manufacture of plastic products - DEU*" has been selected for the **EU** scenario.

Table 20. Countries selected to represent the raw material production of the wood composite benchmark scenarios.

| Non-EU scenario |             |
|-----------------|-------------|
| Material        | Country     |
| Copper          | Chile       |
| Cast iron       | China       |
| Zinc            | China       |
| Aluminium       | China       |
| PA              | USA         |
| POM             | China       |
| LDPE            | USA         |
| EU scenario     |             |
| Material        | Country     |
| Copper          | Germany     |
| Cast iron       | Italy       |
| Zinc            | Sweden      |
| Aluminium       | Norway      |
| PA              | Germany     |
| POM             | Germany     |
| LDPE            | Netherlands |

PE market share has already been discussed beforehand. The PSILCA process "*Commodities - Plastics material and resin manufacturing - USA*" has been selected to represent **Non-EU** scenario, while the PSILCA process "*Commodities - Manufacture of rubber and plastic products - NLD*" has been selected to represent the **EU** scenario.

All other processes included in the sliding bearing benchmarks were modelled consistently with the GREEN-LOOP scenarios (T6.5) whenever it is coherent with the process. The manufacturing process is assumed to take place in Germany, where FHF is geographically located.

<sup>17</sup> Plastic Insights. Plastic World Market of Polyoxymethylene (POM). <https://en.kunststoffe.de/a/specialistarticle/polyoxymethylene-pom-245435>.

## Life Cycle Inventory

The different life cycle inventories (LCI) for each case of use, both for the benchmark and the GREEN-LOOP scenarios, are explained and described in the next sub-sections based on the previous assumptions. All the inventory is scaled to the production of 1 Kg and expressed in monetary values (USD) to be translated to worker hours with the support of the PSILCA database during the LCIA phase.

## Bio-rubber scenario

The first step of the bio-rubber value chain is the lignin recovery. The upstream flows are modelled in the following way:

The process is carried out in Slovenia by the National Institute of Chemistry (NIC). Consequently, the electricity used in the process was represented by the PSILCA process "Commodities - Electrical energy, gas, steam and hot water - SVN". The distilled water and lignocellulose biomass required to complete the reaction was produced by Slovenian companies and represented by the PSILCA processes "Commodities - Collection, purification and distribution of water - SVN" and "Commodities - Manufacture of wood and products of wood and cork, except furniture, manufacture of articles of straw and plaiting materials - SVN", respectively. The other chemicals utilised in the reactions were sourced from the American company Sigma-Aldrich and represented by the PSILCA process "Commodities - Manufacture of chemical products - USA".

Table 21. LCI for the manufacture of 1 kg of bio-rubber panel using natural rubber and lignin powder (BRP1).

| BRP1 STEP 1 - Lignin Recovery             |                |          |
|-------------------------------------------|----------------|----------|
| Material                                  | Quantity (USD) | Country  |
| Distilled water                           | 6.66           | Slovenia |
| Sodium sulphide                           | 2.70           | USA      |
| Sodium hydroxide                          | 11.45          | USA      |
| Lignocellulose biomass                    | 0.56           | Slovenia |
| Sulfuric acid                             | 31.67          | USA      |
| Energy                                    | Quantity (USD) | Country  |
| Batch Reactor                             | 38.967         | Slovenia |
| Material                                  | Quantity (USD) | Country  |
| Lignin Powder                             | 93.414         | Slovenia |
| BRP1 STEP 2 - Bio-rubber panel production |                |          |
| Material                                  | Quantity (USD) | Country  |
| Lignin Powder                             | 93.414         | --       |
| TDP                                       | 0.20           | Germany  |
| Natural rubber                            | 0.25           | Malaysia |
| Low Lead Zinc Oxide                       | 2.57           | USA      |

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|                  |                       |                |
|------------------|-----------------------|----------------|
| Stearic acid     | 0.29                  | USA            |
| MBTS-75          | 0.75                  | USA            |
| 300 Mesh Sulphur | 1.24                  | USA            |
| Energy           | <b>Quantity (USD)</b> | <b>Country</b> |
| Internal mixer   | 0.10                  | UK             |
| Press            | 4.93                  | UK             |
| Material         | <b>Quantity (USD)</b> | <b>Country</b> |
| Bio-rubber panel | 177.02                | UK             |

The direct social impacts, as inventory indicators with PRP and worker hours per USD of output, are obtained from the PSILCA process "*Industries - Manufacture of rubber and plastic products - SVN*".

Table 21 presents the chemicals, materials and processes involved in the lignin recovery step, along with their respective country of origin, scaled to produce 1 Kg of bio-rubber panel (BRP1). Table 68 lists the corresponding PSILCA processes. Labour and environmental costs are only calculated for the final process in the LCC. For the sake of simplification, they will not be included in the output price of the lignin recovery process.

Table 22. LCI for the manufacture of 1 kg of bio-rubber panel using natural rubber (BRP2).

| BRP2 Bio-rubber panel production |                       |                |
|----------------------------------|-----------------------|----------------|
| Material                         | <b>Quantity (USD)</b> | <b>Country</b> |
| TDP                              | 0.23                  | Germany        |
| Natural rubber                   | 0.30                  | Malaysia       |
| Low Lead Zinc Oxide              | 3.01                  | USA            |
| Stearic acid                     | 0.33                  | USA            |
| MBTS-75                          | 0.96                  | USA            |
| 300 Mesh Sulphur                 | 1.45                  | USA            |
| Energy                           | <b>Quantity (USD)</b> | <b>Country</b> |
| Internal mixer                   | 0.10                  | UK             |
| Press                            | 4.81                  | UK             |
| Material                         | <b>Quantity (USD)</b> | <b>Country</b> |
| Bio-rubber panel                 | 56.99                 | UK             |

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The last process is bio-rubber panel manufacture. For this process, two different scenarios are proposed. One in which the lignin powder is included in the final composite (BRP1) and another in which the lignin is excluded (BRP2). The upstream flows for these two scenarios are modelled in the following way:

The process is carried out in Bristol (UK) by the National Composite Centre (NCC). Consequently, the electricity used in the process was represented by the PSILCA process "*Commodities - Transmission of electricity - GBR*". The lignin powder was

sourced from Slovenia and represented by the Lignin recovery process, previously modelled. The tyre-derived polymer (TDP) was provided by the German company Genan Ltd. Innovation Centre and represented by the process "Commodities - Manufacture of rubber products - DEU". The natural rubber was sourced from Malaysia and represented by the PSILCA process "Commodities - Agricultural products other - MYS". The other chemicals are provided by the American company Sigma-Aldrich and represented again by the PSILCA process "Commodities - Manufacture of chemical products - USA".

The direct social impacts, as inventory indicators with PRP and worker hours per USD of output, are obtained from the PSILCA process "Industries - Manufacture of rubber products, tyres and tubes - GBR". Table 21 presents the chemicals, materials and processes involved in the bio-rubber panel manufacture containing lignin powder (BRP1), along with their respective country of origin. Table 69 lists the corresponding PSILCA processes.

Within this value chain, the hypothetical benchmark is the manufacture of rubber panels substituting the TDP and the natural rubber by the proportional quantities of virgin synthetic rubber, carbon black and silica sand. Two different scenarios were considered, one including a European supply chain (**EU benchmark scenario**) and the other including a non-European supply chain (**Non-EU benchmark scenario**). The origin of the substituted materials was deeply discussed beforehand. The remaining chemicals, materials and processes were modelled in the same way as the GREEN-LOOP scenarios.

Table 23 presents the chemicals, materials and processes in the EU benchmark scenario, along with their respective country of origin, while Table 24 presents the same inventory for the non-EU benchmark scenario.

Table 70 and

Table 71 list the corresponding PSILCA processes.

*Table 23. LCI for the manufacture of 1 kg of a rubber panel using synthetic rubber. The process to obtain lignin powder is the same as in the GREEN-LOOP bio-rubber value chain. The synthetic rubber, carbon black and silica sand were considered to be supplied from Europe.*

| <b>BENCHMARK STEP 1 - Lignin Recovery (EU)</b> |                |          |
|------------------------------------------------|----------------|----------|
| Material                                       | Quantity (USD) | Country  |
| Distilled water                                | 5.66           | Slovenia |
| Sodium sulphide                                | 2.43           | USA      |
| Sodium hydroxide                               | 10.30          | USA      |
| Lignocellulose biomass                         | 0.50           | Slovenia |
| Sulfuric acid                                  | 28.47          | USA      |
| Energy                                         | Quantity (USD) | Country  |
| Batch Reactor                                  | 35.03          | Slovenia |

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|                                                            |                       |                |
|------------------------------------------------------------|-----------------------|----------------|
| Material                                                   | <b>Quantity (USD)</b> | <b>Country</b> |
| Lignin Powder                                              | 83.99                 | Slovenia       |
| <b>BENCHMARK STEP 2 – Bio-rubber panel production (EU)</b> |                       |                |
| Material                                                   | <b>Quantity (USD)</b> | <b>Country</b> |
| Lignin Powder                                              | 83.99                 | --             |
| Synthetic rubber                                           | <b>1.49</b>           | <b>Polonia</b> |
| Low Lead Zinc Oxide                                        | 2.56                  | USA            |
| Stearic acid                                               | 0.27                  | USA            |
| MBTS-75                                                    | 0.82                  | USA            |
| 300 Mesh Sulphur                                           | 1.24                  | USA            |
| Energy                                                     | <b>Quantity (USD)</b> | <b>Country</b> |
| Internal mixer                                             | 0.10                  | UK             |
| Press                                                      | 4.93                  | UK             |
| Material                                                   | <b>Quantity (USD)</b> | <b>Country</b> |
| Bio-rubber panel                                           | 185.64                | UK             |

Table 24. LCI for the manufacture of 1 kg of rubber panel using synthetic rubber. The process to obtain lignin powder is the same as in the GREEN-LOOP bio-rubber value chain. The synthetic was considered to be supplied from outside Europe.

|                                                                |                       |                |
|----------------------------------------------------------------|-----------------------|----------------|
| <b>BENCHMARK STEP 1 - Lignin Recovery (Non-EU)</b>             |                       |                |
| Material                                                       | <b>Quantity (USD)</b> | <b>Country</b> |
| Distilled water                                                | 5.66                  | Slovenia       |
| Sodium sulphide                                                | 2.43                  | USA            |
| Sodium hydroxide                                               | 10.30                 | USA            |
| Lignocellulose biomass                                         | 0.50                  | Slovenia       |
| Sulfuric acid                                                  | 28.47                 | USA            |
| Energy                                                         | <b>Quantity (USD)</b> | <b>Country</b> |
| Batch Reactor                                                  | 35.03                 | Slovenia       |
| Material                                                       | <b>Quantity (USD)</b> | <b>Country</b> |
| Lignin Powder                                                  | 83.99                 | Slovenia       |
| <b>BENCHMARK STEP 2 – Bio-rubber panel production (Non-EU)</b> |                       |                |
| Material                                                       | <b>Quantity (USD)</b> | <b>Country</b> |
| Lignin Powder                                                  | 83.99                 | --             |
| Synthetic rubber                                               | <b>1.49</b>           | <b>China</b>   |
| Low Lead Zinc Oxide                                            | 2.56                  | USA            |
| Stearic acid                                                   | 0.27                  | USA            |
| MBTS-75                                                        | 0.82                  | USA            |
| 300 Mesh Sulphur                                               | 1.24                  | USA            |
| Energy                                                         | <b>Quantity (USD)</b> | <b>Country</b> |
| Internal mixer                                                 | 0.10                  | UK             |

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Press

Material

Bio-rubber panel

| 4.93           | UK      |
|----------------|---------|
| Quantity (USD) | Country |
| 185.64         | UK      |

## Bio-plastic scenario

In the T6.3, two value chains were developed: one to make a bioplastic olive oil cap, and other to make a bioplastic Limoncello cap.

The process is carried out in Italy by the companies Mixcycling SRL (MIX) and GUALA Closures (GUALA). Consequently, the electricity used in these two value chains was represented by the PSILCA process "*Commodities - Electrical energy, gas, steam and hot water - ITA*", and the direct social impacts as inventory indicators with PRP and worker hours per USD of output, are obtained from the PSILCA process "*Industries - Manufacture of rubber and plastic products - ITA*".

In both examples, the bioplastic blend is prepared with PHA and rice husk in a 4:1 proportion. The PHA was represented by the PSILCA process "*Commodities - Manufacture of rubber and plastic products - NLD*", while the rice husk was represented by the PSILCA process "*Commodities - Products of agriculture, hunting and related services - ITA*".

Table 25 presents the chemicals, materials and processes involved in the bioplastic olive oil closure (BP OIL), along with their respective country of origin, scaled to produce 1 Kg. Table 72 lists the corresponding PSILCA processes.

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Table 25. LCI for the preparation of 1 Kg of bioplastic olive oil closures.

| BIOPLASTIC OLIVE OIL CLOSURE (BP OIL) |                |             |
|---------------------------------------|----------------|-------------|
| Material                              | Quantity (USD) | Country     |
| PHA                                   | 6.15           | Netherlands |
| Rice Husk                             | 0.04           | Italy       |
| Energy                                | Quantity (USD) | Country     |
| NTP                                   | 0.44           | Italy       |
| Extruder                              | 0.37           | Italy       |
| Hopper Dryer                          | 0.05           | Italy       |
| Hopper Loader                         | 0.29           | Italy       |
| MW preheating system                  | 0.29           | Italy       |
| Injection moulding - caps             | 1.60           | Italy       |
| Injection moulding - Pourer           | 1.60           | Italy       |
| Material                              | Quantity (USD) | Country     |
| Bioplastic Olive Oil closure          | 93.73          | Italy       |

Table 26 presents the chemicals, materials and processes involved in the bioplastic Limoncello closure (BP LIM), along with their respective country of origin, scaled to produce 1 Kg.

Table 73 lists the corresponding PSILCA processes.

Table 26. LCI for the preparation of 1 Kg of bioplastic Limoncello closures.

| LIMONCELLO CLOSURE (BP LIM)   |                |             |
|-------------------------------|----------------|-------------|
| Material                      | Quantity (USD) | Country     |
| PHA                           | 6.15           | Netherlands |
| Rice Husk                     | 0.04           | Italy       |
| Energy                        | Quantity (USD) | Country     |
| NTP                           | 0.44           | Italy       |
| Extruder                      | 0.37           | Italy       |
| Hopper Dryer                  | 0.05           | Italy       |
| Injection moulding - caps     | 1.60           | Italy       |
| Injection moulding - Pourer   | 1.60           | Italy       |
| Material                      | Quantity (USD) | Country     |
| Bioplastic Limoncello closure | 50.75          | Italy       |

In the case of the benchmarks, as it was explained beforehand, one was proposed for the olive oil closures and other for the Limoncello closure. The olive oil closure benchmark is divided into two different scenarios: a Non-EU scenario (Non-EU OO) in which the raw materials are supplied from outside Europe and other EU scenario (EU OO) in which the raw materials are supplied from Europe.

Table 27 presents the chemicals, materials and processes involved in the Non-EU OO, along with their respective country of origin, scaled to produce 1 Kg.

Table 74 lists the corresponding PSILCA processes.

Table 27. LCI for the preparation of 1 Kg of current olive oil closures of LDPE. Raw material providers considered from outside Europe.

| OLIVE OIL CLOSURE CURRENT (NON EU OO) |                |         |
|---------------------------------------|----------------|---------|
| Material                              | Quantity (USD) | Country |
| LDPE                                  | 1.66           | USA     |
| Energy                                | Quantity (USD) | Country |
| NTP                                   | 0.44           | Italy   |
| Extruder                              | 0.37           | Italy   |
| Hopper Dryer                          | 0.05           | Italy   |
| Hopper Loader                         | 0.29           | Italy   |
| MW preheating system                  | 0.29           | Italy   |
| Injection moulding - caps             | 1.60           | Italy   |
| Injection moulding - Pourer           | 1.60           | Italy   |
| Material                              | Quantity (USD) | Country |
| Olive Oil closure (current)           | 88.59          | Italy   |

Table 28 presents the chemicals, materials and processes involved in the EU OO, along with their respective country of origin, scaled to produce 1 Kg. Table 75 lists the corresponding PSILCA processes.

*Table 28. LCI for the preparation of 1 Kg of current olive oil closures of LDPE. Raw material providers are considered from Europe.*

| OLIVE OIL CLOSURE CURRENT (EU OO) |                |             |
|-----------------------------------|----------------|-------------|
| Material                          | Quantity (USD) | Country     |
| LDPE                              | 1.66           | Netherlands |
| Energy                            | Quantity (USD) | Country     |
| NTP                               | 0.44           | Italy       |
| Extruder                          | 0.37           | Italy       |
| Hopper Dryer                      | 0.05           | Italy       |
| Hopper Loader                     | 0.29           | Italy       |
| MW preheating system              | 0.29           | Italy       |
| Injection moulding - caps         | 1.60           | Italy       |
| Injection moulding - Pourer       | 1.60           | Italy       |
| Material                          | Quantity (USD) | Country     |
| Olive Oil closure (current)       | 88.59          | Italy       |

Parallely, the Limoncello closure benchmark is divided, as well, into the same two different scenarios: a Non-EU scenario (Non-EU LIM) in which the raw materials are supplied from outside Europe and other EU scenario (EU LIM) in which the raw materials are supplied from Europe.

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Table 29 presents the chemicals, materials and processes involved in the Non-EU LIM, along with their respective country of origin, scaled to produce 1 Kg. Table 7675 lists the corresponding PSILCA processes.

*Table 29. LCI for the preparation of 1 Kg of current Limoncello closures of PP. Raw material providers considered from outside Europe.*

| LIMONCELLO CLOSURE CURRENT (NON EU LIM) |                |         |
|-----------------------------------------|----------------|---------|
| Material                                | Quantity (USD) | Country |
| PP                                      | 1.43           | USA     |
| Energy                                  | Quantity (USD) | Country |
| NTP                                     | 0.44           | Italy   |
| Extruder                                | 0.37           | Italy   |
| Hopper Dryer                            | 0.05           | Italy   |
| Injection moulding - caps               | 1.60           | Italy   |
| Injection moulding - Pourer             | 1.60           | Italy   |
| Material                                | Quantity (USD) | Country |
| PP Limoncello closure (current)         | 45.19          | Italy   |

Table 30 presents the chemicals, materials and processes involved in the EU LIM, along with their respective country of origin, scaled to produce 1 Kg. Table 77 lists the corresponding PSILCA processes.

Table 30. LCI for the preparation of 1 Kg of current Limoncello closures of PP. Raw material providers are considered from Europe.

| LIMONCELLO CLOSURE CURRENT (EU LIM) |                |          |
|-------------------------------------|----------------|----------|
| Material                            | Quantity (USD) | Country  |
| PP                                  | 1.43           | Portugal |
| Energy                              | Quantity (USD) | Country  |
| NTP                                 | 0.44           | Italy    |
| Extruder                            | 0.37           | Italy    |
| Hopper Dryer                        | 0.05           | Italy    |
| Injection moulding - caps           | 1.60           | Italy    |
| Injection moulding - Pourer         | 1.60           | Italy    |
| Material                            | Quantity (USD) | Country  |
| PP Limoncello closure (current)     | 45.19          | Italy    |

## Wood composites scenario

For the wood-composite value chains, the upstream flows are modelled in the following way:

The process is carried out in Germany by the Fraunhofer Gesellschaft Institute (FHF). Consequently, the electricity consumption in the four steps was represented by the PSILCA process "Commodities - Electricity and district heat - DEU". The biopolymer ARBOBLEND 2241x was produced by the German company TECNARO GmbH and represented by the PSILCA process "Commodities - Manufacture of chemical products - DEU".

The natural wood fibre was provided by the German company RETTENMAIER SÖHNE GmbH and, therefore, represented by the PSILCA process "Commodities - Manufacture of wood and wood products - DEU". Finally, the glass fibre was sourced by the Schwarzwälder Textil-Werke Heinrich Kautzmann GmbH, also a German company, and represented by the PSILCA process "Commodities - Manufacture of glass and glass products - DEU".

Table 31. LCI for wood composite SBS1 (without glass fibre) from T6.5.

| SBS1 (W/O GLASS FIBRE) |                |         |
|------------------------|----------------|---------|
| Material               | Quantity (USD) | Country |
| ARBOBLEND 2241x        | 15.57          | Germany |
| Natural wood fibre     | 0.31           | Germany |
| Energy                 | Quantity (USD) | Country |

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|                                  |                       |                |
|----------------------------------|-----------------------|----------------|
| <i>Eirich mixer</i>              | 0.38                  | Germany        |
| <i>Extruder</i>                  | 0.38                  | Germany        |
| <i>Linden Kneader</i>            | 0.19                  | Germany        |
| <i>Warm press Machine</i>        | 7.69                  | Germany        |
| <b>Material</b>                  | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Wood composite test plate</i> | 226.19                | Germany        |

The direct social impacts, as inventory indicators with PRP and worker hours per USD of output, are obtained from the PSILCA process "Commodities - Manufacture of plastic products - DEU".

Table 32. LCI for wood composite SBS2 (with glass fibre) from T6.5.

| <b>SBS2 (WITH GLASS FIBRE)</b>   |                       |                |
|----------------------------------|-----------------------|----------------|
| <b>Material</b>                  | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>ARBOBLEND 2241x</i>           | 11.39                 | Germany        |
| <i>Natural wood fibre</i>        | 0.22                  | Germany        |
| <i>Glass fibre</i>               | 1.17                  | Germany        |
| <b>Energy</b>                    | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Eirich mixer</i>              | 0.38                  | Germany        |
| <i>Extruder</i>                  | 0.38                  | Germany        |
| <i>Linden Kneader</i>            | 0.19                  | Germany        |
| <i>Warm press Machine</i>        | 7.69                  | Germany        |
| <b>Material</b>                  | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Wood composite test plate</i> | 224.06                | Germany        |

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Table 31 presents the chemicals, materials and processes involved in SBS1, the wood-composite without glass fibre, along with their respective country of origin. Table 7877 lists the corresponding the PSILCA process.

Table 33. LCI for MM benchmark from T6.4. Raw materials providers considered from outside Europe

| <b>MM BENCHMARK (EU)</b>  |                       |                |
|---------------------------|-----------------------|----------------|
| <b>Material</b>           | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Copper</i>             | 2.21                  | Chile          |
| <i>Cast iron</i>          | 0.39                  | China          |
| <i>Zinc</i>               | 0.71                  | China          |
| <i>Aluminium</i>          | 0.60                  | China          |
| <b>Energy</b>             | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Eirich mixer</i>       | 0.38                  | Germany        |
| <i>Extruder</i>           | 0.38                  | Germany        |
| <i>Linden Kneader</i>     | 0.19                  | Germany        |
| <i>Warm press Machine</i> | 7.69                  | Germany        |

| <b>Material</b>                 | <b>Quantity (USD)</b> | <b>Country</b> |
|---------------------------------|-----------------------|----------------|
| <i>Metallic sliding bearing</i> | 214.74                | <i>Germany</i> |

Table 32 presents the chemicals, materials and processes involved in SBS2, the wood-composite containing glass fibre, along with their respective country of origin. Table 79 lists the corresponding PSILCA process.

Table 34. LCI for MM benchmark from T6.4. Raw materials providers considered from Europe

| <b>MM BENCHMARK (EU)</b>        |                       |                |
|---------------------------------|-----------------------|----------------|
| <b>Material</b>                 | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Copper</i>                   | 2.21                  | <i>Germany</i> |
| <i>Cast iron</i>                | 0.39                  | <i>Italy</i>   |
| <i>Zinc</i>                     | 0.71                  | <i>Sweden</i>  |
| <i>Aluminium</i>                | 0.60                  | <i>Norway</i>  |
| <b>Energy</b>                   | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Eirich mixer</i>             | 0.38                  | <i>Germany</i> |
| <i>Extruder</i>                 | 0.38                  | <i>Germany</i> |
| <i>Linden Kneader</i>           | 0.19                  | <i>Germany</i> |
| <i>Warm press Machine</i>       | 7.69                  | <i>Germany</i> |
| <b>Material</b>                 | <b>Quantity (USD)</b> | <b>Country</b> |
| <i>Metallic sliding bearing</i> | 214.74                | <i>Germany</i> |

Within this value chain, the benchmarks were represented as two mixes of petroleum-based polymers (PBP benchmark) and metals (MM benchmark). In both cases, the biopolymers and the biodegradable materials were fully substituted. For each benchmark, two scenarios were established, one including a European supply chain (**EU PBP benchmark** and **EU MM benchmark**) and the other including a non-European supply chain (**Non-EU PBP benchmark** and **Non-EU MM benchmark**), obtaining a total of 4 social scenarios. The origin of the substituted materials, both inside and outside Europe, was deeply discussed in previous sections

The energy consumptions are modelled in the same way as the GREEN-LOOP scenarios, while the social aspects were modelled differently depending on the benchmark. For the **PBP benchmark**, the process "*Commodities - Manufacture of plastic products - DEU*" has been selected in agreement with SBS1 and SBS2, while in the case of the **MM benchmark**, the PSILCA process "*Manufacture of fabricated metal products - DEU*" has been chosen.

Table 33 and Table 80 present the chemicals, materials, monetary flows and PSILCA processes in **EU PBP benchmark scenario**. Table 34, and Table 81 list the corresponding inventory information for the **non-EU PBP benchmark**.

Table 35. LCI for PBP benchmark from T6.4. Raw materials providers considered from outside Europe

| PBP Benchmark (Non-EU)  |                |         |
|-------------------------|----------------|---------|
| Material                | Quantity (USD) | Country |
| PA                      | 1.38           | USA     |
| POM                     | 1.10           | China   |
| HDPE                    | 0.44           | USA     |
| Energy                  | Quantity (USD) | Country |
| Eirich mixer            | 0.38           | Germany |
| Extruder                | 0.38           | Germany |
| Linden Kneader          | 0.19           | Germany |
| Warm press Machine      | 7.69           | Germany |
| Material                | Quantity (USD) | Country |
| Plastic sliding bearing | 213.67         | Germany |

Table 35 and

Table 82 present the chemicals, materials, monetary flows and PSILCA process in the EU **MM benchmark**. Table 36 and Table 8380 list the same corresponding processes for the **non-EU MM benchmark**.

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Table 36. LCI for PBP benchmark from T6.4. Raw materials providers are considered from Europe.

| PBP Benchmark (Non-EU)  |                |             |
|-------------------------|----------------|-------------|
| Material                | Quantity (USD) | Country     |
| PA                      | 1.38           | Germany     |
| POM                     | 1.10           | Germany     |
| HDPE                    | 0.44           | Netherlands |
| Energy                  | Quantity (USD) | Country     |
| Eirich mixer            | 0.38           | Germany     |
| Extruder                | 0.38           | Germany     |
| Linden Kneader          | 0.19           | Germany     |
| Warm press Machine      | 7.69           | Germany     |
| Material                | Quantity (USD) | Country     |
| Plastic sliding bearing | 213.67         | Germany     |

## 4. Analysis of results

The balances of mass, energy and exergy balance have been analysed from a global perspective of the three value chains (VC), in order to provide a discussion that let understand the performance of the whole manufacturing processes and their modifications during scaling up to TRL6.

### 4.1. Mass analysis

In this section, all the results related to the mass balances are shown alongside the percentage of saving of materials in the three VCs compared to the analysis of D2.2.

#### 4.1.1. Bio-rubber manufacture

##### *Lignin extraction*

Compared to TRL5, a 25.22 % of raw material (lignocellulose biomass) is saved in inlet. For this reason, the amount of components derived from the inlet (cellulose and hemicellulose) that are wasted during the process has been reduced, leading to a saving of materials to produce 25 g of lignin. Moreover, the amount of losses generated within the process has been reduced per unit of inlet mass: in results of D2.2, 61.57 % of mixture produced in pulping was removed through the acid liquor, which represents the major fraction of losses in the whole process, whereas in the present deliverable only 49.67 % of raw materials are removed.

##### *Rubber panel production*

Whereas in D2.2 the quantity of raw materials was the same as the product of the previous sub-processes (lignin extraction and rubber functionalisation), now the production of rubber panels (RPs) requires more inlet mass, so that the manufacture gives more amount of product at the end of the process.

In this line, the mass of raw materials (lignin, devulcanized rubber and natural rubber) has been increased (from 25 g to 637 g, from 80 g to 2045 g and from 20 g to 512 g, respectively), what means that the extraction of lignin should be performed around 26 times to give the lignin powder needed to produce the RPs in the last update of PFD. Furthermore, the curatives (ZnO, stearic acid, MBTS-75 and mesh sulphur) used within the process also need to be increased for a major inlet (from a total mass of 9 g to 233 g). Nevertheless, the wastes have completely been eliminated during the compression moulding, whereas they are maintained approximately the same in compounding (from 5 % to 4.74 %) and cutting (from 4.48 % to 4.57 %).

## 4.1.2. Bio-plastic manufacture

At TRL5, 1.33 g of PLA and 2 g of cork were used instead of 5 kg of rice husk, and the amount of PHA has been increased from 6.67 g to 20 kg, giving as a result a total quantity of 25 kg of bio-plastic caps. Only gases from the drying are wasted during extrusion, which are excluded from the 5 kg of rice at inlet, so no wastes are generated in the process.

## 4.1.3. Wood composites manufacture

The recycled glass fibres have been introduced in upscaling, so the mass of inlet material has grown a 36.71 %, but the amount of both bio-polymer mix and wood fibres has decreased a 16,67 % and a 16.65 %, respectively, so both a saving of components and the introduction of recycled materials have been achieved at TRL6, staying in line with the statements of GREEN LOOP project.

## 4.2. Energy analysis

The development of manufacture equipment is analysed through the changes in the energy consumption within the processes. In addition, the mass-energy ratio of final product is provided alongside the comparison to the results at TRL5.

### 4.2.1. Bio-rubber manufacture

In D2.2, the consumption in pulping was the highest fraction of demand during the lignin extraction due to it took place in a reactor, a device that consumes a high amount of energy; the energy used to heat the mixture was unknown, so a total mechanical consumption during pulping was supposed. In the current state of the project, the amount of energy used for heating and cooling is provided by partners, and the consumption due to the mechanical work has been estimated: the total consumption during pulping represents 14.768 % of the RB manufacture. Moreover, the drying oven presents a similar percentage (16.312 %), representing the second major consumption of the whole process.

From the devices involved in the RP sub-process, the compounding only requires mechanical consumption to mix the components, whereas the compression moulding (CM) also includes heating and cooling, and has the highest electrical demand of the whole process (67.078 %) since the press machine needs a high amount of energy to operate.

Regarding the mass-energy ratio, the calculus must be carried out separately for the 26 batches needed for the RP production (**section 4.1.1** Bio-rubber manufacture) and the mass of final product of the VC: i) the total energy consumed during the production of 26 batches of lignin powder is 7877.820 MJ; ii) in a batch of RP, 181495 kJ are consumed. Therefore, the mass of RP produced per energy unit in a batch is 0.38 mg/kJ, less compared to the value obtained in D2.2 (3.40 mg/kJ).

## 4.2.2. Bio-plastic manufacture

### *Limoncello production*

Compared to the analysis of D2.2., the total consumption in extruder and injection has been reduced by 77.47 % and by 91.34 %, respectively, an indicative of the improvement in industrial equipment at higher TRL. On the other hand, the major consumption comes from the extruder representing a 73.49 % of the whole process. The mass-energy ratio of the limoncello caps is 240 mg/kJ, which has highly been improved in the upscaling of the process.

### *Olive oil production*

The change in extruder compared to the previous DV is the same as in limoncello manufacture, whereas the consumption in injection has increased over 100 %, from 124659 kJ to 270000 kJ. Furthermore, the consumption of the process mostly comes from the injection in JSW55, which requires 73.01 % of the total consumption. The ratio in this case has a value of 67.60 mg/kJ.

## 4.2.3. Wood composites manufacture

The consumption in elrich mixer has decreased by 5.88 %, and is divided into heating and mixing, both with 3600 kJ. Ratio values are provided in the case of extruder and kneader (3.6 kJ/g and 1.8 kJ/g, respectively), so that the consumptions can be calculated using the mass flow of compound in a batch (an increment of 2.17 % in extruder and a reduction of 4.56 % in kneader). Finally, the CM presents a provided ratio of 144 kJ/g, and the major change in the VC (from 20502 kJ to 281520 kJ).

The CM has the highest consumption in the VC (94.07 %), and the increment of demand compared to TRL5 comes from the necessity of more electrical demand for pressing when introducing the recycled glass fibres within the inlet materials. The ratio of mass produced per unit of consumed energy in the whole process is 6.67 mg/kJ, which has slightly decreased regarding the previous analysis (37.24 mg/kJ).

## 4.3. Exergy analysis

The destruction of energy derived from consumption is discussed in this section, considering the improvement in the machinery during the upgrade up to TRL6 regarding the utilization of energy.

### 4.3.1. Bio-rubber manufacture

The major consumption within the lignin extraction sub-process comes from the pulping as it needs energy to heat the substances and produce the mixture as well as to cool the machinery, representing the second major weight in the

reversibilities in the manufacture of RPs. Nevertheless, the irreversibilities during drying have been reduced in the upscaling by 99.60 %.

Regarding the second sub-process of the bio-rubber manufacture, the major fraction of consumption is due to the compression moulding, leading to 97.51 % of the total destroyed energy in the whole process.

## 4.3.2. Bio-plastic manufacture

### *Limoncello production*

In this process the major destruction of energy comes from the extruder (65.43 % of total consumption) due to the electrical consumption, which is the higher of the process. The next component with more irreversibility is the NTP system (12.76 %), since all the energy is used for mechanical work.

Compared to the process in the previous TRL, the dispenser presents irreversibility since now the inlets are heated during this step. On the other hand, the irreversibilities have been reduced in extruder and injection moulding by 79.12 % 94.67 %, respectively, due to the better quality of energy derived from the performance of equipment at industry levels.

### *Olive oil production*

Although the hopper MW is introduced in the olive oil production, the increasement of irreversibilities in this process mostly comes from the machine used for injection moulding (JSW55), which needs more electricity to perform than in Baby Pressa, leading to a minor improvement regarding the destruction of energy in comparison to the manufacture at TRL5 (24.32 %).

## 4.3.3. Wood composites manufacture

Since the process operates at the same temperature from the mixer, the irreversibility is mostly due to the shaft work in the rest of steps. For this reason, the compression moulding has the higher value of the process, with 94.03 %.

Regarding the changes in the machinery from the previous state of the manufacturing process, all the steps present lower irreversibility values except the compression moulding; this result could be due to the introduction of the recycled glasses within the inlet mass, requiring more energy consumption in the press per unit of mass at TRL6, alongside irreversibility.

## 4.4. E-LCA impact analysis (LCIA) and interpretations

This section presents a detailed evaluation of the effects resulting from the implementation of the proposed measures in Task T2.3. By analysing all the data, it is aimed to understand the extent, significance, and implications of the observed

changes on recyclability, waste reduction, litter impact, and GHG emissions in comparison with the previous assessment attached in the preliminary deliverable D2.2. As it was previously commented in the Objective and Scope section, reuse and refurbishment could not be analysed since the use phase and the EoL were excluded from the system boundaries.

The interpretation of these impacts is essential to assess the effectiveness of the intervention, identify unintended consequences, and guide future decision-making processes, abiding by the objectives proposed in the grant agreement for T2.3. Through this analysis, we provide a comprehensive overview of how the outcomes align with the original objectives of T2.3 and what insights can be drawn for continuous improvement.

The Life Cycle Assessment (LCA) conducted during the development of various bio-based materials is intended to evaluate their environmental performance at every stage of their life cycle, from the extraction of renewable raw materials to the end of their life. This tool enables impacts associated with key aspects such as resource consumption, atmospheric emissions, water use, and waste generation to be quantified.

Thus, this section of the deliverable D2.3 shows the results obtained for some scenarios for different bio-based material alternatives developed within the project framework, compared with their conventional fossil or mineral-based equivalents. It must be pointed out that, to complete the assessment, it was necessary to consider both the value chain assessment (T2.1) and the energy studies (T2.2).

The analysis not only identifies the potential environmental benefits of bio-based solutions, such as reducing the carbon footprint or the use of non-renewable resources, but also possible challenges or impacts in other categories that need to be mitigated, such as land use and eutrophication. These results provide a solid scientific basis for eco-design decisions, process improvements, and the selection of more sustainable materials within the different evaluated value chains.

#### 4.4.1. Bio-rubber manufacture

The impact categories of each of the steps of the processes and the contribution of different categories (raw materials, electricity and waste) were analysed. In Figure 24, the contribution of each impact category is presented in different colours. For all the scenarios analysed, the main contribution (in mPt) is 'Resource use, Fossils', represented in light orange. In the current scenario, this figure is approximately 22%, while for bio-based solutions, it is 21.5% in BRP1 and 33% in BRP2. The second largest impact category is 'Climate Change', the dark orange, representing 21% in the current system, 21.1% in BRP1, and finally 29% in BRP2. This figure shows that the sum of environmental impacts is slightly higher in BRP1

compared to the current system (a slight increase of 2%), while compared to the scenario without lignin, BRP2, there is a 94% decrease. It should be noted that lignin is a hotspot previously detected in deliverable D2.2 and has been taken into account in the current system as an additive for virgin synthetic rubber, which has been established as a benchmark in VC1. All the data and results for the T6.2 processes are shown in Figure 25 in Environmental impact categories for the three different scenarios. Table 37 collects all the information about environmental impact categories.

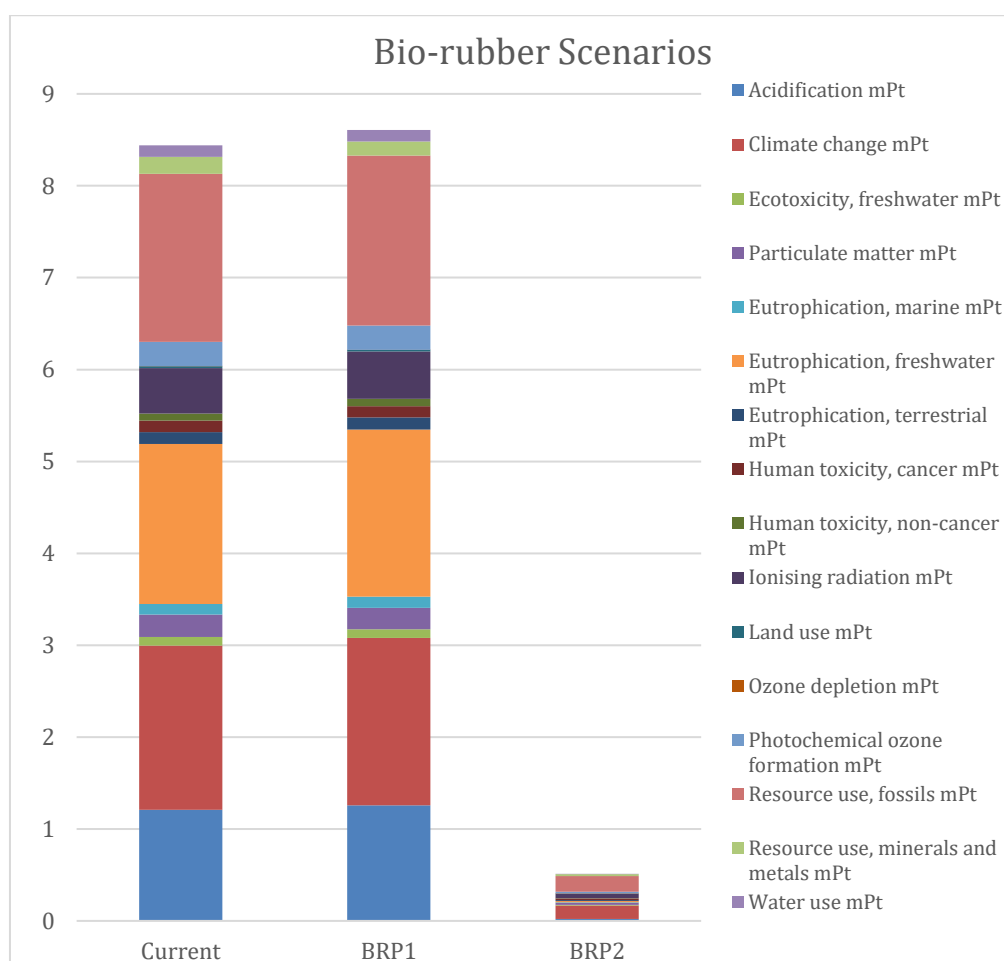


Figure 24. Weighted environmental impacts (mPt) obtained from the ecoinvent database in the T6.2 scenarios aggregated in the 16 environmental impact categories of EF 3.1.

All the impacts are then grouped into three different categories: Raw materials, Electricity, and Waste. The main environmental contribution to environmental impact in all scenarios is the electricity consumption in the manufacturing process, as shown in Figure 25. However, it is important to note that when lignin is not used as an additive, energy consumption decreases, resulting in the lignin extraction process being identified as a hotspot, as demonstrated in the BRP2 scenario and the low environmental impacts it presents. Another interesting remark is that the

environmental impact of Raw Materials is higher with Synthetic Rubber than with TDP-B and Natural rubber, reducing by 55% compared to the BRP1 scenario and 80% compared to the BRP2 scenario.

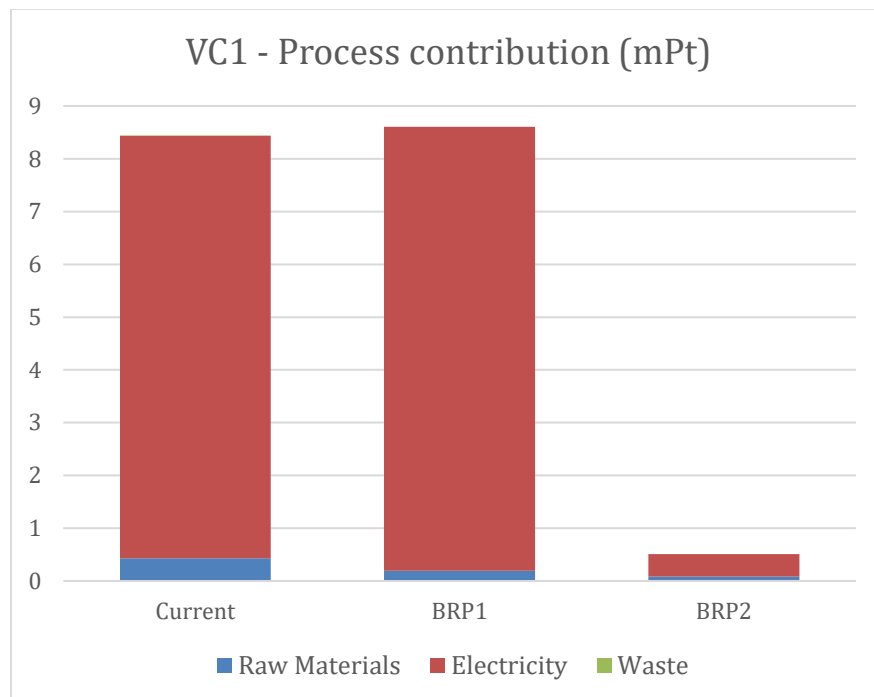


Figure 25. Weighted environmental impacts (mPt) obtained from the ecoinvent database in the T6.2 scenarios aggregated only in three categories: raw materials, electricity and wastes. The raw materials category includes the raw material production and transport to the gate of the facilities. The electricity section includes all the energy consumption within the manufacturing process, and the wastes include the final disposal of the residues generated during the manufacturing process.

As it is possible to see in Table 37, it is important to highlight several decreases generated during the application of the GREEN-LOOP Project systems. The current system and the BRP1 scenario present very similar values, mainly due to the use of lignin as an additive in both cases. The most notable aspect of the data compiled in the table is the significant decrease in all values in BRP2 compared to the current manufacturing system.

Table 37. Environmental impact analysis of T6.2 using the ecoinvent database and SIMAPRO.

| Impact categories       | Unit | Current | BRP1   | BRP2   |
|-------------------------|------|---------|--------|--------|
| Acidification           | mPt  | 1.2086  | 1.2591 | 0.0197 |
| Climate change          | mPt  | 1.7885  | 1.8203 | 0.1478 |
| Ecotoxicity, freshwater | mPt  | 0.0936  | 0.0945 | 0.0064 |
| Particulate matter      | mPt  | 0.2434  | 0.2343 | 0.0210 |

| Impact categories                        | Unit | Current | BRP1   | BRP2   |
|------------------------------------------|------|---------|--------|--------|
| <i>Eutrophication, marine</i>            | mPt  | 0.1160  | 0.1209 | 0.0079 |
| <i>Eutrophication, freshwater</i>        | mPt  | 1.7419  | 1.8193 | 0.0133 |
| <i>Eutrophication, terrestrial</i>       | mPt  | 0.1262  | 0.1299 | 0.0105 |
| <i>Human toxicity, cancer</i>            | mPt  | 0.1255  | 0.1230 | 0.0166 |
| <i>Human toxicity, non-cancer</i>        | mPt  | 0.0791  | 0.0802 | 0.0046 |
| <i>Ionising radiation</i>                | mPt  | 0.4943  | 0.5146 | 0.0473 |
| <i>Land use</i>                          | mPt  | 0.0181  | 0.0177 | 0.0057 |
| <i>Ozone depletion</i>                   | mPt  | 0.0009  | 0.0009 | 0.0003 |
| <i>Photochemical ozone formation</i>     | mPt  | 0.2653  | 0.2645 | 0.0163 |
| <i>Resource use, fossils</i>             | mPt  | 1.8292  | 1.8496 | 0.1706 |
| <i>Resource use, minerals and metals</i> | mPt  | 0.1833  | 0.1535 | 0.0203 |
| <i>Water use</i>                         | mPt  | 0.1261  | 0.1237 | 0.0041 |

## 4.4.2. Bio-plastic manufacture

In Figure 26 it is possible to review the contribution of each category. The greatest contribution to environmental impacts is climate change (in mPt), accounting for around 33% for both olive oil cap scenarios and 32% for limoncello caps. On the other hand, the second largest impact is RuF, representing 29% of the sum of all impacts in the current olive oil scenario, and which is reduced to 26% in the bio-based scenario for the same type of cap. RuF for limoncello closures is 31% with petroleum-based material and 26% with bio-based material; a greater decrease in the change of material for limoncello caps than for olive oil caps. Comparing bottle closures in general, the two scenarios for limoncello generally have a lower total impact than those for olive oil, mainly because olive oil closures require more steps in the process than limoncello closures. If it is analysed the olive oil system in greater depth, we can see that the total environmental impact of the bio-based cap is slightly lower than that of the low-density polyethylene (LDPE) cap.

On the other hand, in limoncello closures, the sum of impacts of the material generated in the GREEN-LOOP project is greater than in the current case produced by polypropylene (PP), due to the LCA results show that, although polyester-complexed starch biopolymer has some minor impacts compared to polypropylene (PP), its total environmental impact may be greater when other categories are considered. In particular, the biopolymer shows higher values for eutrophication, acidification and land use. On the other hand, the agricultural raw material, such as rice husk, requires fertilisation, irrigation and intensive land use. Rice husk is considered a second-generation biomass because it is an agricultural

waste product that does not compete with food production. It comes from the processing of rice and is non-edible, making it suitable for sustainable bioenergy production.

Furthermore, its lower functional density means that a greater volume of material may be required to perform the same function as PP, increasing the impacts per functional unit. This situation highlights that bio-based materials do not always guarantee a better overall environmental profile, and that it is essential to assess multiple impact categories to make informed decisions about their sustainability. Finally, it is important to note that using rice husk aligns with the project's circularity objectives. However, it should be noted that environmental performance will depend on the agricultural context in which the husks are produced and how efficiently they are utilised.

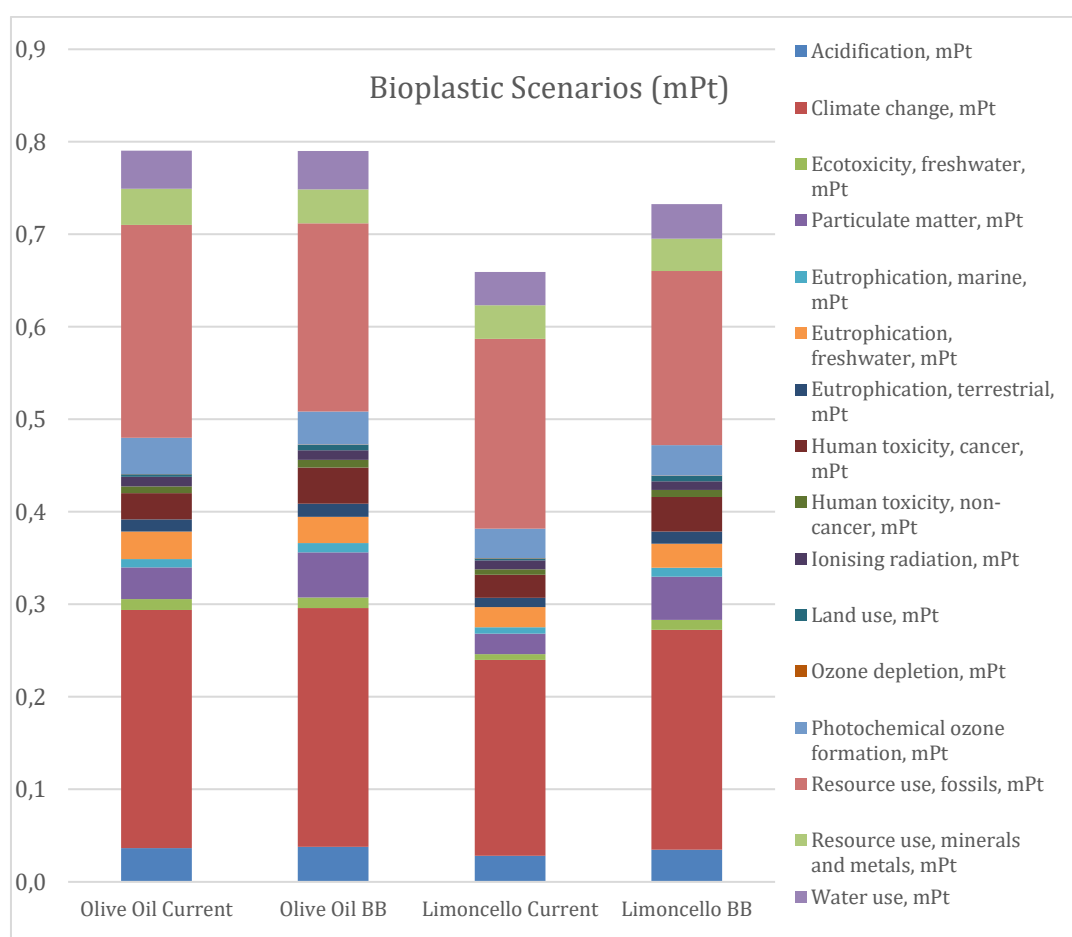


Figure 26. Weighted environmental impacts (mPt) obtained from the ecoinvent database in the T6.3 scenarios aggregated in the 16 environmental impact categories of EF 3.1.

The trend mentioned above continues even if the impacts are separated by category according to process contribution: raw materials and electricity (Figure 27). In the scenarios for olive oil, the impact of raw materials accounts for 42% of

the impacts in both situations, while in the limoncello closures, fossil-based raw materials account for 39% of the impacts, and bio-based raw materials account for 45%.

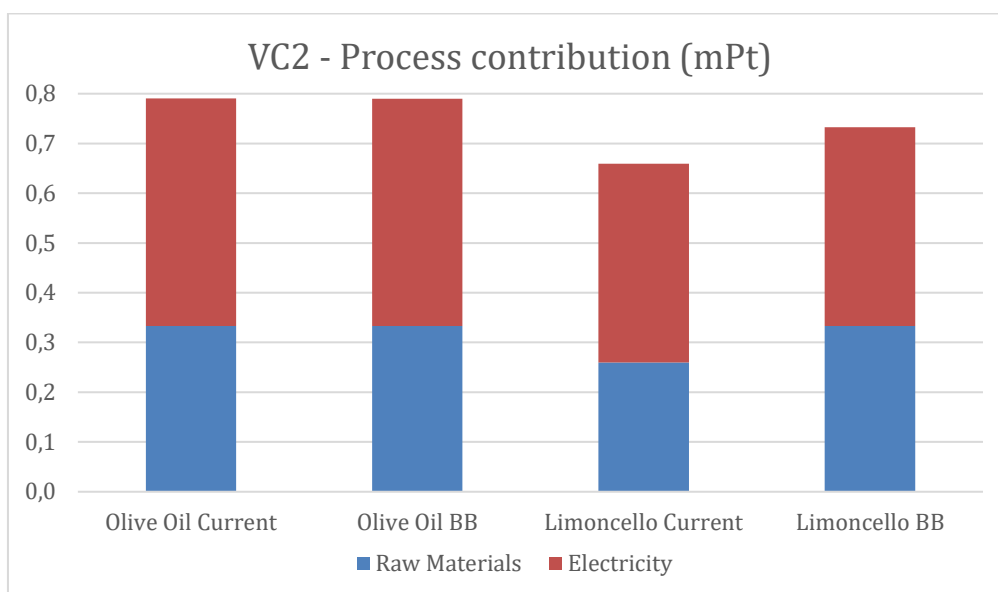


Figure 27. Weighted environmental impacts (mPt) obtained from the ecoinvent database in the T6.3 scenarios were aggregated only in two categories: raw materials and electricity. The raw materials category includes the raw material production and transport to the gate of the facilities. The electricity section includes all the energy consumption within the manufacturing process.

Table 38 shows the trend followed by all impact categories in the four scenarios analysed. In general, limoncello closures have a lower impact than olive oil closures because there are fewer stages in the process. Bio-based materials will have a similar or slightly higher total impact because it depends on how the bio-based materials are extracted or what processes have been carried out to obtain them, as well as any additives they may contain and their origin.

Table 38. Environmental impact analysis of T6.3 using the ecoinvent database and SIMAPRO.

| Impact categories                | Unit | Olive Oil Current | Olive Oil BB | Limoncello Current | Limoncello BB |
|----------------------------------|------|-------------------|--------------|--------------------|---------------|
| Acidification, mPt               | mPt  | 0.03639           | 0.03779      | 0.02814            | 0.03491       |
| Climate change, mPt              | mPt  | 0.25754           | 0.25835      | 0.21177            | 0.23745       |
| Ecotoxicity, freshwater, mPt     | mPt  | 0.01159           | 0.01122      | 0.00629            | 0.01072       |
| Particulate matter, mPt          | mPt  | 0.03436           | 0.04876      | 0.02216            | 0.04681       |
| Eutrophication, marine, mPt      | mPt  | 0.00898           | 0.01019      | 0.00674            | 0.00954       |
| Eutrophication, freshwater, mPt  | mPt  | 0.02974           | 0.02814      | 0.02201            | 0.02605       |
| Eutrophication, terrestrial, mPt | mPt  | 0.01318           | 0.01435      | 0.00992            | 0.01337       |

| Impact categories                      | Unit | Olive Oil Current | Olive Oil BB | Limuncello Current | Limuncello BB |
|----------------------------------------|------|-------------------|--------------|--------------------|---------------|
| Human toxicity, cancer, mPt            | mPt  | 0.02839           | 0.03908      | 0.02502            | 0.03709       |
| Human toxicity, non-cancer, mPt        | mPt  | 0.00712           | 0.00821      | 0.00597            | 0.00776       |
| Ionising radiation, mPt                | mPt  | 0.01061           | 0.01052      | 0.00952            | 0.00944       |
| Land use, mPt                          | mPt  | 0.00255           | 0.00599      | 0.00209            | 0.00578       |
| Ozone depletion, mPt                   | mPt  | 0.00027           | 0.00027      | 0.00027            | 0.00026       |
| Photochemical ozone formation, mPt     | mPt  | 0.03934           | 0.03542      | 0.03197            | 0.03299       |
| Resource use, fossils, mPt             | mPt  | 0.23001           | 0.20370      | 0.20503            | 0.18817       |
| Resource use, minerals and metals, mPt | mPt  | 0.03932           | 0.03645      | 0.03653            | 0.03481       |
| Water use, mPt                         | mPt  | 0.04096           | 0.04143      | 0.03601            | 0.03744       |

### 4.4.3. Wood composites manufacture

Due to the limited availability and variability of data related to the bio-based raw materials used, conducting LCA analyses using two different software tools and databases is especially important for the development of wood composite sliding bearings. Unlike the other two value chains in the project, which have more well-established and documented raw materials in Ecoinvent, (besides from consistent and reliable data on the sourcing) processing and composition of wood composites may be lacking across this database.

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Although both softwares (LCA FE and SimaPro) are widely recognised and used within the scientific, institutional and industrial communities, they not only differ in their modelling structures but also databases, calculation methodologies and user interfaces. LCA FE is geared towards industrial applications. It offers access to its own databases, such as the Sphera Database, as well as optional access to third-party databases. It also has integrated tools for the detailed modelling of technical processes and complex flows. On the contrary, SimaPro is more prevalent in academic and regulatory environments. It features a modular and flexible design and provides native access to ecoinvent, along with other datasets aligned with policy frameworks.

Thus, conducting a Life Cycle Assessment (LCA) with both Sphera's LCA FE and SimaPro by PRé Sustainability can enhance the robustness and credibility of the results by allowing cross-comparison of the same value chain modelled from opposite perspectives.

Additionally, performing a comparative LCA on both platforms enables verification of the consistency of results despite differences in modelling assumptions or internal allocations. Furthermore, as some methodologies and databases may be

implemented differently in each software, cross-comparison is useful for identifying methodological sensitivities (e.g. economic allocation, system boundaries or waste modelling) and ensuring that conclusions are not dependent on a specific tool or database. In this way, this double validation, using different software integrating different databases, can play a key role in supporting reliable and robust decision-making, reflecting a more realistic and representative picture of the material's life cycle impacts [41].

## Results with the LCA for Experts Database

The Table 39 collects all the environmental impacts grouped in 16 impact categories and weighted in mPt for the metallic benchmark (Current Met), the PBP benchmark (Current Pol), SBS1 and SBS2 obtained with the LCA for Experts database and the software LCA for Experts (LCA FE). In the following paragraphs these impact categories are analysed comparing the different scenarios. As the energy consumption is modelled in the same way in the four LCI, the differences between the scenarios could be directly linked to the raw materials and the wastes. Figure 28, Figure 29 and Table 30 represent them graphically.

At first glance, it is possible to see that the two GREEN-LOOP scenarios obtained a substantial reduction of the environmental impact compared with Current Met (70,2% for SBS1 and 72,0% for SBS2). However, when weighed with the other benchmark, the improvement is lesser but still meaningful (39,5% for SBS1 and 43,2% for SBS2). Additionally, when compared to them, SBS2 obtained the best environmental performance with 0,707 mPt.

Except for Current Met, in the other three scenarios, the process “*DE: Electricity mix 1 kV-60 kV*” is responsible for most of the impacts. Concretely, in the two GREEN-LOOP scenarios SBS1 and SBS2, the electricity represents 67,8% and 72,2% of the total environmental burdens, respectively. The proportion is more equal in the case of Current Pol, with 56,3% of impacts due to the electricity and 43,7% due to the raw materials, and finally, in Current Met a 72,4% of the impacts are due to the raw materials (Figure 29).

When it comes to analysing comparatively the different impact categories, “**Resource use, minerals and metals**” stands out since it is the only one with more variation. In the metallic benchmark, this category scores half of the total impacts (1,48 mPt, 58,8% of the total impacts), while in the other three scenarios, it only scores a negligible contribution (0,003 mPt, 0.4%). The huge impact in Current Met is mainly caused by the processes “*GLO: Copper (99.99% cathode)*” and “*RER: Special high-grade zinc only from Zn*” selected to represent the production of high-purity copper and zinc, and representing 50% of the total mix mass. However, even though the obtainment of these two raw materials is very demanding in terms of mineral resources, the low contribution to this indicator of the cast iron

and aluminium, which represent the other 50% of the mass, dilutes this effect. When a mixed benchmark is created, it is reasonable to discuss what materials should be considered since the impacts could vary significantly. In this case, Current Met tries to combine materials that represent the common environmental burdens related to the use of metallic raw materials with the more innocuous options.

In the category “**Resource use, fossil**”, the highest value is scored by Current Pol (0,310 mPt, 24,9%), which is reasonable considering the raw materials are obtained from petroleum. The second highest value is obtained in Current Met (0,253 mPt), and the lowest values are obtained in SBS1 (0.207 mPt) and SBS2 (0.206 mPt). Although the improvement was because of the substitution of petroleum-based raw materials or metals by biobased and renewable materials, in this category, even the GREEN-LOOP scenarios have scored high values due to the energy consumption that should be reduced.

The results in “**Climate change**” are more similar in the two benchmark scenarios (0,410 mPt in Current Met and 0,402 mPt in Current Pol). However, the values are reduced in SBS1 (0,321 mPt, 42,6% of total impacts) and SBS2 (0,318 mPt, 44,9% of total impacts). Concretely, in SBS2 the processes “US: Ingeo Polylactide (PLA) biopolymer production” (1,24 Kg of CO<sub>2</sub> equiv.), and “DE: Glass fibre” (0,681 Kg CO<sub>2</sub> equiv.) representing 78% of the total mass scored less punctuation together than the dataset “RER: Aluminium ingot mix” (2,48 Kg of CO<sub>2</sub> equiv.) representing 30% of Current Pol mass. Additionally, the process “GLO: Copper (99.99% cathode)” is also contributing substantially, while that from the process “RER: Lightweight wood fibre panel (EN15804 A1-A3)” is negligible. This category provides the highest mPt values within SBS1 and SBS2 with the process “DE: Electricity mix 1Kv-60 kV” as the main contributor, thus their reduction should be linked to the energy efficiency.



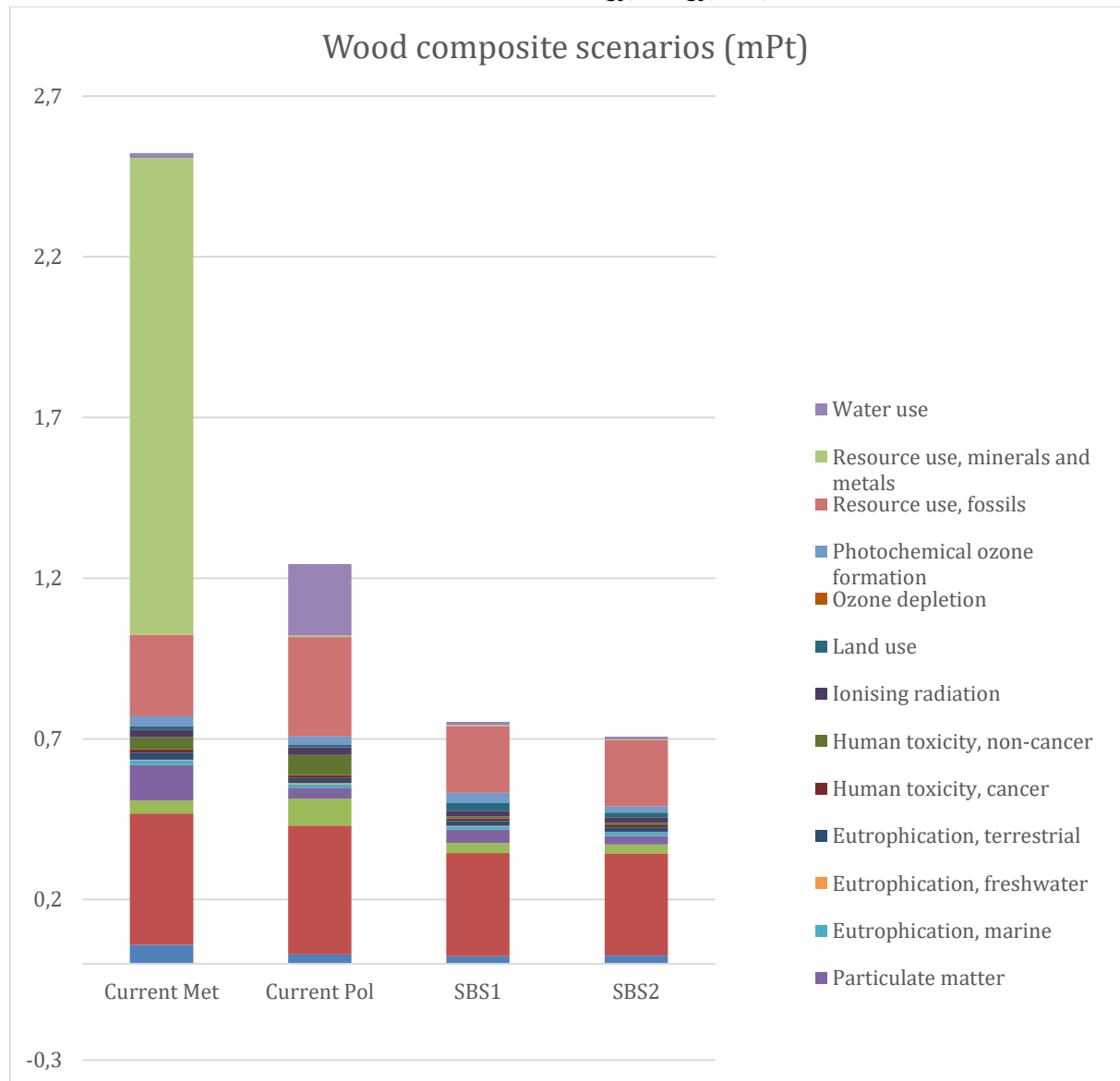


Figure 28. Weighted environmental impacts (mPt) obtained from the LCA for Experts database in the T6.4 scenarios aggregated in the 16 environmental impact categories of EF 3.1.

The “**Water use**” category scores its highest value in Current Pol (0,223 mPt, 17,9%). The other three scenarios - Current Met, SBS1 and SBS2 – scored lower and very similar values (0,015, 0,010 and 0,008 mPt, respectively), supposing an improvement of more than 90%. The excessive water use of the PBP benchmark could be explained by polymer production processes that rely on steam to produce heat or use water in the chemical reaction. Therefore, in this case, the reduction of the polymeric containment within the sliding bearing is affecting positively the results.

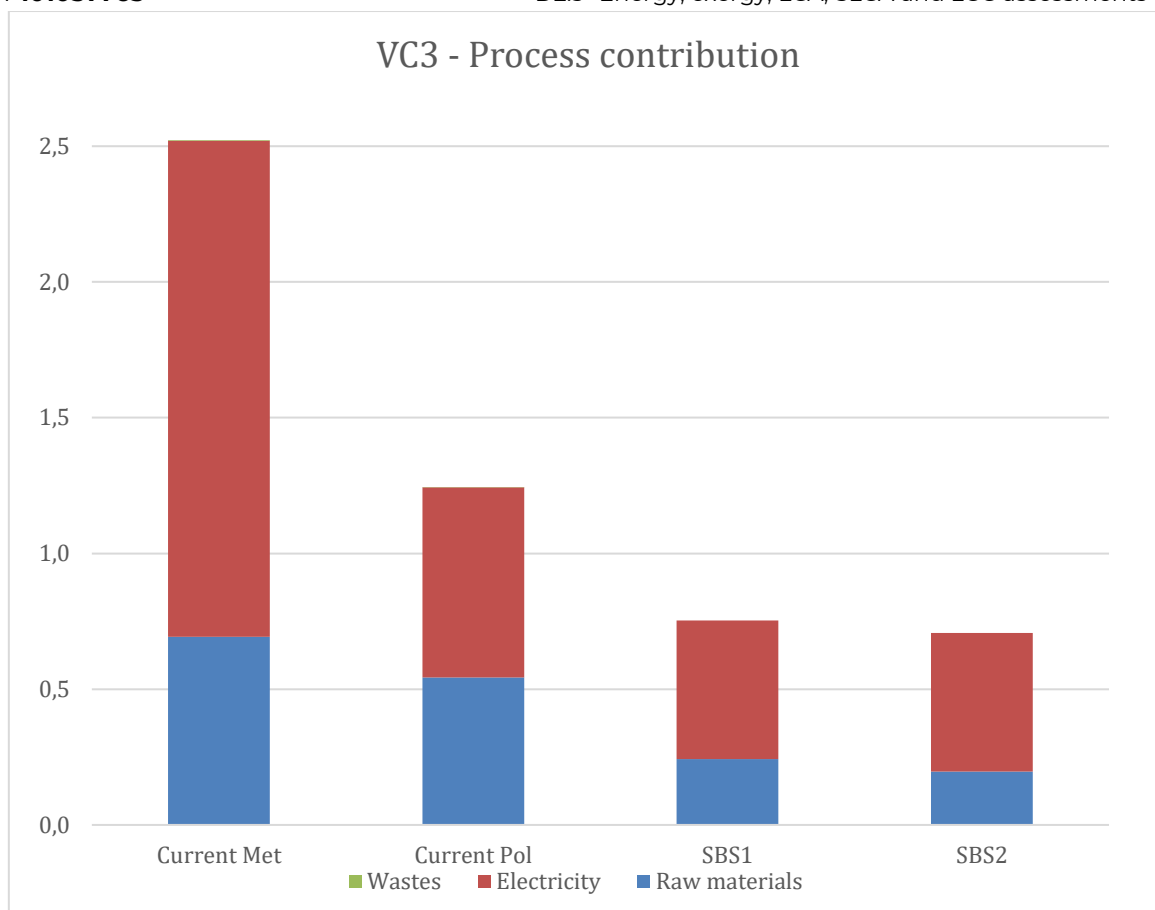


Figure 29. Weighted environmental impacts (mPt) obtained from the LCA for Experts database in the T6.4 scenarios aggregated only in three categories: raw materials, electricity and wastes. The raw materials category includes the raw material production and transport to the gate of the facilities. The electricity section includes all the energy consumption within the manufacturing process, and the wastes include the final disposal of the residues generated during the manufacturing process.

In "**Particulate matter formation**", Current Met scores the highest values (0,111 mPt) due to the possible release of thin dust during the manufacturing processes. This value is reduced in Current Pol (0,032 mPt), SBS1 (0,041 mPt) and SBS2 (0,027 mPt). Hence, it was concluded that replacing metallic content with plastic or biomaterials reduces the particle matter formation.

In "**Ecotoxicity, freshwater**", Current Pol scores the highest (0,083 mPt). This value is reduced in Current Met (0,040 mPt) and even more in SBS1 (0,031 mPt) and SBS2 (0,028 mPt). Thus, it was concluded that the greater proportion of petroleum-based plastic the material has, the more value it obtains in this indicator. The relation between plastic and this indicator could be explained due to their likelihood of releasing pollutants such as microplastics (MP) to the environment.

Owing to this, a similar tendency is seen in the indicator “**Human toxicity, non-cancer**”.

In “**Acidification**”, Current Met scores the highest value (0,058 mPt) due to the mining and industrial activities. These values are reduced between 56-59%, obtaining similar values for SBS1 (0,024 mPt), SBS2 (0,026 mPt) and Current Pol (0,029 mPt).

Finally, the indicator “**Land use**” scores its highest values in SBS1 (0,024 mPt). This result, higher in the scenario without glass fibre (SBS1), could be explained by the necessity of occupying cultivable land to produce the biopolymer or fertile soil to produce the wood. However, the impact only represents 3,2% of their total impacts. SBS2 scored a smaller value, more similar to the benchmarks (0,014 mPt). The other indicators follow a similar tendency, scoring almost equal or slightly lower values in SBS1 and SBS2.

Table 39. Environmental impact analysis of T6.4 using LCA for Experts software and database

| Environmental impact category    | Unit | MM benchmark         | PBP mix benchmark   | SBS1 (w/o glass fibre) | SBS2 (w/ glass fibre) |
|----------------------------------|------|----------------------|---------------------|------------------------|-----------------------|
| Acidification                    | mPt  | 0.058                | 0.029               | 0.024                  | 0.026                 |
| Climate change total             | mPt  | 0.410                | 0.402               | 0.321                  | 0.318                 |
| Ecotoxicity freshwater           | mPt  | 0.040                | 0.083               | 0.031                  | 0.028                 |
| Particle matter formation        | mPt  | 0.111                | 0.032               | 0.041                  | 0.027                 |
| Eutrophication marine            | mPt  | 0.015                | 0.012               | 0.011                  | 0.011                 |
| Eutrophication freshwater        | mPt  | 0.001                | 0.005               | 0.001                  | 0.001                 |
| Eutrophication terrestrial       | mPt  | 0.022                | 0.016               | 0.015                  | 0.015                 |
| Human toxicity cancer            | mPt  | 0.010                | 0.009               | 0.008                  | 0.007                 |
| Human toxicity non-cancer        | mPt  | 0.038                | 0.063               | 0.007                  | 0.007                 |
| Ionising radiation               | mPt  | 0.024                | 0.024               | 0.018                  | 0.018                 |
| Land use                         | mPt  | 0.010                | 0.009               | 0.024                  | 0.014                 |
| Ozone depletion                  | mPt  | $3.59 \cdot 10^{-7}$ | $4.9 \cdot 10^{-7}$ | $7.75 \cdot 10^{-7}$   | $4.50 \cdot 10^{-7}$  |
| Photochemical ozone formation    | mPt  | 0.032                | 0.025               | 0.032                  | 0.020                 |
| Resource use fossil              | mPt  | 0.253                | 0.310               | 0.207                  | 0.206                 |
| Resource use minerals and metals | mPt  | 1.483                | 0.004               | 0.003                  | 0.003                 |
| Water use                        | mPt  | 0.015                | 0.223               | 0.010                  | 0.008                 |
| TOTAL                            | mPt  | <b>2.523</b>         | <b>1.244</b>        | <b>0.753</b>           | <b>0.707</b>          |

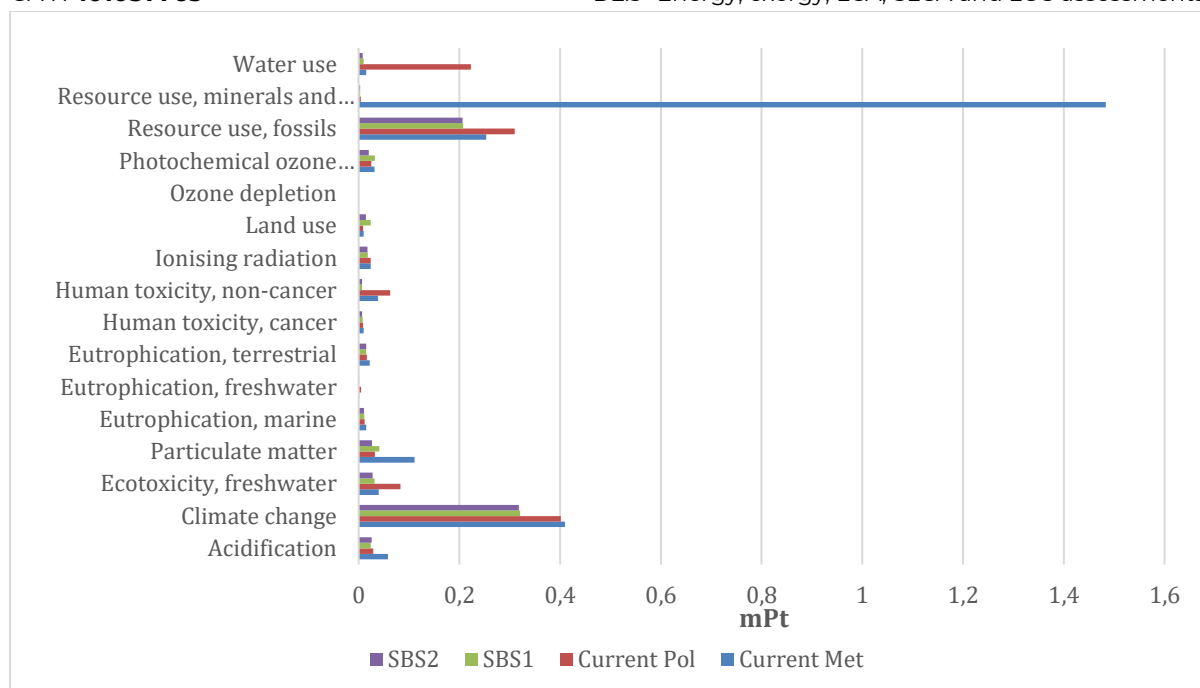


Figure 30. Environmental impacts (mPt) obtained from the LCA for Experts database in the T6.4 scenarios were aggregated only in the 16 categories described in EF3.1. Within each category, the 4 scenarios were compared

In both cases of use, **SBS1** and **SBS2**, the environmental burdens are similar or reduced in 15 out of the 16 impact categories of EF 3.1 compared with at least one of the benchmarks. Concretely, SBS1 reduced the environmental impacts by 39.5% compared to Current Pol and 70.2% compared to Current Met, while SBS2 obtained a 43.2% improvement compared to Current Pol and 72% compared to Current Met. Compared with Current Met, the improvements were significant in the categories “Acidification”, “Climate change, total”, “Particle matter formation”, “Human toxicity, non-cancer”, “Resource use, fossil” and, especially, “Resource use, minerals and metals”. Compared with Current Pol, the more meaningful reductions were obtained in “Climate change, total”, “Ecotoxicity, freshwater”, “Human toxicity, non-cancer”, “Resource use, fossil” and “Water use”.

On the other hand, the GREEN-LOOP scenarios only scored higher than the benchmarks in the category “Land use”, which is readily explained by the production process of two of the biobased raw materials: the wood composite and the biopolymer. However, the mPt of this indicator represents only 3.2% of the total environmental impacts of SBS1 and even less in SBS2, and is therefore not the most important one.

Additionally, the reduction in some categories like “Human toxicity, non-cancer” or “Ecotoxicity, freshwater” could be explained by the substitution of hazardous materials like heavy metals or plastics by harmless biobased alternatives. In other categories like “Resource use, minerals and metals” or “Resource use, fossil”, the

improvement is derived from the selection of materials not mineral or petroleum-based.

In the GREEN-LOOP scenarios, in all the categories except for “*Water use*”, the major contributor to the environmental impacts is the process “*DE: Electricity mix 1 kV-60 kV*”, which represents the energy consumption during the manufacturing process (78-79% of the total mPt). This underlines one of the main issues of the wood composite value chains: the manufacturing processes, especially the Test Plate Moulding (Figure 23), are highly energy demanding, thus energy efficiency must be targeted in the following steps.

In the “*Water use*” category, the main contributor is the process “*US: Ingeo Polylactide (PLA) biopolymer production*”, which is a simple proxy for the ARBOBLEND 2241X. This proxy is probably the weakest part of the models presented herein, since it is only surrogating the complex biopolymer for a dataset that includes the general impacts derived from the production of a bioplastic material. Thus, it is possible to see an increase in the environmental impacts derived from this biopolymer in future assessments in which the proxy is refined. However, due to the outperformance of the GREEN-LOOP scenarios compared to the two current benchmark scenarios, we are confident that the results herein modelled are representative enough and will not mislead the decision-making process.

As similar results were obtained when directly comparing SBS1 and SBS2, it could be concluded that the environmental burdens derived from the substitution of some biopolymers and wood for glass fibre are insignificant, and since the glass fibre has been demonstrated to improve the final properties of the composite, their use is highly recommended.

## Results with the Ecoinvent Database

Table 40 collects all the environmental impacts grouped in 16 impact categories and weighted in mPt for the MM benchmark, the PBP benchmark, SBS1 and SBS2 obtained in the database Ecoinvent with the software SIMAPRO. In the following paragraphs, these impact categories are analysed by comparing the different scenarios. As the energy consumption is modelled in the same way in the four LCI, the differences between the scenarios could be directly linked to the raw materials and the wastes. Figure 31, Figure 32 and Figure 33 represent graphically the environmental impacts in different ways.

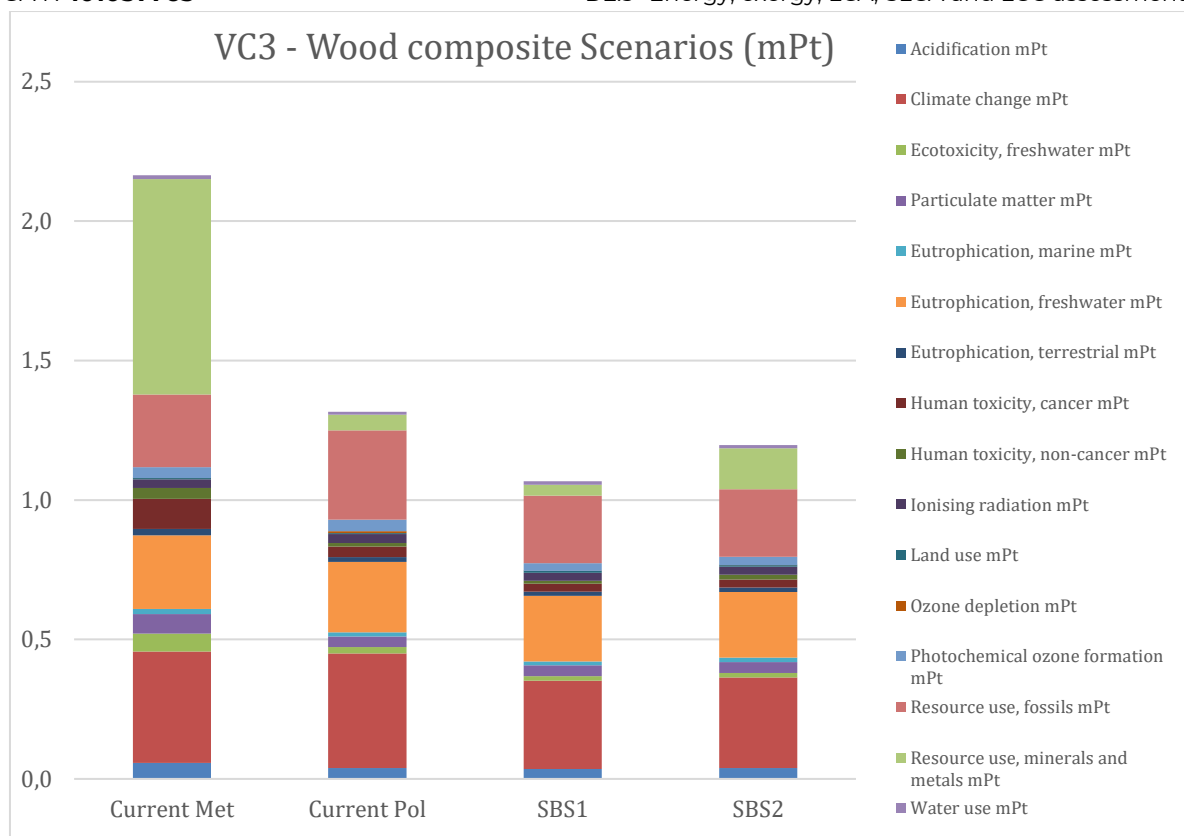


Figure 31. Weighted environmental impacts (mPt) obtained from Ecoinvent and SIMAPRO in the T6.4 scenarios aggregated in the 16 environmental impact categories of EF 3.1.

At first sight, the two GREEN-LOOP scenarios obtained a substantial reduction of the environmental burdens compared with the Current Met (50,7% for SBS1 and 44,7% for SBS2). However, when weighed against the Current Pol benchmark, they only obtain a modest improvement (18.9% for SBS1 and 9.1% for SBS2). Besides, when compared to them, SBS1 obtained the best environmental performance (1,068 mPt SBS1 and 1,197 mPt SBS2).

In the scenarios SBS1, SBS2, and Current Pol, more than half of the environmental burdens come from the market process “*Electricity, medium voltage {DE}*”. Concretely, this process represents 86,5% of the total impacts of SBS1, 82,5% of SBS2 and 72% of the total impacts of Current Pol. However, in the Current Met benchmark, it only represents a 35,5%, where the raw materials are the main contributor (Figure 32).

In this assessment, the Current Met scores the highest values due to the high environmental impacts obtained in the category “**Resource use, minerals and metals**” (0,773 mPt). This indicator represents 35,7% of the total impacts and is mainly provided by the process “*GLO: Copper (99.99% cathode)*” while the other three metals of the mix palliate the effect, reinforcing the idea of representing the

metallic benchmark as a mix. In the other three scenarios, the values are drastically reduced and roughly represent 3,6% of the total impacts in SBS1 (0.039 mPt), 12,2% in SBS2 (0,146 mPt) and 4,29% in Current Pol (0.056 mPt). The reduction is less pronounced than in the previous assessment, since the process “Glass fibre {GLO} market for / Cut-off, U” is contributing more actively for it and justifying that the lowest score was obtained by SBS1.

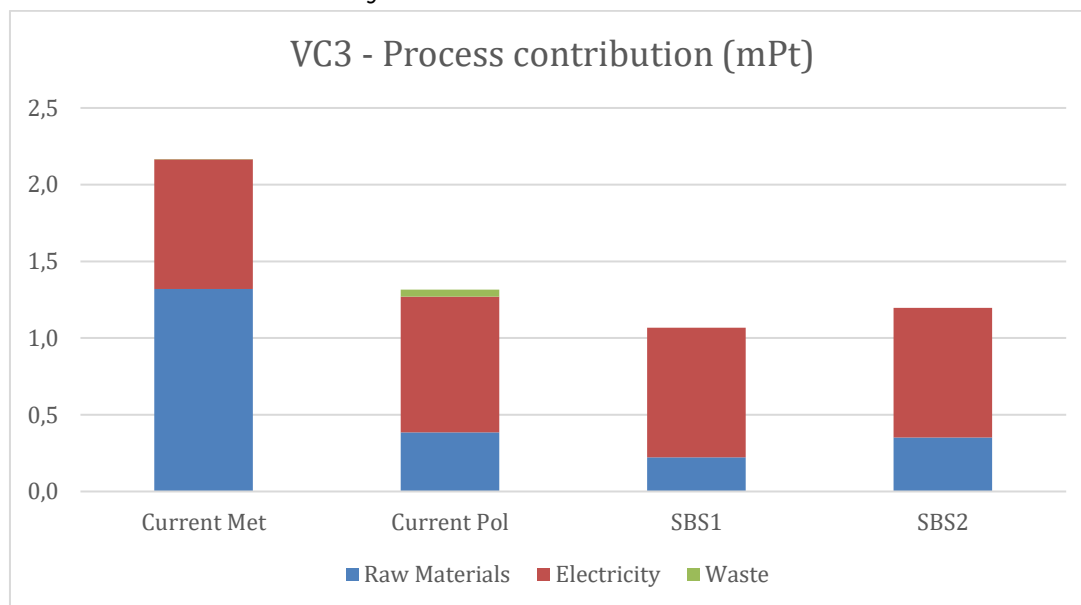


Figure 32. Weighted environmental impacts (mPt) obtained from Ecoinvent and SIMAPRO in the T6.4 scenarios aggregated only in three categories: raw materials, electricity and wastes. The raw materials category includes the raw material production and transport to the gate of the facilities. The electricity section includes all the energy consumption within the manufacturing process, and the wastes include the final disposal of the residues generated during the manufacturing process.

In “**Climate change**”, both benchmark scenarios obtained similar values (0.400 mPt for Current Met and 0,411 mPt for Current Pol). On the other hand, the GREEN-LOOP scenarios obtained a significant reduction of around 20% compared to the benchmarks (0.316 mPt for SBS1 and 0.325 for SBS2). The main responsibility of this reduction is the process “Bark chips, wet, measured as dry mass”, while the processes “Polylactic acid, granulate {GLO}” and “Glass fibre {GLO}” obtained values comparable with the petroleum-based plastics or the metals. However, it must be underlined that this category is the main contributor in both GREEN-LOOP scenarios due to the process “Electricity, medium voltage {DE}”, representing around 30% of the total impacts.

In “**Resource use, fossil**”, the highest value is obtained by the Current Pol (0,320 mPt), being its second biggest contributor to the total impacts (24,3%), followed by the Current Met (0,260 mPt). In this case, both SBS1 and SBS2 scored similar values (0,242 mPt). However, it must be pointed out that this category is one of the three

biggest contributors to the overall impacts in the GREEN-LOOP scenarios (22,7% for SBS1 and 20,3% for SBS2) owing to the process "*Electricity, medium voltage {DE}*" one more time.

In "**Eutrophication, freshwater**", the Current Met obtained the highest value (0,2634 mPt) followed by the Current Pol (0,253 mPt). Conversely, SBS1 (0,235 mPt) and SBS2 (0,236 mPt) obtained a meaningful reduction of around 10%. However, this category scored the third biggest value in the GREEN-LOOP scenarios (22% for SBS1 and 19,7% for SBS2) due to the process "*Electricity, medium voltage {DE}*".

In "**Ecotoxicity, freshwater**", Current Met obtained the highest value (0,0641 mPt) due to the market processes "*Copper, cathode {GLO}*" and "*Zinc {GLO}*". The GREEN-LOOP scenarios scored an intermediate punctuation, with a significant reduction of around 73% (0.017 mPt for SBS1 and 0.016 mPt for SBS2). Finally, the Current Pol benchmark obtained a mid-value (0.022 mPt), since the process "*Polylactic acid, granulate {GLO}*" contributes less to this category than PA, POM and LDPE.

In "**Particulate matter formation**", the Current Met obtained the highest values once again (0,0694 mPt), due to the release of thin dust during mining activities. The value is reduced by 45.2% in Current Pol (0.038 mPt), SBS1 (0.038 mPt) and SBS2 (0.039 mPt). Thus, it could be concluded that the highest improvements in this field are related to the removal of metallic components (Figure 31, yellow).

In "**Human toxicity, cancer**" and "**Human toxicity, non-cancer**", the Current Met is obtaining the highest environmental impacts, with meaningful reductions in SBS1, SBS2 and PBP benchmark. In the category "**Human toxicity, cancer**", GREEN-LOOP scenarios are better, with a 74% improvement compared to the metallic benchmark (0,108 mPt) and a 24,5% compared to the PBP benchmark (0,038 mPt). In the "**Human toxicity, non-cancer**" indicator, the impacts of SBS1, SBS2 and Current Met are comparable (Figure 31, bright green) and reduced in around a 58% compared to Current Met. but not very meaningful in the total impacts (less than 4% together in both cases).

In "**Acidification**", SBS1, SBS2 and Current Pol obtained values that represent around 3% of the total impacts (0.036 to 0.040 mPt), while Current Met obtained a higher value (0,058 mPt) owing to the process "*Copper, cathode {GLO}*".

In "**Land use**", the two benchmarks and SBS2 scored similar while SBS1 obtained the highest value (0,067 mPt), and the four scenarios scored very similar in "**Water use**".

Finally, the four scenarios scored similarly in "**Land use**" (Figure 28, deep blue and purple) and the remaining five categories, with slight improvements in the GREEN-LOOP scenarios.

Table 40. Environmental impact analysis of T6.4 using Ecoinvent 3.11 and SIMAPRO

| Impact categories                 | Unit       | Current Met   | Current Pol   | SBS1          | SBS2          |
|-----------------------------------|------------|---------------|---------------|---------------|---------------|
| Acidification                     | mPt        | 0.0575        | 0.0395        | 0.0360        | 0.0389        |
| Climate change                    | mPt        | 0.3999        | 0.4109        | 0.3159        | 0.3251        |
| Ecotoxicity, freshwater           | mPt        | 0.0641        | 0.0220        | 0.0168        | 0.0163        |
| Particulate matter                | mPt        | 0.0691        | 0.0381        | 0.0384        | 0.0390        |
| Eutrophication, marine            | mPt        | 0.0192        | 0.0152        | 0.0145        | 0.0152        |
| Eutrophication, freshwater        | mPt        | 0.2634        | 0.2530        | 0.2347        | 0.2358        |
| Eutrophication, terrestrial       | mPt        | 0.0229        | 0.0165        | 0.0153        | 0.0166        |
| Human toxicity, cancer            | mPt        | 0.1083        | 0.0376        | 0.0284        | 0.0287        |
| Human toxicity, non-cancer        | mPt        | 0.0389        | 0.0136        | 0.0110        | 0.0163        |
| Ionising radiation                | mPt        | 0.0316        | 0.0312        | 0.0284        | 0.0290        |
| Land use                          | mPt        | 0.0038        | 0.0036        | 0.0067        | 0.0057        |
| Ozone depletion                   | mPt        | 0.0002        | 0.0076        | 0.0002        | 0.0002        |
| Photochemical ozone formation     | mPt        | 0.0395        | 0.0407        | 0.0276        | 0.0296        |
| Resource use, fossils             | mPt        | 0.2598        | 0.3200        | 0.2422        | 0.2424        |
| Resource use, minerals and metals | mPt        | 0.7729        | 0.0564        | 0.0388        | 0.1463        |
| Water use                         | mPt        | 0.0138        | 0.0102        | 0.0126        | 0.0115        |
| <b>TOTAL</b>                      | <b>mPt</b> | <b>2.1649</b> | <b>1.3161</b> | <b>1.0675</b> | <b>1.1966</b> |

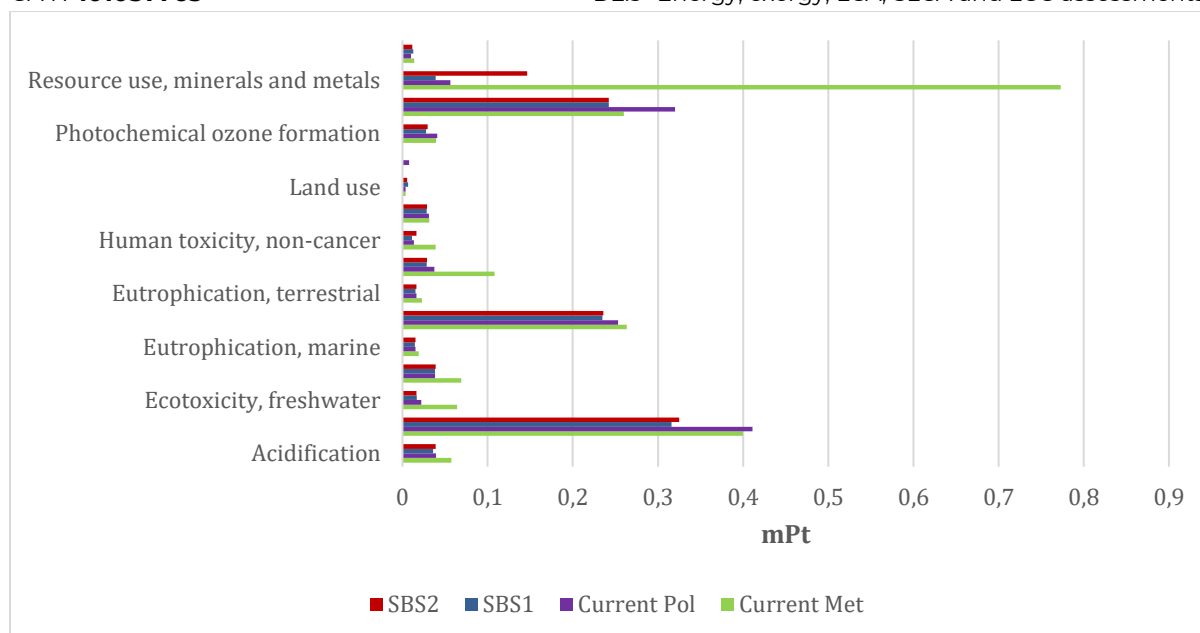


Figure 33. Environmental impacts (mPt) obtained from the Ecoinvent database and SIMAPRO software in the T6.4 scenarios were aggregated only in the 16 categories described in EF3.1. Within each category, the 4 scenarios were compared

In both cases of use, **SBS1** and **SBS2**, the environmental burdens are similar or reduced in 13 out of the 16 impact categories of EF 3.1 compared with at least one of the benchmarks. In the remaining three categories – “Ecotoxicity, freshwater”, “Human toxicity, non-cancer” and “Land use” – the results are comparable to the PBP benchmark. Concretely, SBS1 reduced the environmental impacts by 18,9% compared to Current Pol and 50,6% compared to Current Met, while SBS2 obtained a 9,1% improvement compared to Current Pol and 44,7% compared to the Current Met.

Compared with the metallic benchmark, the improvements were significant in the categories “Acidification”, “Climate change, total”, “Ecotoxicity, freshwater”, “Particle matter formation”, “Human toxicity, cancer”, “Human toxicity, non-cancer”, “Photochemical ozone formation”, “Resource use, fossil” and, specially, “Resource use, minerals and metals”. Compared with the PBP benchmark, the more meaningful reductions were obtained in “Climate change, total”, “Particle matter formation”, “Human toxicity, cancer” and “Resource use, fossil”. In this case, GREEN-LOOP scenarios have not scored significantly higher than the benchmark in any category, but in “Land use” SBS1 obtained 100% more impacts than the other scenarios. However, it must be pointed out that SBS1 slightly outperformed SBS2 due to the category “Resource use, minerals and metals”, in which removing the market process “Glass fibre [GLO]” reduced the result by 73,5%.

In the GREEN-LOOP scenarios, in all the categories except for “*Land use*”, the major contributor to the environmental impacts is the process “*Electricity, medium voltage {DE}*”, which represents the energy consumption during the manufacturing process (82-86% of the total mPt). Therefore, the energy consumption could be considered a hotspot within this value chain that must be addressed by improving the energy efficiency. In the “*Land use*” category, the main contributor is the market process “*Polylactic acid, granulate {GLO}*” that, as it was previously discussed, is a weak data availability proxy.

To conclude, since small differences were obtained between SBS1 and SBS2 and considering that environmental results should be assessed, including the functionality, the SBS2 scenario is preferred.

## *General conclusions and comparison between LCA for Experts and Ecoinvent databases*

After modelling and performing both assessments separately and selecting always similar datasets, similar results were obtained. In both cases, the metallic benchmark (Current Met) obtained the overall greatest impacts, followed by the PBP benchmark (Current Pol). Besides, the two GREEN-LOOP scenarios obtained comparable scores, outperforming the benchmarks in more than half of the categories and matching them, at least, in the other half.

Based on this, it could be concluded that the sensitivity study with different databases does not affect the conclusions of the E-LCA. These conclusions indicate that:

- GREEN-LOOP scenarios reduce the environmental burdens compared to the two benchmarks presented as a mix.
- The inclusion of glass fibre in the composite formulation improves the performance without significant increases in the environmental impacts.
- Energy consumption is a hotspot within this value chain that must be solved via energy efficiency measures.

However, some differences were spotted when comparing the results, such as the total values obtained for 16 indicators, which in Ecoinvent are higher, except for “*Climate change, total*”, which scores pretty much similar values. It should be mentioned that similar trends have been found in the literature [42]. In addition to the different system boundaries and amount of background data, these differences may be in part related to the inexact equivalences between the processes selected in the databases to represent the same materials. For example, the copper is represented with the Ecoinvent dataset “*Copper, cathode {GLO} / market for copper, cathode / Cut-off, U*” and with the LCA FE dataset “*GLO: Copper (99.99% cathode) ICA*”. While both are apparently related to the same process, the

primary data used to create them differ, resulting in slightly different results that are accumulated, which in turn affect the overall outcome. In other cases, the differences are explained by the lack of representative datasets, as is the case with biopolymers, leading practitioners to decide on a proxy based on their expertise and the availability of data.

However, the weightiest difference is obtained in the category “*Eutrophication, freshwater*”, which in LCA FE is totally negligible in the four scenarios, while in Ecoinvent represents the third biggest contributor. The Ecoinvent market process “*Electricity, medium voltage {DE}*” is responsible for up to 96% of the impacts in this category, while its counterpart in the LCA FE database “*DE: Electricity mix 1kV-60kV*” does not have big impacts in this category.

Finally, one notable difference between the two databases is the flexibility they offer for modifying datasets. In Ecoinvent, it is generally easier for practitioners to create proxies or adapt data, thanks to its transparent modelling structure. This can be especially valuable when assessing innovative technologies or low-TRL processes, where existing datasets may be lacking. For this reason, Ecoinvent is often preferred in early-stage LCA studies that require custom modelling. As these are different databases, the results will not align, since the indicators and system limits will be calculated differently, generating discrepancies in the obtained impacts.

To conclude, the data obtained using the SimaPro and Ecoinvent software will be taken into account for GREEN-LOOP project comparison purposes. As mentioned above, this database is more useful for processes with a lower level of technological maturity, offering greater flexibility and clarity.

## 4.5. LCC impact analysis (LCIA) and interpretations

### 4.5.1. Bio-rubber manufacture

In line with LCC analysis, the costing regarding the three scenarios in T6.2 is shown in Table 41. For the results plotted in Figure 34, the Labour cost has not been taken into account because it is a non-representative value due to the low TRL level of the process at this stage (TRL6). At a higher industrial scale, it is anticipated that the labour cost will not be equivalent to the process hour duration due to the high level of process automation.

So, in these conditions, the main economic impact is the purchasing of Raw Materials, with a value of Net Present Value (NPV) around 30-40% in all scenarios, followed by the Direct manufacture cost in the BB solutions (25% and 31% of the NPV for each scenario); and by the Environmental cost in the current scenario (23,50% of NPV). As it was mentioned above, the consumption would not be

comparable for a lab-scale process against an industrial one. Hence, the energy consumption for BRP1 and Current manufacturing is assumed to be equivalent for the same scale. One part of the Indirect cost is calculated as 5% of the direct cost, and the Manufacture profits as 7% of the direct cost, according to the assumptions explained in section 2.3.1.2 *LCC Methodology*. Finally, the Environmental externalities are calculated with SIMAPRO software and the Environmental Prices (Europe) database.

Table 41. Environmental impact analysis of T6.2 using Ecoinvent 3.11 and SIMAPRO.

| Data for 1kg of:          |                                      | Current RP      | BRP1            | BRP2           |
|---------------------------|--------------------------------------|-----------------|-----------------|----------------|
| Raw materials             | RM purchase                          | 49.24 €         | 53.13 €         | 5.72 €         |
| Direct manufacture cost   | Energy                               | 36.49 €         | 40.07 €         | 4.47 €         |
|                           | Labour cost                          | -               | -               | -              |
| Indirect manufacture cost | Waste management                     | 5.89 €          | 5.89 €          | 0.15 €         |
|                           | 5% direct                            | 1.82 €          | 2.00 €          | 1.97 €         |
|                           | Equipment cost                       | 29.02 €         | 29.02 €         | 0.65 €         |
| Manufacture profits       | 7% direct                            | 2.55 €          | 2.80 €          | 2.76 €         |
| Environmental cost        | Environmental Prices V1.00 - SIMAPRO | 38.40 €         | 28.30 €         | 1.18 €         |
| Component cost            | <b>TOTAL</b>                         | <b>163.42 €</b> | <b>161.22 €</b> | <b>16.91 €</b> |

The use of these natural resources has a lower NPV impact in comparison with the synthetic rubber of the reference system, although it is drastically lower in BRP2 than in BRP1, confirming the suspicions of deliverable D2.2 that the lignin extraction process had been detected as a hotspot. The absence of lignin in the BRP2 scenario material reduces the NPV of energy, waste management, equipment costs, and environmental prices. Also, regarding the decrease in Environmental Prices, it is important to mention that a reduction in the environmental impacts produces a reduction of the Environmental Externalities costs; this second scenario (BRP2) has the lowest economic impact.



Figure 34. Economic impacts (NPV) for the bio-rubber value chain. Within each category, the 3 scenarios were compared.

## 4.5.2. Bio-plastic manufacture

In the LCC analysis, all the economic data obtained for the three scenarios in T6.3 are summarised in Table 42. In this case, the Labour cost is included in the Direct manufacture cost because it is not as high as in the previous case. Still, these costs are the main impact detected (between 62-78%), but it is considered a more realistic situation due to it is not a very high value in comparison with the rest of the values; it is more balanced across the whole LCC. In the case Labour cost was not taken into account, in the olive oil scenarios, the Indirect manufacture cost would be the main impact, while in the limoncello situation are split: the second impact in the BB one is the raw materials purchasing, and the indirect manufacture cost in the current one. The info from this Table is reflected in Figure

35. For each type of bottle closure, in both cases, the sum of NPV in the current system is lower than in the system developed in the GREEN-LOOP project, mainly due to nowadays the plastic market is well established around the world, with lower prices than the biodegradable options. Even if Environmental externalities are quite similar for current materials, it does not compensate for the price difference in raw materials.

Table 42. Environmental impact analysis of T6.3 using Ecoinvent 3.11 and SIMAPRO

| Data for 1kg of:          |                                      | OliveOil BB    | OliveOil current | Limoncello BB  | Limoncello current |
|---------------------------|--------------------------------------|----------------|------------------|----------------|--------------------|
| Raw materials             | RM purchase                          | 5.64 €         | 1.51 €           | 5.64 €         | 1.30 €             |
| Direct manufacture cost   | Energy                               | 4.23 €         | 4.23 €           | 3.70 €         | 3.70 €             |
|                           | Labour cost                          | 48.17 €        | 48.17 €          | 17.77 €        | 17.77 €            |
| Indirect manufacture cost | Waste management                     | 0.00 €         | 0.00 €           | 0.00 €         | 0.00 €             |
|                           | 5% direct                            | 2.62 €         | 2.62 €           | 1.07 €         | 1.07 €             |
|                           | Equipment cost                       | 5.86 €         | 5.86 €           | 3.16 €         | 3.16 €             |
| Manufacture profits       | 7% direct                            | 3.67 €         | 3.67 €           | 1.50 €         | 1.50 €             |
| Environmental cost        | Environmental Prices V1.00 - SIMAPRO | 2.05 €         | 1.50 €           | 1.89 €         | 1.17 €             |
| Component cost            | TOTAL                                | <b>72.24 €</b> | <b>67.56 €</b>   | <b>34.74 €</b> | <b>29.68 €</b>     |

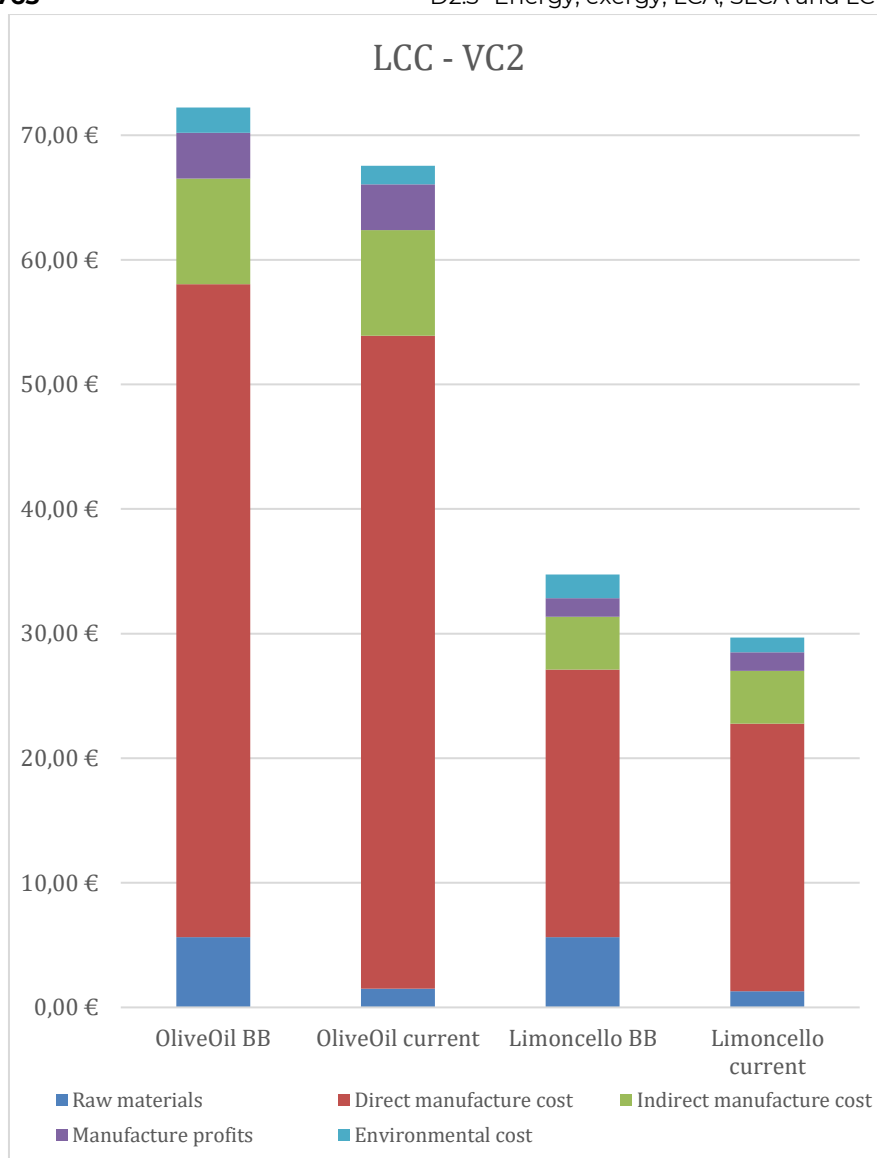


Figure 35. Economic impacts (NPV) for the bioplastic value chain. Within each category, the 4 scenarios were compared for each kind of closure

### 4.5.3. Wood composites manufacture

For the LCC analysis related to the T6.4, all the costs associated with these scenarios are collected in Table 43. Making the same considerations as in the previous Tasks, the NPV for direct costs accounts for more than 80% of the impacts in the four scenarios evaluated: the two bio-based scenarios and the two most common scenarios in the current market. For the current metal mix system, the second most significant impact on the system is manufacturing profits, accounting for 6% of the total NPV. On the other hand, in the current polymer mix, the second largest impact is indirect costs. Within bio-based systems, for both scenarios, SBS1 and SBS2, the second largest impact is indirect costs. Finally, it is important to comment that in this value chain, the environmental externalities are as expected

for each scenario except for SBS2. This has a value similar to the current metal situation, mainly due to the addition of Glass Fibre to the composition.

Table 43. Environmental impact analysis of T6.4 using Ecoinvent 3.11 and SIMAPRO

| Data for 1kg of:                |                                      | Current -<br>met | Current -<br>pol | SBS1            | SBS2            |
|---------------------------------|--------------------------------------|------------------|------------------|-----------------|-----------------|
| Raw materials                   | RM purchase                          | 3.56 €           | 2.66 €           | 14.46 €         | 11.64 €         |
| Direct<br>manufacture<br>cost   | Energy                               | 7.88 €           | 7.88 €           | 7.88 €          | 7.88 €          |
|                                 | Labour cost                          | 157.50 €         | 157.50 €         | 157.50 €        | 157.50 €        |
|                                 | Waste management                     | -0.67 €          | 0.03 €           | -0.04 €         | -0.13 €         |
| Indirect<br>manufacture<br>cost | 5% direct                            | 8.27 €           | 8.27 €           | 8.27 €          | 8.27 €          |
|                                 | Equipment cost                       | 3.91 €           | 3.91 €           | 3.91 €          | 3.91 €          |
|                                 | 7% direct                            | 11.58 €          | 11.58 €          | 11.58 €         | 11.58 €         |
| Manufacture profits             |                                      |                  |                  |                 |                 |
| Environmental cost              | Environmental Prices V1.00 - SIMAPRO | 3.55 €           | 2.77 €           | 2.45 €          | 3.41 €          |
| Component cost                  | TOTAL                                | <b>195.58 €</b>  | <b>194.60 €</b>  | <b>206.00 €</b> | <b>204.06 €</b> |

Figure 36 shows that the purchase of raw materials makes the biggest difference in terms of impact, as was the case in the analysis of task T6.3 above. This is because, at present, the market price of commonly used metals and polymers is very stable, with a very distinct niche, while bio-based biodegradable compounds are still entering the market at higher prices, but these are expected to decrease as the industry increasingly opts for the use of this type of material.

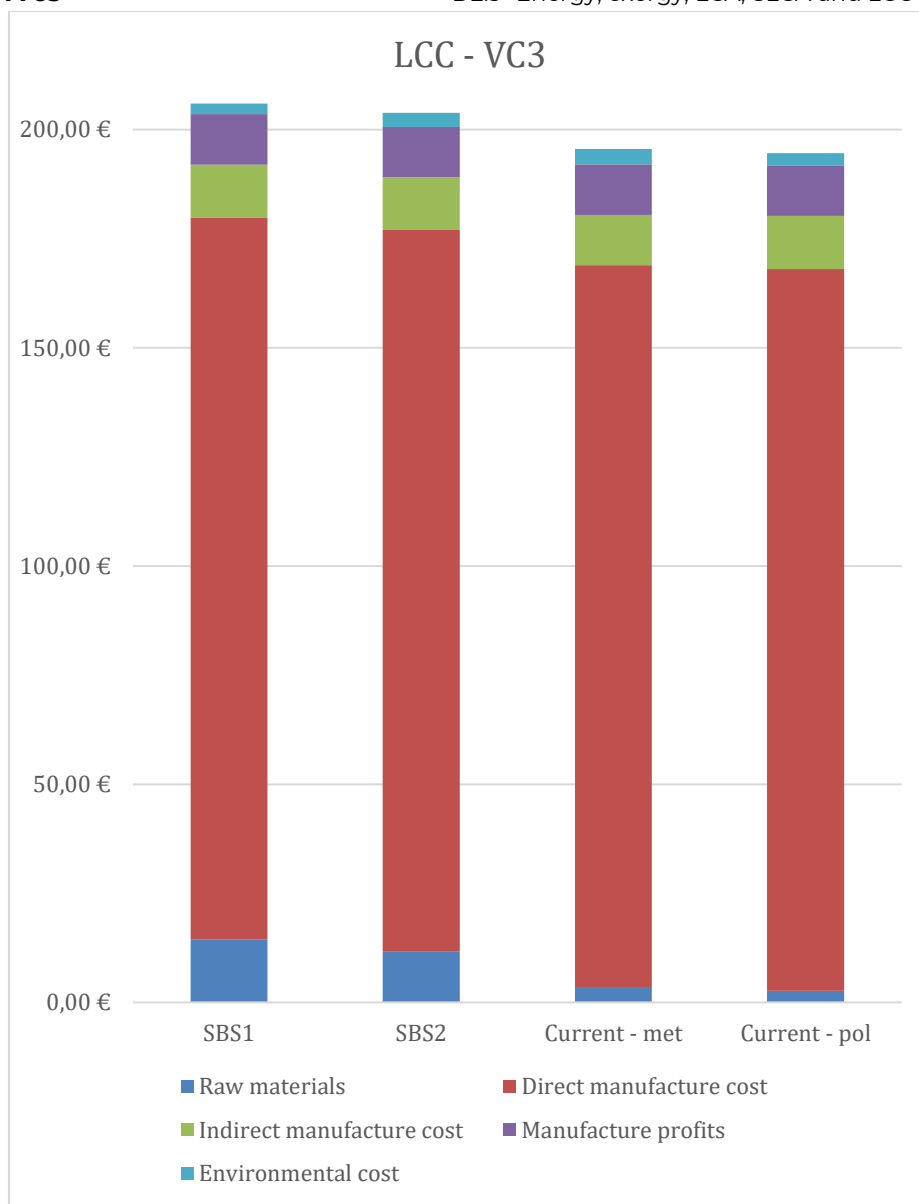


Figure 36. Economic impacts (NPV) for the wood composite value chain. Within each category, the 4 scenarios were compared for each kind of closure

#### 4.6. S-LCA impact analysis (LCIA) and interpretations

The LCIA was made following the Reference Approach (Type I) proposed by UNEP guidelines [18]. In order to calculate the medium risk hours (**mrh**), the PRPs are combined with the worker hours scaled by the output price. This way, the results are dependent both on the risk associated with the inventory indicator and the amount of time expended carrying it out, i.e. more **mrh** could be obtained from a process that implies medium risk and 20 h of work than a high-risk process that last 1 hour. This methodology, if not perfect, is reliable enough to compare the results within each subcategory in different scenarios.

## 4.6.1. Bio-rubber manufacture

In line with the other two dimensions, the lignin recovery process bears most of the impacts. Thus, it was considered more interesting to analyse this process individually and lately analyse comparatively the bio-rubber panel production in BRP1, BRP2 and the two benchmarks.

### Lignin extraction

The lignin recovery process is carried out in Slovenia and represented by the inventory indicators contained in the dataset “*Manufacture of rubber and plastic products - SVN*”. Within this dataset, the sector-base risk assessment states that: from the 16 inventory indicators, 3 are associated with no risk, 7 are associated to very low or low risk, 2 are associated with medium risk, 3 are associated with high risk and only 1 is associated with very high risk (Table 44). If a preliminary assessment is carried out considering only this PRPs, the subcategories that might be concerning are “*Fair Salary*”, “*Discrimination*”, “*Freedom of association and collective bargaining*” and “*Corruption*” as they include high or very high risks. Conversely, other categories such as “*Child labour*”, “*Working time*”, “*Health and Safety (Workers)*” and “*Social benefits, legal issues*” do not bear an intrinsic significant risk.

Table 44. PRP for the inventory indicators assessed during the S-LCA of GREEN-LOOP (NR = No risk, VLR = Very Low Risk, LR = Low Risk, MR = Medium Risk, HR = High Risk, VHR = Very High Risk).

| Subcategory                                      | PSILCA Inventory Indicator                                  | PRP |
|--------------------------------------------------|-------------------------------------------------------------|-----|
| Child labour                                     | Children in employment, total                               | VLR |
| Fair salary                                      | Living wage, per month                                      | HR  |
|                                                  | Sector average wage, per month                              | VLR |
| Working time                                     | Weekly hours of work per employee                           | LR  |
| Discrimination                                   | Gender wage gap                                             | HR  |
|                                                  | Women in the sectoral labour force                          | MR  |
| Health and safety (Workers)                      | Rate of fatal accidents at workplace                        | VLR |
|                                                  | Rate of non-fatal accidents at workplace                    | VLR |
| Social benefits, legal issues                    | Violations of employment laws and regulations               | LR  |
|                                                  | Social security expenditures                                | LR  |
| Freedom of association and collective bargaining | Right of association                                        | NR  |
|                                                  | Right of collective bargaining                              | NR  |
|                                                  | Right to strike                                             | NR  |
| Corruption                                       | Trade union density                                         | HR  |
|                                                  | Active involvement of enterprises in corruption and bribery | MR  |
|                                                  | Public sector corruption                                    | VHR |

However, despite the fact of having low social risk in the country of production it is possible to perform poorly in some indicators due to the upstream flows, or the quantity of time hours expended doing a process (worker hours). While the poor

results related to the upstream flows could be fixed by modifying the supply chain, the ones not directly related to the social quality of the providers need to be tackled from other perspectives. For instance, in the lignin recovery process most of the impacts obtained in the environmental and economical dimensions are related to the high energy consumption. Consequently, the conclusions presented were based on improving the energy efficiency.

In the following sections, the contribution of the different processes will be itemised within each subcategory to better understand the results. While the subcategory results are not aggregable as it happens in E-LCA, their absolute values but USD of output will be used to discuss the weight of the social impact in the overall process.

## **Child labour**

The inventory indicator "*Child labour, total*" provided 0.002 mrh/USD, a very low value, supposing a meaningless social risk. The contribution analysis to the subcategory shows that the supply chain to produce chemicals products in USA accounts for the 47.3% of the total impacts, followed by the electrical industry in Slovakia with a 39.9%.

## **Fair salary**

The subcategory "*Fair salary*" (that includes the impact indicators "*Living wage, per month*" and "*Sector average wage, per month*") obtained the highest score of 7.77 mrh/USD. Its contribution analysis shows that the supply chain to produce electricity in Slovenia accounts for the 47.1% of the impact, closely followed by the production of chemical products in USA, with a 41.2%. The other three process together represent less than a 12%. This result is reasonable since the PRP of their inventory indicator "*Living wage, per month*" is very high risk.

## **Working time**

The indicator "*Weekly hours of work per employee*" obtained 0.0085 mrh/USD, one of the smallest values. The contribution analysis shows that 61.2% of these impacts are produced in the electricity sector of Slovenia, while a meaningful 26.7% was produced in the USA.

## **Discrimination**

This subcategory is analysed by two inventory indicators. The first one, "*Gender wage gap*", obtained a score of 0.2113 mrh/USD. Its contribution analysis shows that the plastic and rubber sector in Slovenia accounts for 54.5% of the total impacts despite the fact this inventory indicators has a medium risk. In the case of "*Women in sectoral labour force*", the score is higher, 0.866 mrh/USD, with the electricity supply chain in Slovenia again as the main contributor, with an 86.9% of the total impacts.

## **Health and safety (workers)**

Within this category two inventory indicators are assessed. The "*Rate of fatal accidents*" scored a meaningless value of 0.002 mrh/USD, similar to the child labour, with contribution divided between the electricity production in Slovenia (49.8%) and the chemicals products in US (37.4%). The "*Rate of non-fatal accidents*" scored a significantly higher value of 0.74 mrh/USD, mainly driven by contributions from the electricity production in Slovenia (95.3%).

## **Social benefits, legal issues**

Within this category, other two inventory indicators were evaluated. The indicator "*Social security expenditures*" provides a meaningful score of 0.285 mrh/USD with a 71.5% of contribution from the production of chemicals in USA, where this inventory indicator has a medium risk, and 25.2% from the energy sector in Slovenia, where the indicator has a low risk. Conversely, the indicator "*Violation of employment laws and regulations*" obtained a high impact, 1.72 mrh/USD. Its contribution analysis shows that most of the impact arise from the production of chemicals products in USA (93.1%).

## **Freedom of association and collective bargain**

Two inventory indicators are calculated to analyse this subcategory. The indicator "*Association and bargain rights*" (that includes "*Right of association*", "*Right of collective bargaining*" and "*Right to strike*") scored 0.215 mrh/USD, with a 68.5% of contribution from the production of chemicals products in USA. The electricity supply chain in Slovenia contributes with a 27.7% while the other two sectors does not contribute significantly. The second indicator, "*Trade Unionism*" (obtained from the inventory indicator "*Trade union density*") scored the third biggest value, 2.41 mrh/USD, with a 71.3% of contribution from the production of chemicals in USA and 20.1% contribution of the electricity sector in Slovenia.

## **Corruption**

This subcategory is assessed using two inventory indicators. The "*Active involvement of enterprises in corruption and bribery*" obtained 0.876 mrh/USD with a 90.2% contribution of the electricity sector in Slovenia. Finally, the inventory indicator "*Public sector corruption*" scored 6.51 mrh/USD, the second highest value, and distributes more the impacts between the electricity sector in Slovenia (48.0%), the production of chemicals in USA (23.6%) and the production of plastic and rubber materials in Slovenia (17.7%).

As it was previously mentioned, the workers' hours scale up with the price, providing a qualitative vision of in which activity the stakeholders will expend more time. Each of these different activities have associated their own risk levels. Thus, by combining the risk levels with the worker hours it is possible to estimate what social impacts could be more concerning within the supply chains. In the lignin

recovery step, the main social issues arise from the subcategories “**Fair salary**”, “**Corruption**”, “**Freedom of association and collective bargain**” and “**Social benefits, legal issues**”, in this order. It must be pointed out that only in the case of “**Public sector corruption**” the rubber and plastic industry in Slovenia contributes significantly (17.7%). In the remaining cases, the electricity sector in Slovenia and the production of chemicals in USA gather almost all the social impacts, mainly because they include so many worker hours.

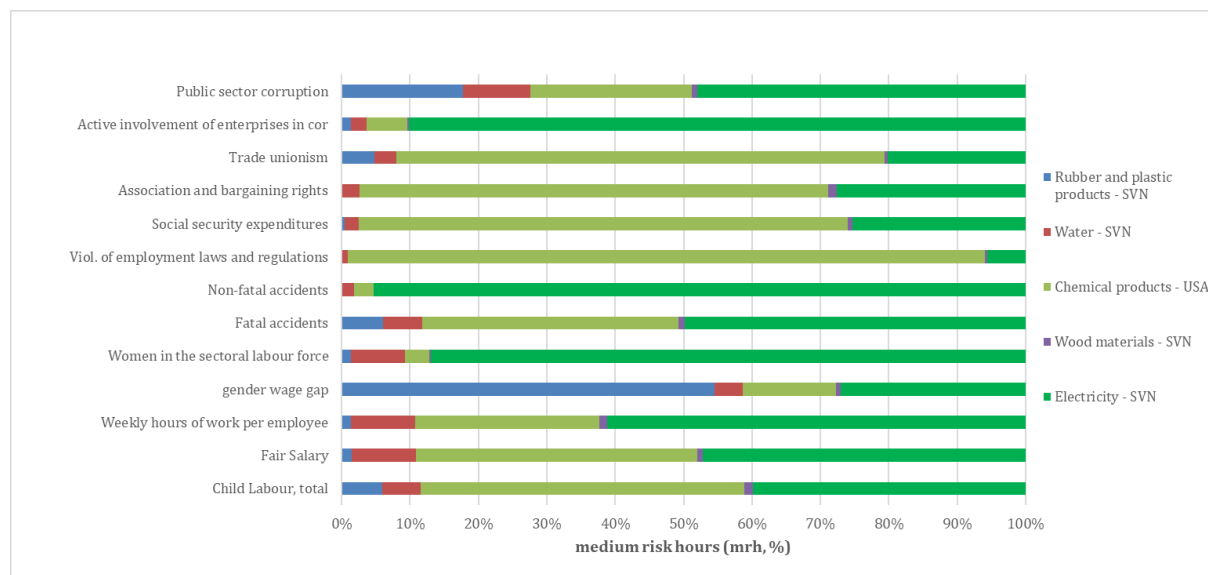


Figure 37. Itemised contribution (%) of the different process to the medium risk hours (mrh) of the Lignin Recovery process

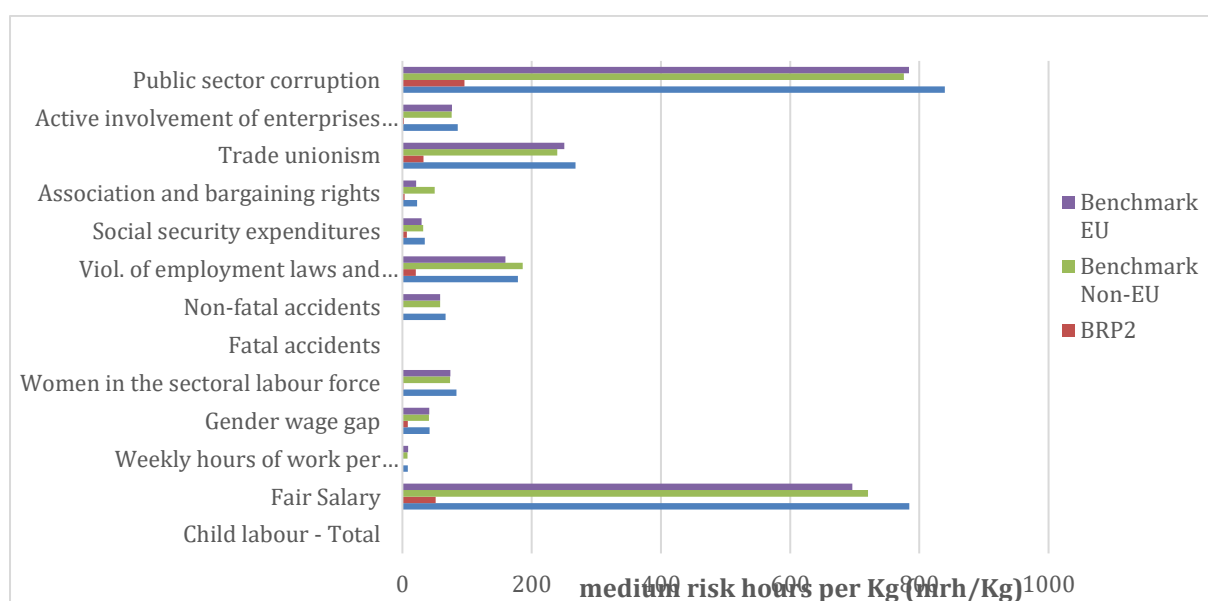


Figure 38. Comparison of the four different scenarios of T6.2 in medium risk hours per Kg (mrh/Kg) for the bio-rubber production process

Table 45. Medium risk hours (mrh) per Kg of bio-rubber panel production in the processes BRP1, BRP2 and the benchmark scenario with supply chain inside Europe (EU Benchmark) and outside Europe (Non-EU benchmark) in the T6.2

| Impact category                                                    | Medium risk hours |       |                  |              |
|--------------------------------------------------------------------|-------------------|-------|------------------|--------------|
|                                                                    | BRP1              | BRP2  | Non-EU Benchmark | EU Benchmark |
| <b>Child labour - Total</b>                                        | 0.223             | 0.030 | 0.212            | 0.208        |
| <b>Fair Salary</b>                                                 | 784.50            | 51.25 | 720.40           | 696.17       |
| <b>Weekly hours of work per employee</b>                           | 8.61              | 0.524 | 7.80             | 8.66         |
| <b>Gender wage gap</b>                                             | 42.07             | 8.55  | 41.21            | 41.40        |
| <b>Women in the sectoral labour force</b>                          | 83.59             | 1.34  | 73.60            | 74.08        |
| <b>Fatal accidents</b>                                             | 0.213             | 0.023 | 0.22             | 0.197        |
| <b>Non-fatal accidents</b>                                         | 67.04             | 0.362 | 58.58            | 58.61        |
| <b>Viol. of employment laws and regulations</b>                    | 178.88            | 20.71 | 185.98           | 159.68       |
| <b>Social security expenditures</b>                                | 34.86             | 6.68  | 31.91            | 29.69        |
| <b>Association and bargaining rights</b>                           | 22.96             | 3.21  | 50.03            | 21.31        |
| <b>Trade unionism</b>                                              | 267.85            | 32.52 | 239.67           | 250.34       |
| <b>Active involvement of enterprises in corruption and bribery</b> | 85.59             | 2.44  | 76.46            | 76.93        |
| <b>Public sector corruption</b>                                    | 839.43            | 95.92 | 776.07           | 784.21       |

## Rubber panels production

Since the lignin step contributes significantly to the output price of the bio-rubber panel manufacture and the two benchmarks, most of the workers' hours will be assigned to this process, leading to similar situations. Thus, in these three scenarios, the same four subcategories ("**Fair salary**", "**Corruption**", "**Freedom of association and collective bargain**" and "**Social benefits, legal issues**") will be of special concern in terms of social impacts. Indeed, the amount of lignin powder included in the reference flows will be key to deciding which scenario has more social impacts. SBS1 is where more lignin powder is used (11% more than in the benchmarks), so it obtained the worst results in the social indicator, with only three exceptions: "**Weekly hours of work per employee**", "**Rate of fatal accidents**" and "**Violation of employment laws and regulations**". Additionally, the fourth scenario,

BRP2, outperformed the other three without exception due to removing the lignin extraction process.

In the following paragraphs, the results of BRP1, BRP2, Benchmark EU and Benchmark Non-EU will be compared in the same 8 subcategories. All of them are references to the functional unit of 1 Kg.

## **Child labour**

This indicator is, along with "*Rate of fatal accidents*", the one that scored the least impact. The BRP1 scenario obtained 0.223 mrh, with an 81.3% contribution of the lignin recovery process. In the benchmarks, the sensitivity analysis concludes that the EU scenario slightly outperformed the Non-EU scenario since the manufacture of rubber products in Poland reduced the social impacts by 46% compared to the rubber sector in China (from 0.0073 to 0.0039 mrh). Additionally, the social impacts provided by the synthetic rubber in the EU scenario (0.0039 mrh) and the summation of the TDP and the natural rubber in BRP1 (0.0043 mrh) are comparable. In the case of BRP2, since more TBD and natural rubber is used, the impact was higher (0.097 mrh)

## **Fair salary**

The subcategory "*Fair salary*" (that includes the impact indicators "*Living wage, per month*" and "*Sector average wage, per month*") obtained the highest social impacts, with 784.50 mrh for SBS1 and the lignin recovery process representing 92.5% of these impacts. Besides, the benchmark EU outperformed the Non-EU benchmark due to the huge difference between the rubber industry in Poland and China (from 27.96 to 3.73 mrh). Additionally, when comparing the TBD and the natural rubber from BRP1 and BRP2 with the synthetic rubber of the EU scenario, a reduction of 18.4% for BRP1 and 4.5% for BRP2 in the mrh was achieved.

## **Working time**

The indicator "*Weekly hours of work per employee*" is one of the exceptions in which SBS1 outperformed the EU Benchmark, obtaining 8.65 mrh, a small value. One more time, the lignin recovery process stand as the main contributor with a 92.9% of the total impacts in SBS1. Between the two benchmarks, the best results are obtained in the in the Non-EU, since the rubber industry in China scored 83.5% less than the rubber industry in Poland. Besides, when the synthetic rubber production in the Non-EU benchmark is compared with the recycled rubber industry in Germany (TBD) and the natural rubber supplied from Malaysia, the impact are reduced in a 57.6% for BRP1 and 50.3% for BRP2.

## **Discrimination**

The indicator "*Gender wage gap*" obtained 42.07 mrh for SBS1. However, in this case the lignin recovery only bears with 46.9% of the social burdens. The other 48.5% is obtained by the rubber industry in Slovenia, where the indicator has a

medium risk. Among the two benchmarks, one more time the EU scenario scored worse results than the Non-EU scenario, since the rubber industry in China reduced in a 63.8% the social impacts. The comparison between the synthetic rubber and the recycled rubber combined with natural rubber is negative for the GREEN-LOOP scenarios, as the natural rubber from Malaysia obtained, alone, worse results than the rubber industry in China.

In the case of "*Women in sectoral labour force*", SBS1 obtained 83.59 mrh, with a 96.8% contribution of the lignin recovery process. Between the two benchmarks, the Non-EU scenario outperformed the EU scenario due to a significant 90.6% reduction of this social impact in the rubber industry in China compared to Poland. Besides, SBS1 and SBS2 obtained mrh comparable with the rubber industry in China.

## **Health and safety (workers)**

The indicator "*Rate of fatal accidents*" is another example in which SBS1 outperformed one of the benchmarks, with the former scoring 0.21 mrh and the latter 0.22 mrh. One more time the lignin recovery is the main contributor with a 83.5%. Among the two benchmarks, the best results are obtained in the EU scenario, since the rubber industry in Poland reduces the impacts in a 84% compared with the rubber industry in China. SBS1 and SBS2 obtained a significant reduction in 30.1% and 18.1%, respectively, when the recycled and natural rubber is compared with the production of synthetic rubber in Poland.

In the case of "*Rate of non-fatal accidents*" the results are more aligned with the previous subcategories, with SBS1 scoring 67.04 mrh, worse than the benchmarks, and more than 99% of contribution from the lignin recovery process. The two benchmarks obtained very similar values, with the Non-EU scenario slightly outperforming the EU scenario, and the natural and recycled rubber obtained results comparable with them as well.

## **Social benefits, legal issues**

The indicator "*Social security expenditures*" obtained 34.86 mrh in SBS1 with a 79.1% contribution from the lignin recovery step. The EU benchmark outperformed the Non-EU benchmark due to a 73.4% reduction in the rubber industry in Poland compared to China. Regarding the social impacts of the TBD and the natural rubber, BRP1 and BRP2 obtained scored comparable with the Non-EU benchmark, thus worse than the EU benchmark.

The indicator "*Violation of employment laws and regulations*" scored 178.88 mrh in SBS1, one of the worst punctuations, with a contribution 90.0% from the lignin extraction step. The EU benchmark obtained better results to the Non-EU benchmark due to a 96.4% reduction in the Poland rubber sector. In this case, the

recycled and natural rubber from BRP1 and BRP2 obtained better social results than the synthetic rubber, with a 45.3% and a 36.0% reduction, respectively.

## ***Freedom of association and collective bargain***

The indicator "*Association and bargain rights*" is another exception in which the Non-EU benchmark scored worse results than SBS1, with 50.03 mrh for the former and 22.97 for the latter. However, one more time the main contributor, by far, is the process lignin recovery, with an 87.6%. Regarding the benchmarks, a 57.4% reduction of the mrh is obtained in the EU benchmark, compared with the Non-EU scenario. Additionally, the recycled and natural rubber production in BRP1 and BRP2 obtained better results than both benchmarks.

The indicator "*Trade unionism*" scored on the highest impacts, with 267.85 mrh in SBS1, and an 84.0% of contribution from the lignin recovery step. In this case the EU benchmark obtained worse results than the Non-EU benchmark, with a 92.8% reduction in the manufacture of rubber in China compared with Poland. Besides, the recycled and natural rubber obtained results worse than the Non-EU benchmark, and better than the EU benchmark.

## ***Corruption***

The indicator "*Active involvement of enterprises in corruption and bribery*" scored 85.59 mrh in the scenario SBS1, with a 95.6% of contribution from the lignin extraction. In the benchmarks, the rubber industry in China obtained a significant reduction of 88.2% compared to Poland. However, since this sector only contributes between a 0.08-0.069%, the results of both benchmarks are very similar, with slightly better values in the Non-EU scenario. The natural and recycled rubber in SBS1 and SBS2 obtained better results than both benchmarks, with a reduction of 53.9% and 45.8%, respectively, compared to the Non-EU scenarios

Finally, the indicator "Public sector corruption" obtained the worst results, with 839.43 mrh for SBS1. The lignin recovery step contributed one more time with a meaningful 72.5% and, between the benchmarks, the Non-EU obtained the best results. Additionally, the recycled and natural rubber scored values comparable with the recycled rubber in the Non-EU benchmark.

In the BRP (BRP1 and BRP2) production, the main social issues arise from the subcategories "***Corruption***", "***Fair salary***", "***Freedom of association and collective bargain***" and "***Health and safety (workers)***", in this order. In BRP2 the main contributors to these impacts are the manufacture of chemical products in USA and the rubber sector in Slovenia. In the case of BRP1 the majority of the social burden are derived from the use of lignin powder, produced during the lignin recovery step.

The sensibility analysis between the benchmark supply chain does not provide a clear winner, but it depends on the subcategory. The EU benchmark performs clearly better in “**Fair salary**”, “**Health and safety (Workers)**”, “**Social benefits and legal issues**”; while the Non-EU benchmark (mainly located in USA and China) performed clearly better in “**Working time**” and “**Corruption**”. In the other subcategories the results are comparable.

When compared with the benchmark, BRP2 obtained better social results in all the subcategories, while BRP1 only obtained better results in “**Working time**”. However, if the use of recycled and natural rubber is compared specifically with the use of synthetic rubber in the benchmarks, BRP1 and BRP2 obtained better results in the subcategories “**Fair salary**”, “**Working time**” and “**Corruption**” and comparable results with the best benchmark in the other categories except from “**Freedom of association and collective bargain**”.

By analysing BRP2, the only scenario without the lignin recovery process, it is possible to see that just by reducing the lignin powder content of the bio-rubber panel, a significant improvement of the social impacts could be obtained. It could be concluded that the process of lignin recovery is the main hotspot, especially in the categories “**Corruption**”, “**Fair salary**”, “**Freedom of association and collective bargain**” and “**Health and safety (workers)**”. Inside this process, the electricity sector in Slovenia and the production of chemicals in the USA are the main contributors. To reduce these impacts, it is recommended to improve the energy efficiency of the process to reduce the necessity of producing that much electricity and to try to improve the circularity of the process to reduce the consumption of chemicals.

## 4.6.2. Bio-plastic manufacture

The bioplastic closures (for olive oil and Limoncello) are manufactured in Italy and represented by the inventory indicators contained in the PSILCA dataset “*Manufacture of rubber and plastic products - ITA*”. In this demo case, all the LCI were modelled considering the same energy consumption. Therefore, the difference only could be explained by the different raw materials and the worker hours associated with the rubber industry in Italy.

Within this dataset, the sector-base risk assessment states that: from the 16 inventory indicators, 3 are associated with no risk, 5 are associated to very low or low risk, 4 are associated with medium risk, 2 are associated with high risk and another 2 are associated with very high risk (Table 46). If a preliminary assessment is carried out considering only this PRPs, the subcategories that might be concerning are “**Fair Salary**”, “**Working time**”, “**Freedom of association and collective bargaining**” and “**Corruption**” as they include high or very high risks,

while the categories "Child labour" and "Health and safety (Workers)" do not bear an intrinsic significant risk.

Table 46. PRP for the inventory indicators assessed during the S-LCA of GREEN-LOOP for the BP OO and BP LIM (NR = No risk, VLR = Very Low Risk, LR = Low Risk, MR = Medium Risk, HR = High Risk, VHR = Very High Risk).

| Subcategory                                      | PSILCA Inventory Indicator                                  | PRP |
|--------------------------------------------------|-------------------------------------------------------------|-----|
| Child labour                                     | Children in employment, total                               | VLR |
| Fair salary                                      | Living wage, per month                                      | VHR |
|                                                  | Sector average wage, per month                              | MR  |
| Working time                                     | Weekly hours of work per employee                           | HR  |
| Discrimination                                   | Gender wage gap                                             | MR  |
|                                                  | Women in the sectoral labour force                          | LR  |
| Health and safety (Workers)                      | Rate of fatal accidents at workplace                        | VLR |
|                                                  | Rate of non-fatal accidents at workplace                    | VLR |
| Social benefits, legal issues                    | Violations of employment laws and regulations               | MR  |
|                                                  | Social security expenditures                                | LR  |
| Freedom of association and collective bargaining | Right of association                                        | NR  |
|                                                  | Right of collective bargaining                              | NR  |
|                                                  | Right to strike                                             | NR  |
|                                                  | Trade union density                                         | HR  |
| Corruption                                       | Active involvement of enterprises in corruption and bribery | MR  |
|                                                  | Public sector corruption                                    | VHR |

In the following paragraphs, the results of Bioplastic Olive Oil closures (BP OO) and Bioplastic Limoncello closures (BP LIM) were compared with their respective benchmarks. Additionally, for each benchmark a sensibility analysis was made to consider the differences between supply chains inside and outside Europe and, since the only difference between them is the supply chain for one raw material, all the results could be readily explained.

All the mrh reported are reference to the functional unit of 1 Kg.

## Limoncello production

As it happened with the olive oil scenario, the social results of BR LIM scenario compared with the benchmark concluded that the latter performed better. The reasons that justify these results were analysed in the different subcategories.

### Child labour

This subcategory scored the smallest values, with 0.03 mrh for the BP OO. One more time, this worse result compared with the benchmark is mainly because the output price of the PHA is higher than the output price of the PP. The agriculture sector in Italy, responsible of producing the rice husk, palliates this effect with significant reductions. Both benchmark scenarios obtained comparable results.

## **Fair salary**

In this subcategory scored BP LIM obtained 61.61 mrh, the highest value. The contributing analysis revealed that the impact are shared between the manufacture of plastic processes in Italy (37.4%), the manufacture of plastic products in Netherlands (35.7%) and the energy sector in Italy (26.5%). Regarding the benchmarks, the European supply chain outperformed the Non-EU supply chain in the benchmark.

## **Working time**

Within this subcategory, BP LIM obtained 4.04 mrh, with a 56.2% of the social impact due to the manufacture of plastic products in Italy. In this case, the Non-EU benchmark outperformed the EU benchmark.

## **Discrimination**

In this subcategory both inventory indicators scored small values for BP LIM, with 1.53 mrh for "*Gender wage gap*" and 1.52 mrh for "*Women in sectoral labour force*". In both inventory indicators, the main contributor is the manufacture of plastic products in Netherlands, with a 58.6% and a 46.0% of the total impacts, respectively. Additionally, in both cases the non-EU scenario outperforms the EU scenario.

## **Health and safety (workers)**

The two inventories indicators within this subcategory, "*Risk of non-fatal accidents*" and "*Risk of Fatal accidents*", obtained small scored in the BP LIM: 0.70 mrh for the former and 0.03 mrh for the latter. In both cases, the plastic industry accounted for more than half of the impacts, especially in "*Risk of non-fatal accidents*" with 86.3%. Besides, the Non-EU benchmark obtained lower impacts than the EU LIM.

## **Social benefits, legal issues**

The two inventories indicators within this subcategory, "*Violation of employment laws and regulations*" and "*Social security expenditures*" obtained 6.35 and 6.10 mrh for BP LIM, very similar values. The contribution analysis shows that, in both cases, the plastic industry in Netherlands is responsible for more than half of the mrh, with 78.6%. Regarding the benchmarks, the EU scenario largely outperformed the Non-EU scenario, especially in "*Violation of employment laws and regulations*" with a 67.0% reduction of the social impacts.

## **Freedom of association and collective bargain**

In this category, while "*Association and bargaining right*" scores only 4.52 mrh, "*Trade unionism*" obtained the third highest score with 24.24 mrh. The contribution of analysis revealed that the plastic industry is Netherlands is once again accounting for most of the impacts, with a 83.8% for the former and a 77.2%

for the latter. When comparing the benchmarks, the results are less uniform. In the case of "*Association and bargaining right*" both supply chains are comparable, while in "*Trade unionism*" the non-EU supply chain obtained 17.7% less impacts.

## Corruption

In this subcategory the inventory indicator "*Active involvement of enterprises in corruption and bribery*" obtained a small value of 2 mrh for BP LIM, with the energy sector in Italy as the main contributor (55.8%). However, in "*Public sector corruption*" the second biggest value was obtained: 49.2 mrh for BP LIM. The contribution of analysis of this category revealed that 46.3% of the impacts are produced by the plastic sector in Italy and 33.8% in the plastic sector in Netherland. In both cases the supply chains outside and inside Europe for the benchmarks are comparable, especially in "*Active involvement of enterprises in corruption and bribery*".

The principal conclusion of this case study is one more time that the BP LIM did not outperform none of the benchmarks. The reason behind this is the high output price of the bioplastic compared with the PP currently used in the market (6.15 USD versus 1.43 USD). As it was previously explained, the UNEP guidelines for S-LCA linked the output value with the worker hours. Thus, the more expensive the raw materials are, the more time the workers (the stakeholder of interest here) have spent carrying out the process and, therefore, exposed to the risks. However, the rice husk obtained very promising results in all the indicators so, providing it does not affect negatively the functionality of the final product, raising its content could improve the social results.

According to the results, the most concerning subcategories are "**Fair salary**", "**Corruption**" and "**Freedom of association and collective bargain**". Conversely, Other categories such as "**Child labour**" and "**Health and safety (workers)**" performed extremely well.

The sensibility analysis concluded that the EU supply chain performed better in "**Fair salary**", the most concerning category, while the non-EU supply chain (located in USA) performed better in "**Corruption**" and "**Freedom of association and collective bargain**". However, the differences are small in all the examples (2% for "**Fair salary**" or 8% in "*Public sector corruption*"), and in the other subcategories is not clear who is performing better.

## Olive oil production

The social results of this scenario compared with the benchmark concluded that the BP OO conducted to more social impacts than the benchmarks. The reasons that justify these results were analysed in the different subcategories.

## **Child labour**

This subcategory scored the smallest values, with 0.03 mrh for the BP OO. The worse result compared with the benchmark is mainly because the output price of the PHA is higher than the LDPE, which implies more workers hours invested to prepare this raw material. However, the agriculture sector in Italy, responsible of producing the rice husk, obtained a 97% reduction compared with the benchmarks plastic sector, palliating the effect of the bioplastic price. Additionally, the benchmark sensitivity analysis obtained comparable results.

## **Fair salary**

This subcategory scored the highest value, with 86.43 mrh for the BP OO. As in the previous case, the higher output price of the PHA is responsible for the worse result, while the agricultural sector in Italy obtained the lowest impact. In this indicator, the European supply chain outperformed the Non-EU supply chain in the benchmark, since the production of plastic materials in Netherland provided a 47% reduction in this social impact compared with the plastic sector in USA.

## **Working time**

Within this subcategory, BP OO obtained 6.12 mrh, with a 68.7% of the social impact due to the manufacture of plastic products in Italy. However, as in the previous subcategories, the results of the rice husk are very promising. In this case, the Non-EU benchmark slightly outperformed the EU benchmark (5.26 versus 5.34 mrh).

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## **Discrimination**

In this subcategory both inventory indicators scored small values for BP OO, with 1.78 mrh for "*Gender wage gap*" and 1.65 mrh for "*Women in sectoral labour force*". In "*Gender wage gap*", the main contributor is the manufacture of plastic products in Netherlands, with a 50.3%, while in "*Women in sectoral labour force*" the energy production in Italy accounts for 55% of the total impacts. The reasons to justify why the BP OO obtained higher scores are pretty much the same as in the previous subcategories: major output price, leading to more worker hours. Additionally, in both cases the non-EU scenario outperforms the EU scenario.

## **Health and safety (workers)**

In this subcategory both inventory indicators scored small values for BP OO, 0.03 mrh for "*Risk of Fatal accidents*" and 0.71 mrh for "*Risk of non-fatal accidents*". In "*Risk of Fatal accidents*" the contribution is shared between the PHA, the electricity and the manufacture process industrial sectors. However, in the "*Risk of non-fatal accidents*" the manufacture of plastic products in Netherland accounts for 84.4% of the total impacts. Additionally, while in the former the benchmarks obtained similar results, in the latter the EU OO outperformed the non-EU scenario.

## **Social benefits, legal issues**

In this subcategory the inventory indicator "*Violation of employment laws and regulations*" obtained 6.72 mrh, while "*Social security expenditures*" obtained 6.39 mrh for BP OO. The main contributor for these two inventory indicators is one more time the manufacture of plastic products in Netherlands, with a 76.1% and a 74.3%, respectively. The benchmark EU largely outperformed the Non-EU scenario in "*Violation of employment laws and regulations*", while the opposite situation was obtained in "*Social security expenditures*".

## **Freedom of association and collective bargain**

"Association and bargaining rights" obtained 4.62 mrh and "Trade unionism" obtained 26.63 mrh, the third biggest impact, both for BP OO. In the benchmarks in the former the supply chain outside Europe performed better, while in the latter the supply chain inside Europe is preferred. Additionally, in these two indicators the value of BP OO is around 200% bigger than the benchmarks and the manufacture of plastic products in Netherlands is the biggest contribution.

## **Corruption**

The inventory indicator "*Active involvement of enterprises in corruption and bribery*" obtained only 2.36 mrh for BP OO, with the energy industry in Italy accounting for 54.3% of the total impacts. Both benchmarks obtained comparable results.

In "*Public sector corruption*" the BPOO obtained the second worst value, with 69.86 mrh. In this case the main contributor is the plastic industry in Italy, with a meaningful 60.2%. However, both benchmarks are very close to it with 55.16 mrh for EU OO and 55.95 mrh for Non-EU OO.

The main conclusion of this case of study is that the BP OO was not able to outperform the benchmarks in any case. This could be explained by the high difference between the output prices of the PHA and the PE: 6.33 USD for PHA and 1.66 USD for PE, both referred to the functional unit. Higher prices are translated in more worker hours and, consequently, more impacts. However, the rice husk obtained very promising results, so, providing it does not negatively affect the functionality of the final product, raising its content could improve the social results.

According to the results, the most concerning subcategories are "**Fair salary**", "**Corruption**" and "**Freedom of association and collective bargain**". Conversely, Other categories such as "**Child labour**" and "**Health and safety (workers)**" performed very well.

Unfortunately, in this case, the sensitivity analysis between the supply chains inside and outside Europe (located in the USA) was not very conclusive.

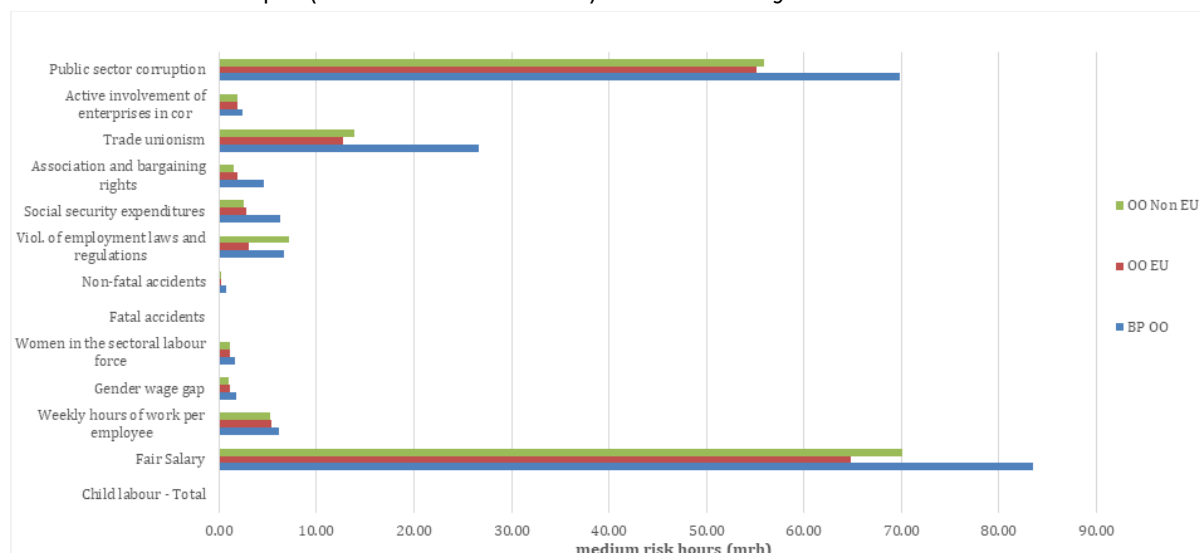


Figure 39. Comparison of mrh of the bioplastic olive oil closure scenario (BP OO) with the olive oil benchmark with supply chain inside (OO EU) and outside Europe (OO Non-EU)

Table 47. Comparison of mrh of the bioplastic olive oil closure scenario (BP OO) with the olive oil benchmark with supply chain inside (OO EU) and outside Europe (OO Non-EU).

| Categoría de impacto                                               | Medium Risk Hours (mrh) |       |           |
|--------------------------------------------------------------------|-------------------------|-------|-----------|
|                                                                    | BP OO                   | OO EU | OO Non EU |
| <b>Child labour - Total</b>                                        | 0.03                    | 0.02  | 0.02      |
| <b>Fair Salary</b>                                                 | 83.43                   | 64.76 | 70.03     |
| <b>Weekly hours of work per employee</b>                           | 6.12                    | 5.34  | 5.26      |
| <b>Gender wage gap</b>                                             | 1.78                    | 1.10  | 0.98      |
| <b>Women in the sectoral labour force</b>                          | 1.65                    | 1.13  | 1.11      |
| <b>Fatal accidents</b>                                             | 0.03                    | 0.02  | 0.02      |
| <b>Non-fatal accidents</b>                                         | 0.71                    | 0.27  | 0.18      |
| <b>Viol. of employment laws and regulations</b>                    | 6.72                    | 3.04  | 7.23      |
| <b>Social security expenditures</b>                                | 6.30                    | 2.79  | 2.50      |
| <b>Association and bargaining rights</b>                           | 4.62                    | 1.86  | 1.48      |
| <b>Trade unionism</b>                                              | 26.63                   | 12.69 | 13.94     |
| <b>Active involvement of enterprises in corruption and bribery</b> | 2.36                    | 1.85  | 1.93      |
| <b>Public sector corruption</b>                                    | 69.86                   | 55.16 | 55.95     |

Table 48. Comparison of mrh of the bioplastic Limoncello closure scenario (BP LIM) with the Limoncello closure benchmark with supply chain inside (LIM EU) and outside Europe (LIM Non-EU).

| Categoría de impacto                                               | Medium Risk Hours (mrh) |       |           |
|--------------------------------------------------------------------|-------------------------|-------|-----------|
|                                                                    | BP OO                   | OO EU | OO Non EU |
| <b>Child labour - Total</b>                                        | 0.03                    | 0.01  | 0.01      |
| <b>Fair Salary</b>                                                 | 61.61                   | 45.54 | 46.46     |
| <b>Weekly hours of work per employee</b>                           | 4.05                    | 3.70  | 3.15      |
| <b>Gender wage gap</b>                                             | 1.53                    | 0.86  | 0.71      |
| <b>Women in the sectoral labour force</b>                          | 1.52                    | 1.02  | 0.95      |
| <b>Fatal accidents</b>                                             | 0.03                    | 0.02  | 0.01      |
| <b>Non-fatal accidents</b>                                         | 0.70                    | 0.45  | 0.16      |
| <b>Viol. of employment laws and regulations</b>                    | 6.35                    | 2.01  | 6.09      |
| <b>Social security expenditures</b>                                | 6.10                    | 1.84  | 2.16      |
| <b>Association and bargaining rights</b>                           | 4.52                    | 1.15  | 1.28      |
| <b>Trade unionism</b>                                              | 24.24                   | 12.95 | 10.66     |
| <b>Active involvement of enterprises in corruption and bribery</b> | 2.00                    | 1.56  | 1.54      |
| <b>Public sector corruption</b>                                    | 49.20                   | 37.35 | 34.37     |

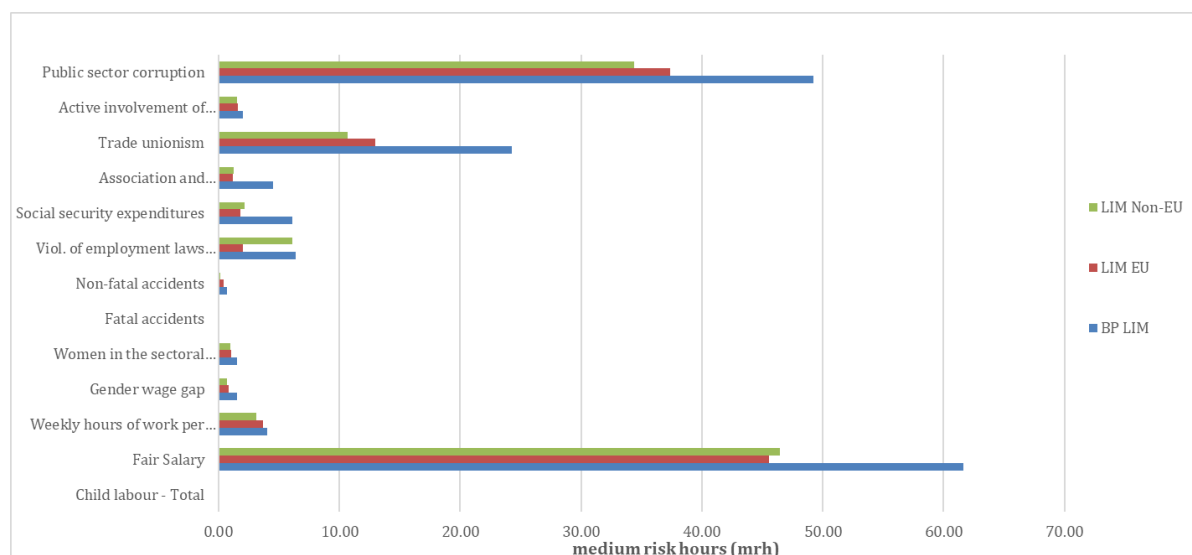


Figure 40. Comparison of mrh of the bioplastic Limoncello closure scenario (BP LIM) with the Limoncello closure benchmark with supply chain inside (LIM EU) and outside Europe (LIM Non-EU)

### 4.6.3. Wood composites manufacture

The wood-composite demonstrator is manufactured in Germany and represented by the inventory indicators contained in the PSILCA dataset "Manufacture of plastic products - DEU". Within this dataset, the sector-based risk assessment states that: from the 16 inventory indicators, 3 are associated with no risk, 3 are associated with very low or low risk, 4 are associated with medium risk, 2 are

associated with high risk and only 3 are associated with very high risk (Table 49). If a preliminary assessment is carried out considering only this PRPs, the subcategories that might be concerning are “Fair Salary”, “Discrimination”, “Health and Safety (Workers)”, “Freedom of association and collective bargaining” and “Corruption” as they include high or very high risks, while the category “Child labour” does not bear an intrinsic significant risk.

The LCI modelled for T6.4 uses the same energy consumption both in the GREEN-LOOP scenarios and the two benchmarks, thus the main differences between the social burdens are readily explained by the raw materials. Besides, both benchmarks (MM and PBP) are assessed considering the supply chain inside and outside Europe.

In the following paragraphs, the results of SBS1, SBS2, PBP Benchmark and MM Benchmark will be compared in the same 8 subcategories. Additionally, for each benchmark, a sensitivity analysis was made to consider the differences between supply chains inside and outside Europe. All the mrh reported are referenced to the functional unit of 1 Kg.

Table 49. PRP for the inventory indicators assessed during the S-LCA of GREEN-LOOP for the SBS1 and SBS2 (NR = No risk, VLR = Very Low Risk, LR = Low Risk, MR = Medium Risk, HR = High Risk, VHR = Very High Risk).

| Subcategory                                      | PSILCA Inventory Indicator                                  | PRP |
|--------------------------------------------------|-------------------------------------------------------------|-----|
| Child labour                                     | Children in employment, total                               | VLR |
| Fair salary                                      | Living wage, per month                                      | VHR |
|                                                  | Sector average wage, per month                              | VLR |
| Working time                                     | Weekly hours of work per employee                           | MR  |
| Discrimination                                   | Gender wage gap                                             | HR  |
|                                                  | Women in the sectoral labour force                          | MR  |
| Health and safety (Workers)                      | Rate of fatal accidents at workplace                        | VLR |
|                                                  | Rate of non-fatal accidents at workplace                    | HR  |
| Social benefits, legal issues                    | Violations of employment laws and regulations               | MR  |
|                                                  | Social security expenditures                                | LR  |
| Freedom of association and collective bargaining | Right of association                                        | NR  |
|                                                  | Right of collective bargaining                              | NR  |
|                                                  | Right to strike                                             | NR  |
|                                                  | Trade union density                                         | VHR |
| Corruption                                       | Active involvement of enterprises in corruption and bribery | MR  |
|                                                  | Public sector corruption                                    | VHR |

## Child labour

This indicator scores the smallest impacts, with both GREEN-LOOP scenarios obtaining worse results than the 4 benchmarks. The scenario SBS1 obtained the highest value, with 0.060 mrh, followed by SBS2 with 0.052 mrh. The impacts were distributed between the chemical products sector in Germany (40.2%), the energy

sector in Germany (38.9%) and the manufacture of the wood composite in Germany (20.6%). Regarding the PBP, the supply chain inside Europe performed better than the supply chain inside Europe. In the MM benchmark, the result was the same.

## **Fair salary**

The inventory indicator “*Fair salary*” obtained the highest value both in SBS1 and SBS2, with 194.9 and 185.81 mrh, respectively. The contribution analysis revealed that the plastic industry in Germany, selected to represent the manufacturing process, was responsible for at least 70.6% of the impacts. The worst performance of SBS1 is explained by the use of more ARBOBLEND 2241x, which in this assessment was linked to the chemical industry in Germany. Compared with the four benchmarks, SBS1 and SBS2 obtained worse results than the PBP benchmarks, comparable results with the MM benchmark with supply chain inside Europe and clearly better results than the MM Non-EU. Besides, in both benchmarks, the scenarios inside Europe outperformed the scenarios outside Europe, which were located in China, the USA and Chile.

## **Working time**

In “*Weekly hours of work per employee*”, SBS1 obtained worse results than SBS2 with 3.42 and 3.05 mrh, respectively. In BRP1, the contribution analysis showed that the chemical industry in Germany accounted for 47.0% of the impacts, while the other 40.3% is linked with the plastic industry in Germany, responsible for the wood-composite panel manufacturing. However, in SBS2 the plastic industry in Germany is the main contributor with a 44.8% and the chemical industry in Germany only produced 38.6% of the impacts. Compared with the 4 benchmark scenarios, SBS1 and SBS2 scored worse values, increasing values by at least 52.8% compared with the PBP and a 22.0% compared with the MM. Additionally, in this category the non-EU scenarios slightly outperformed the EU scenarios.

## **Discrimination**

In “*Gender wage gap*” the BRP1 obtained 19.46 mrh and BRP2, 18.69 mrh being in both cases the manufacture of the wood composite panel being responsible for at least 70.7% of the social burdens. When compared with the MM benchmark, the GREEN-LOOP scenarios performed similarly, but relative to the PBP benchmark both provided a significant increase in the social impacts of around a 22%.

On the other hand, in “*Women in sectoral labour force*” SBS1 and SBS2 obtained better values: 3.37 and 3.08 mrh, respectively. The contribution analysis revealed that the weight of the impacts in BRP1 is shared between the manufacture of the wood composite panel (40.9%) and the production of the ARBOBLEND 2241x (39.3%). Conversely, in SBS1 the contribution of ARBOBLEND 2241x is substantially reduced to a 31.4%. Besides, neither SBS1 nor SBS2 outperformed the benchmarks.

## Health and safety (workers)

In "Rate of fatal accidents", SBS1 and SBS2 obtained very low impacts, comparable with the subcategory "Child labour". Additionally, they outperformed the MM benchmark and obtained worse scores than the PBP benchmark. Regarding the sensitivity analysis, the Non-EU supply chain reduced the impacts in the MM benchmark, while the EU supply chain performed better in the PBP benchmark. In "Rate of non-fatal accidents" the values were higher, with 14.60 mrh for SBS1 and 14.42 mrh for SBS2. The impacts were mainly provided by the manufacture of the wood-composite panel, which accounted for 94% of the impacts in both scenarios. In this case, the GREEN-LOOP scenarios obtained slightly higher values than the PBP benchmarks (around 8% more) but far more impacts than the MM benchmark.

## Social benefits, legal issues

In "Social security expenditures", SBS1 scored 9.96 mrh and SBS2, 7.97 mrh. Within this inventory indicator, the chemical industry in Germany, selected as a proxy of the manufacture of ARBOBLEND2241x, is responsible for the huge difference between the scenarios, accounting for 84.0% and 76.8% of the impacts, respectively. One more time, the four benchmarks outperformed SBS1 and SBS2. Besides, the Non-EU supply chain obtained significant reductions in the social burdens, with a 52.8% for MM and a 31.5% for PBP.

In "Violation of employment laws and regulations", SBS1 obtained 13.60 mrh and SBS2, 11.44 mrh. In both cases, the main contributor is once again the manufacture of ARBOBLEND 2241x. Compared with the Non-EU benchmarks, SBS1 and SBS2 obtained a substantial reduction in the impacts. Concretely, SBS1 reduced the social burdens in 59.0% compared to Non-EU MM and in 44.4% compared to Non-EU PBP. However, both EU benchmarks outperformed them significantly.

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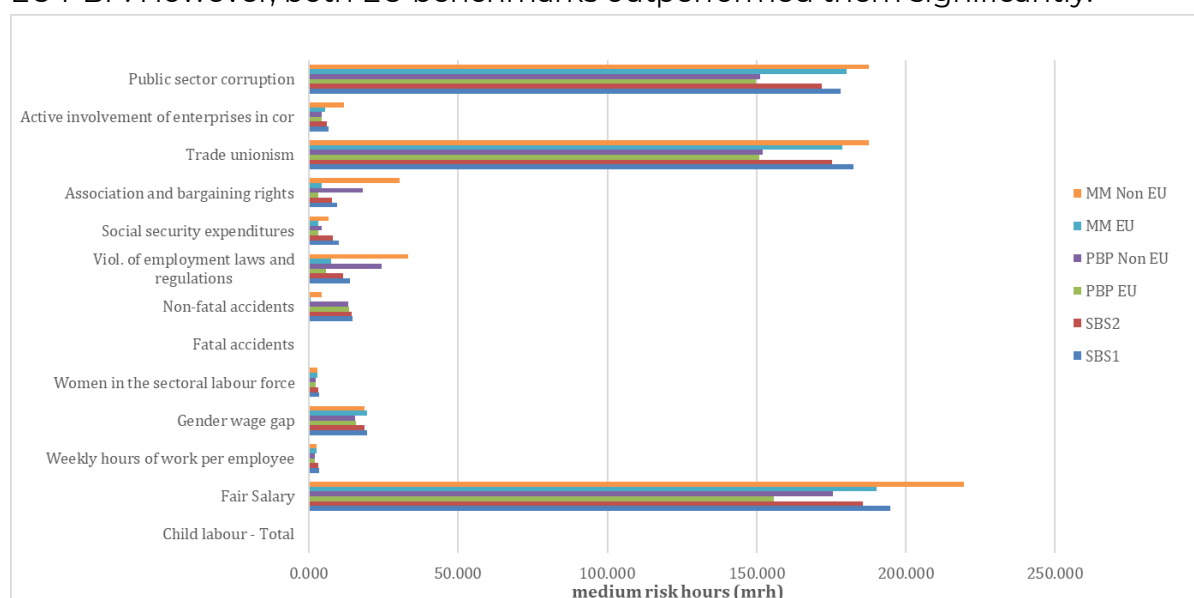


Figure 41. Comparison of the six different scenarios of T6.3 in medium risk hours per Kg (mrh/Kg) for the bioplastic closures production process

Table 50. Medium risk hours (mrh) per Kg of olive oil and Limoncello closures production in the processes SBS1, SBS2 and the benchmark scenarios with supply chain inside Europe (EU Benchmark) and outside Europe (Non-EU benchmark) in the T6.4

| <b>Categoría de impacto</b>                                        | <b>MEDIUM RISK HOURS</b> |             |               |                   |              |                  |
|--------------------------------------------------------------------|--------------------------|-------------|---------------|-------------------|--------------|------------------|
|                                                                    | <b>SBS1</b>              | <b>SBS2</b> | <b>PBP EU</b> | <b>PBP Non-EU</b> | <b>MM EU</b> | <b>MM Non-EU</b> |
| <b>Child labour - Total</b>                                        | 0.060                    | 0.052       | 0.028         | 0.031             | 0.038        | 0.050            |
| <b>Fair Salary</b>                                                 | 194.939                  | 185.813     | 155.952       | 175.742           | 190,352      | 219.497          |
| <b>Weekly hours of work per employee</b>                           | 3.420                    | 3.046       | 1.993         | 1.944             | 2,497        | 2.481            |
| <b>Gender wage gap</b>                                             | 19.458                   | 18.690      | 15.723        | 15.325            | 19.382       | 18.500           |
| <b>Women in the sectoral labour force</b>                          | 3.367                    | 3.080       | 2.175         | 2.181             | 2.908        | 2.739            |
| <b>Fatal accidents</b>                                             | 0.062                    | 0.055       | 0.037         | 0,050             | 0,070        | 0.066            |
| <b>Non-fatal accidents</b>                                         | 14.602                   | 14.416      | 13.486        | 13.264            | 0.424        | 4.281            |
| <b>Viol. of employment laws and regulations</b>                    | 13.599                   | 11.438      | 5.558         | 24.452            | 7.417        | 33.160           |
| <b>Social security expenditures</b>                                | 9.961                    | 7.975       | 2.987         | 4,359             | 3.137        | 6.649            |
| <b>Association and bargaining rights</b>                           | 9.290                    | 7.638       | 3.154         | 18.158            | 4.195        | 30.399           |
| <b>Trade unionism</b>                                              | 182.619                  | 175.301     | 150.991       | 152.040           | 178.793      | 187.591          |
| <b>Active involvement of enterprises in corruption and bribery</b> | 6.667                    | 6.096       | 4.201         | 4.222             | 5.447        | 11.582           |
| <b>Public sector corruption</b>                                    | 178.259                  | 171.859     | 149.763       | 151.354           | 180.078      | 187.762          |

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## Freedom of association and collective bargain

In "Association and bargain rights", SBS1 scored 9.29 mrh and SBS2 scored 7.64 mrh with the chemical industry in the Germany accounting for most of the impacts (79.2% for SBS1 and 70.5% for SBS2). As it happened with "Violation of employment laws and regulations", the GREEN-LOOP scenarios only outperformed the Non-EU benchmarks, obtaining more social impacts than the EU benchmarks.

The indicator "Trade Unionism" obtained the second highest values, with 182.62 mrh for SBS1 and 175.30 mrh for SBS2. In both cases the manufacture of the wood-composite panel accounted for most of the impacts, with a 75.4% and a 77.8%, respectively. Additionally, in this inventory indicator the GREEN-LOOP scenarios

outperformed the PBP benchmarks and obtained comparable values with the MM benchmarks. Conversely, the EU supply chains in the benchmarks achieved better results than the Non-EU supply chains.

## Corruption

In "Active involvement of enterprises in corruption and bribery" SBS1 scored 6.67 mrh and SBS2 scored 6.10 mrh. The contribution analysis showed that in this indicator the impacts are divided into the energy sector in Germany (38.9% in SBS1 and 42.5% in SBS2), the manufacture of ARBOBLEND 2241x (40.2% in SBS1 and 32.2% in SBS2) and the manufacture of the wood-composite panel (20.6% in SBS1 and 22.4% in SBS2). Unfortunately, these scenarios only outperformed the Non-EU MM benchmark, which is as well a 113% higher than the EU MM. Besides, the two supply chains for PBP obtained comparable results.

The indicator "Public sector corruption" obtained the third highest value, with 178.26 mrh for SBS1 and 171.86 mrh for SBS2. The main contributor in both examples were the plastic sector in Germany, selected to represent the manufacture of the wood-composite panel, that accounted for up to 79.3% of the social impacts. When compared with the benchmarks, SBS1 and SBS2 outperformed the MM and obtained worse values than the PBP benchmark. Regarding the sensibility analysis, the supply chains outside Europe scored worse values in both benchmarks.

The main conclusions that could be extracted from the social assessment of T6.4 is that neither SBS1 nor SBS2 outperformed the PBP benchmark in almost any category. The only exceptions are the Non-EU PBP of "Violation of employment laws and regulations" and "Association and bargaining rights".

Aligned with the conclusions of the previous assessment of T6.3, this result could be explained by the market prices. The higher output price of ARBOBLEND 2241 compared to the plastic materials used to create the PBP mix (which, for instance, in SBS1 was 15.57 USD only for the biopolymer compared with 2.92 USD for all the PBP raw materials) is a rough representation of the amount of time that the stakeholders need to be invested to produce a certain mass of this material. While the common petroleum-based plastic are produced in tonnes/day in a fully optimised industrial process, the new bioplastic are produced in modest scales with less automatization. In the economic dimensions this difference is represented as a higher market price but, in social LCA, it is linked to more worker hours per Kg of output.

In the case of the MM benchmarks, SBS1 and SBS2 obtained comparable or better results with them in the most concerning categories, i.e. "Fair salary"; "Freedom of association and collective bargain" and "Corruption". In the other categories the

results are less uniform, performing clearly better in “**Social benefits, legal issues**”, comparable in “**Discrimination**” or clearly worse in “**Health and safety (workers)**”. When compared between them, in all the examples SBS2 reduced the social impacts. Thus, it is concluded that the introduction of glass fibre in the demonstrators provides better results. Therefore, increasing the proportion of glass fibre in the final bioplastic blend is recommended providing it does not be detrimental to the functionality.

The sensitivity analysis of the benchmark provided clear results in the most concerning categories (previously listed), with the supply chains inside Europe outperforming the supply chains outside Europe (located in USA, China and Chile), especially in the MM. In other subcategories the results are less uniform, but in general the tendency is the same.

## 5. Conclusions

In the present deliverable 2.3, the energy and exergy analyses, as well as the life cycle analysis, were carried out. They were developed for the three different value chains developed in GREEN-LOOP project during the last three years (M1-M36) up to the end of development at TRL6, namely bio-rubber manufacturing (developed by NCC in WP3), bio-plastic manufacturing (developed by GUALA in WP4) and wood composites manufacturing (developed by FHF in WP5). The two tasks related these two kinds of analyses (T2.2 And T2.3) have been successfully conducted up to the goals of Wp6, which are in accordance with the upgrading of the manufacturing within the objectives pursued by GREEN-LOOP project

### 5.1. Energy and exergy analysis

As in D2.2, data collection has been carried out through the gathering of information provided by manufacturing partners by completing the questionnaires created to include the data of the processes. Alongside, the PFDs have been updated with feedback of WP leaders to complement the analysis of the three value chains (VCs). After the questionnaires are validated, they are circulated to seek the necessary information for the establishment of mass and energy balances. The processes are broken down into separate parts, and mass, energy, and exergy balances are calculated for each phase and the complete operations. Moreover,

First, the raw materials have been used to determine the mass flows throughout the whole process, which are required to determine the heat exchange within the steps involved and finally obtain the exergy balance, i. e., the irreversibilities present in the manufacture. In addition, the electrical demand has been divided into the machinery that operates during the performance of the processes, and the

consumption of this machinery is also classified by heating demand, cooling systems and mechanical consumption; with this regard, partners are required to provide details pertaining to the power consumption and duration of operation for each equipment utilised in the manufacturing process. The analysis of energy involves identifying and calculating the different energy consumptions that occur at various stages of the processes and conduct to the exergy analysis.

The following conclusions can be obtained from the energy and exergy analyses developed in this deliverable:

- **Bio-rubber manufacture (WP3):** in contrary to TRL5, the process has been split into two main sub-processes, first the extraction of lignin and secondly the production of the rubber panels. Since the quantity of raw materials has been increased in the rubber panels production (lignin, devulcanized rubber and natural rubber), the lignin extraction also requires a major inlet of raw materials; since the hemicellulose biomass is the same as in previous state, this sub-process must be carried out 26 times to give the lignin powder needed at the inlet of the production of bio-rubber products. Consequently, the energy consumption has also been increased at TRL6, although the mass-energy ratio remains approximately the same, which shows that the industry equipment can afford a bigger amount of materials with a similar efficiency of production.

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Regarding the destruction of energy, the pulping is expected to be the component with the major consumption in bio-rubber manufacture since its operation includes a reactor (which requires large amounts of energy), but due to the lack of mechanical consumption data the comparison to TRL5 is excluded. On the contrary, the compression moulding represents a significant fraction of energy consumption, leading to the destruction of a high amount of energy due to the requirements of heating demand and mechanical energy.

- **Bio-plastic manufacture (WP4):** the data at TRL6 allows for a better understanding of the process that at TRL5. The selected formulation for official testing is PHBH modified MFI formula, which has been treated in two separate processes, giving two kinds of products, limoncello caps and olive oil caps. In both processes the main consumptions come from the extruder and the injection moulding; from these two components, the moulder considered depends on the manufacture process: "Baby Pressa" in limoncello process, and JSW55 moulder in olive oil process.

Although the amount of raw materials used within the process are larger than the ones used at TRL5, the energy efficiency of industrial equipment

gives a minor necessity of electrical consumption and, therefore, a better mass-energy ratio than in previous TRLs. In quality of energy terms, the energy losses have been reduced in extruder and injection moulding, which represent the most significant fractions of irreversibility in the limoncello and olive oil manufacturing processes, respectively.

- **Wood composites (WP5):** recycled materials have been introduced as components of compound mixture within the process, so the energy consumption has increased during compression moulding at TRL6 as it requires more energy per mass unit to press the species. Therefore, the mass treated per unit of consumed energy to generate the plates of wood composite is slightly higher compared to TRL5. Furthermore, since the compression moulding presents the highest mechanical consumption as well as heating and cooling demand, it represents most of the irreversibilities involved in the process.

The development of the three VCs (bio-rubber, bio-plastic and wood composites) that are considered under the assessments of GREEN LOOP project have been analysed during upscaling up to TRL6, to determine the scope of the modifications in the reduction of material waste and the quantity and quality of the energy consumed during the processes. The analysis of mass and energy consumption have allowed for a conclusion about the state of the project at TRL6, which is in alignment with WP6 development during the end of the project, i. e., as the update of PFDs and the gathering of related data as their use to properly analyse the manufactures of the different value chains and draw conclusions about their performance at industrial levels.

From the analysis of the manufacturing processes, the bio-plastic has shown significant improvement over the last year of the GREEN-LOOP project, leading to both a substantial increase in bio-plastic cap production and the introduction of two types of products with distinct properties (limoncello and olive oil). Moreover, the electrical energy consumption and irreversibilities have been reduced at TRL6, which, alongside the increase in materials, yields the highest mass-energy ratio of the three VCs and, consequently, better performance of the manufacturing processes analysed at TRL6.

Nevertheless, wood composites manufacture also includes the introduction of recycled glass as the reutilisation of a fraction of the mixture in consecutive batches, staying in alignment with the assessments of the circular economy established under the scope of GREEN-LOOP.

The bio-rubber performance requires more energy consumption through the whole process since it includes more raw materials in the inlet, giving a mass-energy ratio similar that the one obtained in D2.2.

Table 51. Main results of upscaling up to TRL6 in VCs

| Value chain                                       |                 | Bio-Rubber | Bio-Plastic     |                | Wood Composites |
|---------------------------------------------------|-----------------|------------|-----------------|----------------|-----------------|
|                                                   |                 |            | Limoncello caps | Olive oil caps |                 |
| Material wastes / Mass of inlet mixture (%)       | TRL5            | 97.422     | -               |                | -               |
|                                                   | TRL6            | 96.432     | -               | -              | -               |
|                                                   | Improvement (%) | 1.016      | -               | -              | -               |
| Energy consumption / Mass of final product (J/mg) | TRL5            | 249.118    | 457.457         |                | 26.853          |
|                                                   | TRL6            | 2631.579   | 4.167           | 14.793         | 149.925         |
|                                                   | Improvement (%) | < -100     | 99.089          | 96.766         | < -100          |
| Energy destroyed / Mass of final product (J/g)    | TRL5            | 196.832    | 34840.232       |                | 17.960          |
|                                                   | TRL6            | 85.431     | 23.220          | 72.072         | 98.529          |
|                                                   | Improvement (%) | 56.597     | 99.933          | 99.793         | < -100          |

## 5.2. LCA, LCC and s-LCA analysis

This study, performed following the initial objectives of T2.3, have analysed the environmental, economic and social performance of new bio-based alternative materials, comparing them with their conventional, fossil- or mineral-based equivalents using a comprehensive life cycle sustainability assessment (LCSA).

For the environmental dimension, a Life Cycle Assessment (LCA) was conducted using the Ecoinvent database and an attribution system, and the results were evaluated using the Environmental Footprint 3.1 (EF 3.1) impact method. This was done following the European Commission's recommendations for multi-criteria comparative analyses. Besides, a comparison between two different databases (Ecoinvent and LCA FE) were carried out for the weakest data-availability value chain: the wood composite sliding bearings (T6.4). The economic dimension was assessed using a Life Cycle Costing (LCC) analysis based on primary economic and market data provided by technical partners.

Finally, the social dimension was assessed using a Life Cycle Assessment (sLCA) with the PSILCA database with a quantitative focus on social risks per unit of added value. In addition to the technical tasks carried out in the first work packages (WPs 3, 4 and 5), and the scaling activities (T6.2, T6.3 and T6.4), it is important to highlight the relevance of other project tasks that have provided essential support for the progress outlined in this document. Notably, the work in T2.1 has facilitated the introduction and organisation of the project's core inputs, particularly in the analysis of value chains, offering a robust contextual framework for subsequent

technical development. Similarly, the data collected, and energy analyses conducted in T2.2 have been instrumental in informing decisions in later project phases, improving our understanding of the impact and viability of the proposed solutions.

Furthermore, active collaboration has taken place within the framework of T2.4, with the aim of demonstrating the standardisation of bio-based materials. This collaborative effort has been instrumental in ensuring that developments are consistent with and aligned to technical and regulatory standards, paving the way for their future integration into industrial applications and promoting the replicability of the results obtained.

In order to improve the robustness of the comparison, social scenarios inside and outside Europe were modelled for the benchmarks. In all the cases, the GREEN-LOOP value chains were compared to state-of-art benchmarks to provide results contextualized with the current market alternatives. The conclusions, divided into the different VC, were reported below.

- **Bio-plastic manufacture (WP3):** In the bio rubber VC (T6.2), most of the environmental, economic and social impacts are derived from the use of lignin as it can be seen in the comparison between BRP1 (the bio-rubber panel with lignin) and BRP2 (without lignin).

Regarding BRP1, the E-LCA provided the highest impacts in the categories ‘*Resource use, Fossils*’ (21.5%) and ‘*Climate Change*’ (21%). In the case of the LCC, 33% of the cost are provided by the raw materials, while other significant 24.8% are related to the energy consumption. Finally, the sLCA shows that the BRP2 scenario, reducing the lignin content in bio-rubber panels, has a significant positive impact on social issues, with the lignin recovery process identified as a critical area for improvement, particularly concerning in the categories “fair salary”, “occupational health and safety”, “corruption”, and “freedom of association and collective bargain”. The main contributors to these impacts are the electricity sector in Slovenia and the chemical industry in the United States.

Thus, it could be concluded that the lignin extraction process is a hotspot within this VC that could be improved either by optimizing the energy consumption of the process or by reducing the content of lignin in the final demonstrator.

- **Bio-plastic manufacture (WP4):** In the case of the bioplastic closures VC (T6.3), it is not a clear improvement in the GREEN-LOOP scenarios compared to the benchmarks. This result could be attributable to the possible origin of

the new materials and the scaling up of the industrial processing of bio-based materials, demonstrating that a material of renewable origin does not necessarily imply a lower total environmental burden.

However, when compared between them, the Limoncello closures outperformed the olive oil closures since less steps are required to prepare them, leading to an overall minor energy consumption. In the E-LCA, the “*Climate change*” category account for a 32-33% of the total impacts, followed by “*Resource use, Fossil*” with a 26% for the limoncello closures (Limoncello BB) and a 29% for the Olive oil closures (Olive Oil BB).

In the LCC, the results showed that bio-based materials currently incur higher total costs compared to the conventional petroleum-based alternatives. The situation is mainly driven by their limited inclusion in the industrial market due to less optimised industrial processes and low commercial production scale, all of which limit their competitiveness compared to well-established fossil and mineral alternatives.

In the s-LCA the conclusions are similar to other two dimensions, with the limoncello and the olive oil bioplastic closures not outperforming conventional materials due to the less optimised industrial processes.

- **Wood composites manufacture (WP5):** In the sliding bearings VC (T6.4), the GREEN-LOOP scenarios reduced the overall impacts compared to the metallic benchmarks in two of the three dimensions, with especially promising results in the environmental dimension. However, compared with the petroleum-based-polymer (PBP) benchmark, the GREEN-LOOP scenarios only obtained better results in the environmental dimension. Besides, the inclusion of glass fibre in the composite formulation (that improves the performance of the materials) does not increase the overall impacts.

The sensibility assessment carried out within this value chain using two different E-LCA databases (Ecoinvent and LCA FE) concluded that the assumptions made to complete the environmental assessment are consistent and reliable.

In the E-LCA for SBS2 (the wood composite with glass fibre) reduced the impacts in 15 out of the 16 categories compared to the benchmarks. Concretely, in the Ecoinvent database, the worst values were obtained in the categories “*Climate change*” (27,2%) and “*Resource use, fossils*” (20,2%), and “*Eutrophication, freshwater*” (19,7%), with electricity as the main contributor in all of them.

In the case of the LCC, the GREEN LOOP scenarios performed worse than the benchmark mainly because of the higher raw material price compared to the metallic and PBP benchmarks (11,64€ in SBS2 compared to 3,56€ in the metallic benchmark and 2,66€ in the PBP benchmark). This result supports the conclusions given in the Bioplastic manufacture VC (T6.3).

In the S-LCA, the use of wood composites has shown promising social results compared with the metallic benchmark but does not outperform the PBP benchmark. Additionally, the increase of glass fibre content in the formulation have proven to reduce the social impacts. Based on the environmental results, the electricity consumption could be considered a hotspot within this value, that must be tackled with energy efficiency measures.

Overall, although the E-LCA results indicate that two (VC1 and VC3) of the three analysed value chains show lower overall environmental impacts in most categories assessed by the EF 3.0 method. On the other VC2, it is notable that high contributions to impacts are mainly attributable to immaturity of the industrial processes to prepare bio-based materials. As it was previously mentioned, these results demonstrate that a material's renewable origin does not necessarily imply a lower total environmental burden.

From an economic perspective, and in line with environmental results, the LCC results show that bio-based materials increase the raw material costs in two of the three value chains. This increase is primarily due to their limited competitiveness compared to fossil and mineral alternatives. Therefore, only one of the value chains shows lower costs, thanks to the use of secondary raw materials and the avoidance of immature, over-scaled transformation technologies.

### 5.3. Recommendations for future upscaling of the technologies

The upgrades for future upscaling of the three VC manufactures are discussed, paying attention to the drop in quality of results compared to D2.2. In this statement, the improvements in the analysis of energy are represented with positive values in Error! Reference source not found.. In contrast, the values that are improvable regarding the mechanisms of the processes at TRL5 are represented by negative ratios:

- **Bio-rubber manufacture (WP3):** the materials wasted per inlet during the process are approximately the same, highlighting the acid liquors, which are the main flow of wastes. Furthermore, the amount of energy consumed per

unit of final product has increased compared to TRL5; in contrary, the quality of energy per unit of final product has improved by 56.60 %. Therefore, the efficiency of the machinery has better performance than at previous TRLs, but a decrease of the energy required for the operation of the equipment would lead to both a better relation between the product and the energy consumption and an improved use of the available energy.

- **Bio-plastic manufacture (WP4):** no wastes are considered in the analysis since the vacuum gases are excluded of the inlet rice husk's mass flow; for this reason, no wates are present neither in the current study nor in the results of D2.2. Regarding the energy and exergy analysis, both has improvements over 90 % meaning that the production of bio-plastic caps requires less energy than at TRL5, and this energy is optimally utilized. To summarize up, the development of equipment up to industrial levels has completely achieved the assessments of the project up to TRL6.
- **Wood composites (WP6):** no wastes are considered in the PFD of this VC, so no values are available for the analysis of wasting materials per inlet batch. Nevertheless, both the energy consumption and the energy destruction present increased values per unit of final product than in the analysis of the previous state of the project. This result shows that the performance of equipment should be improved in more advanced states to reduce the operation energy requirements, which would also decrease the irreversibilities; moreover, instead of the reutilization of 1/6 of the formulations in the next batch, the compression moulding could be developed to effectively use this quantity to produce the final plates, allowing for a greater saving of energy consumption. However, the exploitation of these losses represents the circular economy promoted by GREEN-LOOP project, which must be taken into account in future upscaling of the manufacture.

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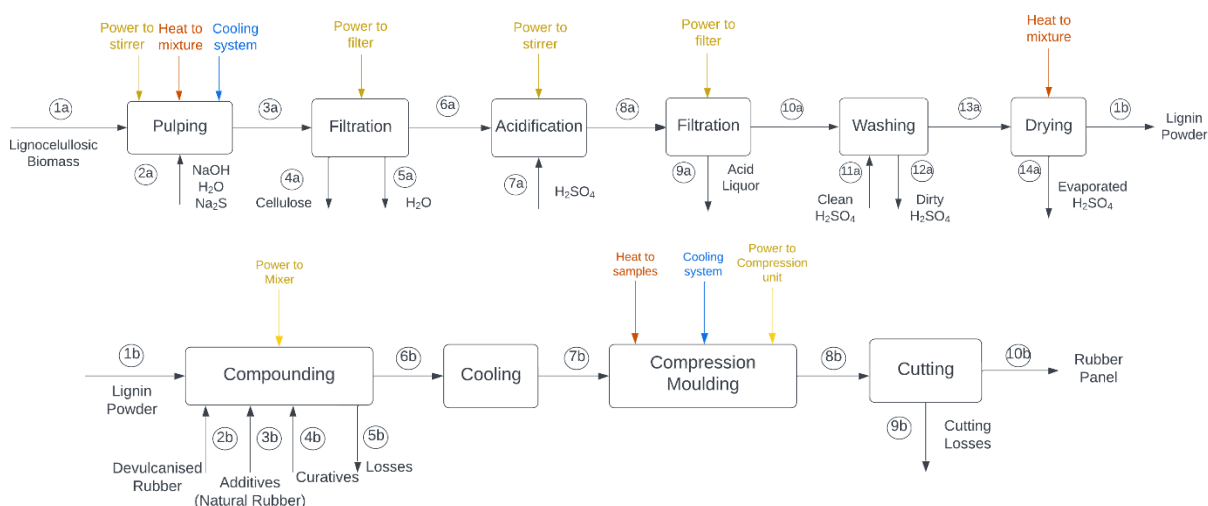
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## Annex 1: Process datasheets for mass, energy and exergy balance

| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-rubber  | WP3 | T6.2 | NCC       | UBRIS, NIC and ZAG  |

### PFDs:



### Process description:

Two sub-processes are considered separately in the bio-rubber manufacture: i) the lignin extraction, which consists of the production of lignin powder with the separation of lignocellulosic biomass into cellulose, hemicellulose and lignin, and the treatment of products throughout acidification and washing using  $H_2SO_4$ ; and ii) the production of rubber panel, in this process several species are mixed in compounding, including curatives (ZnO, stearic acid, MBTS-75 and sulphur) to the main components of the process (lignin powder, devulcanized rubber and natural rubber). During the final process the solutions are compressed and cut to produce panels of cured rubber.

|      |      | idener.ai                      |                                                                                                         | PROYECT | GREEN-LOOP                                 |                   |               | Mass and Energy |           |                  |    |
|------|------|--------------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------|-------------------|---------------|-----------------|-----------|------------------|----|
|      |      |                                |                                                                                                         | Process | Bio-rubber manufacture (lignin extraction) |                   |               | Page            | 1         | of               | 10 |
| Item | Rev. | MASS AND ENERGY BALANCES       |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 1    |      | Operational data and flows     |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 2    |      | Design case                    |                                                                                                         |         |                                            | Basic engineering |               |                 |           |                  |    |
| 3    |      | Stream n°                      |                                                                                                         |         |                                            | 1a                | 2a            | 3a              | 4a        | 5a               |    |
| 4    |      | Description                    |                                                                                                         |         |                                            | Lignocellulose    | Inlet mixture | Outlet mixture  | Cellulose | H <sub>2</sub> O |    |
| 5    |      |                                |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 6    |      | Pressure                       | bar                                                                                                     |         |                                            | 1.000             | 1.000         | 1.000           | 1.000     | 1.000            |    |
| 7    |      | Temperature                    | °C                                                                                                      |         |                                            | 25.000            | 25.000        | 175.000         | 25.000    | 25.000           |    |
| 8    |      | Mass flow                      | g                                                                                                       |         |                                            | 103.910           | 718.480       | 822.390         | 134.460   | 358.37           |    |
| 9    |      | % Vapor                        | -                                                                                                       |         |                                            | 0.000             | 0.000         | 0.000           | 0.000     | 0.000            |    |
| 10   |      | Total vapor mass flow          | g                                                                                                       |         |                                            | 0.000             | 0.000         | 0.000           | 0.000     | 0.000            |    |
| 11   |      | Non condensable (N2,...)       | g                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 12   |      | Water steam                    | g                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 13   |      | Hydrocarbons                   | g                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 14   |      | Total liquid mass flow         | g                                                                                                       |         |                                            | 0.000             | 718.480       | 718.48          | 11.70     | 358.37           |    |
| 15   |      | Free water                     | g                                                                                                       |         |                                            | 0.000             | 687.93        | 687.930         | 11.70     | 358.37           |    |
| 16   |      | Hydrocarbons                   | g                                                                                                       |         |                                            | 0.000             | Unknown       | 63.920          | 0.000     | 0.000            |    |
| 17   |      | Total enthalpy flow            | J                                                                                                       |         |                                            | Unknown           | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 18   |      | Corrosive and toxic compounds  | %w                                                                                                      |         |                                            | 0.000             | 3.560         | 3.560           | 0.000     | 0.000            |    |
| 19   |      | Solids present                 | %                                                                                                       |         |                                            | 100.000           | 16.200        | 9.320           | 80.000    | 0.000            |    |
| 20   |      | Solids particle size           | Microns                                                                                                 |         |                                            | 700.000           | 700.000       | Unknown         | Unknown   | -                |    |
| 21   |      | (Wet) Steam phase properties   |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 22   |      | Volumetric flow @P,T           | dm <sup>3</sup>                                                                                         |         |                                            | -                 | -             | -               | -         | -                |    |
| 23   |      | Volumetric flow @(1 atm, 0°C)  | dm <sup>3</sup>                                                                                         |         |                                            | -                 | -             | -               | -         | -                |    |
| 24   |      | Molecular weight               | g/mol                                                                                                   |         |                                            | -                 | -             | -               | -         | -                |    |
| 25   |      | Density @T                     | g/dm <sup>3</sup>                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 26   |      | Density @(1 atm, 0°C)          | g/dm <sup>3</sup>                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 27   |      | Viscosity @T                   | cP                                                                                                      |         |                                            | -                 | -             | -               | -         | -                |    |
| 28   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         |                                            | -                 | -             | -               | -         | -                |    |
| 29   |      | Specific Heat @T               | J/(g·K)                                                                                                 |         |                                            | -                 | -             | -               | -         | -                |    |
| 30   |      | Compressibility factor @P,T    | -                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 31   |      | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 32   |      | Enthalpy flow                  | J                                                                                                       |         |                                            | -                 | -             | -               | -         | -                |    |
| 33   |      | Liquid phase properties        |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 34   |      | Volumetric flow @P,T           | dm <sup>3</sup>                                                                                         |         |                                            | -                 | 0.688         | 0.703           | 0.0269    | 0.358            |    |
| 35   |      | Volumetric flow @15°C          | dm <sup>3</sup>                                                                                         |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 36   |      | Density @T                     | g/dm <sup>3</sup>                                                                                       |         |                                            | -                 | 1040.000      | 1.020.000       | 1000.000  | 1000.000         |    |
| 37   |      | Density @15°C                  | g/dm <sup>3</sup>                                                                                       |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 38   |      | Kinematic viscosity @T         | cSt                                                                                                     |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 39   |      | Kinematic viscosity @50°C      | cSt                                                                                                     |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 40   |      | Kinematic viscosity @100°C     | cSt                                                                                                     |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 41   |      | Kinematic viscosity @150°C     | cSt                                                                                                     |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 42   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 43   |      | Specific Heat @T               | J/(g·K)                                                                                                 |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 44   |      | Surface tension @P,T           | dinas/cm                                                                                                |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 45   |      | Vapor pressure                 | kg/cm <sup>2</sup> a                                                                                    |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 46   |      | Enthalpy flow                  | J                                                                                                       |         |                                            | -                 | Unknown       | Unknown         | Unknown   | Unknown          |    |
| 47   |      | Miscellaneous                  |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 48   |      |                                |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 49   |      | Notes                          |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 50   |      | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                            |                   |               |                 |           |                  |    |
| 51   |      | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                            |                   |               |                 |           |                  |    |
| 52   |      | 3                              | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction           |         |                                            |                   |               |                 |           |                  |    |
| 53   |      | 4                              |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| 54   |      | 5                              |                                                                                                         |         |                                            |                   |               |                 |           |                  |    |
| Rev. |      | by                             | 1.0                                                                                                     | SDFG    |                                            |                   |               |                 |           |                  |    |
| Date |      | Approved                       | 29-08-25                                                                                                | PRG     |                                            |                   |               |                 |           |                  |    |

|                            |      | idener.ai                             |                                                                                                         | PROYECT | GREEN-LOOP                                 | Mass and Energy   |                                    |          |             |        |    |    |
|----------------------------|------|---------------------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------|-------------------|------------------------------------|----------|-------------|--------|----|----|
|                            |      |                                       |                                                                                                         | Process | Bio-rubber manufacture (lignin extraction) |                   |                                    |          | Page        | 2      | of | 10 |
| Item                       | Rev. | MASS AND ENERGY BALANCES              |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| Operational data and flows |      |                                       |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 1                          |      |                                       |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 2                          |      | Design case                           |                                                                                                         |         |                                            | Basic engineering |                                    |          |             |        |    |    |
| 3                          |      | Stream n°                             |                                                                                                         |         |                                            | 6a                | 7a                                 | 8a       | 9a          | 10a    |    |    |
| 4                          |      | Description                           |                                                                                                         |         |                                            | Compound          | H <sub>2</sub> SO <sub>4</sub> 15% | Compound | Acid liquor | Lignin |    |    |
| 5                          |      |                                       |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 6                          |      | Pressure                              | bar                                                                                                     |         | 1.000                                      | 1.000             | 1.000                              | 1.000    | 1.000       |        |    |    |
| 7                          |      | Temperature                           | °C                                                                                                      |         | 25.000                                     | 25.000            | 25.000                             | 25.000   | 25.000      |        |    |    |
| 8                          |      | Mass flow                             | g                                                                                                       |         | 329.560                                    | 112.300           | 441.860                            | 408.510  | 33.350      |        |    |    |
| 9                          |      | % Vapor                               | -                                                                                                       |         | 0.000                                      | 0.000             | 0.000                              | 0.000    | 0.000       |        |    |    |
| 10                         |      | Total vapor mass flow                 | g                                                                                                       |         | 0.000                                      | 0.000             | 0.000                              | 0.000    | 0.000       |        |    |    |
| 11                         |      | Non condensable (N <sub>2</sub> ,...) | g                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 12                         |      | Water steam                           | g                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 13                         |      | Hydrocarbons                          | g                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 14                         |      | Total liquid mass flow                | g                                                                                                       |         | 296.000                                    | 112.300           | 408.510                            | 408.510  | 6.670       |        |    |    |
| 15                         |      | Free water                            | g                                                                                                       |         | 156.940                                    | 94.750            | 362.960                            | 335.337  | 6.670       |        |    |    |
| 16                         |      | Hydrocarbons                          | g                                                                                                       |         | 52.700                                     | 0.000             | 30.570                             | 28.243   | 0.000       |        |    |    |
| 17                         |      | Total enthalpy flow                   | J                                                                                                       |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 18                         |      | Corrosive and toxic compounds         | %w                                                                                                      |         | 9.270                                      | 15.000            | 10.310                             | 11.150   | 0.000       |        |    |    |
| 19                         |      | Solids present                        | %                                                                                                       |         | 33.350                                     | 0.000             | 33.350                             | 7.61     | 80.000      |        |    |    |
| 20                         |      | Solids particle size                  | Microns                                                                                                 |         | Unknown                                    | -                 | Unknown                            | Unknown  | Unknown     |        |    |    |
| 21                         |      | (Wet) Steam phase properties          |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 22                         |      | Volumetric flow @P,T                  | dm <sup>3</sup>                                                                                         |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 23                         |      | Volumetric flow @(1 atm, 0°C)         | dm <sup>3</sup>                                                                                         |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 24                         |      | Molecular weight                      | g/mol                                                                                                   |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 25                         |      | Density @T                            | g/dm <sup>3</sup>                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 26                         |      | Density @(1 atm, 0°C)                 | g/dm <sup>3</sup>                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 27                         |      | Viscosity @T                          | cP                                                                                                      |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 28                         |      | Thermal conductivity @T               | J/(s·m·K)                                                                                               |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 29                         |      | Specific Heat @T                      | J/(g·K)                                                                                                 |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 30                         |      | Compressibility factor @P,T           | -                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 31                         |      | C <sub>p</sub> /C <sub>v</sub>        | -                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 32                         |      | Enthalpy flow                         | J                                                                                                       |         | -                                          | -                 | -                                  | -        | -           |        |    |    |
| 33                         |      | Liquid phase properties               |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 34                         |      | Volumetric flow @P,T                  | dm <sup>3</sup>                                                                                         |         | 0.158                                      | 0.0999            | 0.390                              | 0.344    | 0.0067      |        |    |    |
| 35                         |      | Volumetric flow @15°C                 | dm <sup>3</sup>                                                                                         |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 36                         |      | Density @T                            | g/dm <sup>3</sup>                                                                                       |         | 1390.000                                   | 1120.000          | 1050.000                           | 1100.000 | 1000.000    |        |    |    |
| 37                         |      | Density @15°C                         | g/dm <sup>3</sup>                                                                                       |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 38                         |      | Kinematic viscosity @T                | cSt                                                                                                     |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 39                         |      | Kinematic viscosity @50°C             | cSt                                                                                                     |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 40                         |      | Kinematic viscosity @100°C            | cSt                                                                                                     |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 41                         |      | Kinematic viscosity @150°C            | cSt                                                                                                     |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 42                         |      | Thermal conductivity @T               | J/(s·m·K)                                                                                               |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 43                         |      | Specific Heat @T                      | J/(g·K)                                                                                                 |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 44                         |      | Surface tension @P,T                  | dinas/cm                                                                                                |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 45                         |      | Vapor pressure                        | kg/cm <sup>2</sup> a                                                                                    |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 46                         |      | Enthalpy flow                         | J                                                                                                       |         | Unknown                                    | Unknown           | Unknown                            | Unknown  | Unknown     |        |    |    |
| 47                         |      | Miscellaneous                         |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 48                         |      |                                       |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 49                         |      | Notes                                 |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 50                         |      | 1                                     | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                            |                   |                                    |          |             |        |    |    |
| 51                         |      | 2                                     | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                            |                   |                                    |          |             |        |    |    |
| 52                         |      | 3                                     | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction           |         |                                            |                   |                                    |          |             |        |    |    |
| 53                         |      | 4                                     |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| 54                         |      | 5                                     |                                                                                                         |         |                                            |                   |                                    |          |             |        |    |    |
| Rev.                       |      | by                                    | 1.0                                                                                                     | SDFG    |                                            |                   |                                    |          |             |        |    |    |
| Date                       |      | Approved                              | 29-08-25                                                                                                | PRG     |                                            |                   |                                    |          |             |        |    |    |

|      |      | idener.ai                      |                                                                                                         | PROYECT  | GREEN-LOOP                                 | Mass and Energy                         |               |                                               |               |    |    |
|------|------|--------------------------------|---------------------------------------------------------------------------------------------------------|----------|--------------------------------------------|-----------------------------------------|---------------|-----------------------------------------------|---------------|----|----|
|      |      |                                |                                                                                                         | Process  | Bio-rubber manufacture (lignin extraction) |                                         |               | Page                                          | 3             | of | 10 |
| Item | Rev. | MASS AND ENERGY BALANCES       |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 1    |      | Operational data and flows     |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 2    |      | Design case                    |                                                                                                         |          | Basic engineering                          |                                         |               |                                               |               |    |    |
| 3    |      | Stream n°                      |                                                                                                         |          | 11a                                        | 12a                                     | 13a           | 14a                                           | 1b            |    |    |
| 4    |      | Description                    |                                                                                                         |          | Clean H <sub>2</sub> SO <sub>4</sub> 5%    | Dirty H <sub>2</sub> SO <sub>4</sub> 5% | Washed lignin | Evaporated H <sub>2</sub> SO <sub>4</sub> 15% | Lignin powder |    |    |
| 5    |      |                                |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 6    |      | Pressure                       | bar                                                                                                     | 1.000    | 1.000                                      | 1.000                                   | 1.000         | 1.000                                         |               |    |    |
| 7    |      | Temperature                    | °C                                                                                                      | 25.000   | 25.000                                     | 25.000                                  | 40.000        | 25.000                                        |               |    |    |
| 8    |      | Mass flow                      | g                                                                                                       | 218.190  | 187.000                                    | 64.540                                  | 39.540        | 25.000                                        |               |    |    |
| 9    |      | % Vapor                        | -                                                                                                       | 0.000    | 0.000                                      | 0.000                                   | 100.000       | 0.000                                         |               |    |    |
| 10   |      | Total vapor mass flow          | g                                                                                                       | 0.000    | 0.000                                      | 0.000                                   | 39.540        | 0.000                                         |               |    |    |
| 11   |      | Non condensable (N2,...)       | g                                                                                                       | -        | -                                          | -                                       | 0.000         | -                                             |               |    |    |
| 12   |      | Water steam                    | g                                                                                                       | -        | -                                          | -                                       | 37.500        | -                                             |               |    |    |
| 13   |      | Hydrocarbons                   | g                                                                                                       | -        | -                                          | -                                       | 0.000         | -                                             |               |    |    |
| 14   |      | Total liquid mass flow         | g                                                                                                       | 218.190  | 187.000                                    | 39.500                                  | 0.000         | 0.000                                         |               |    |    |
| 15   |      | Free water                     | g                                                                                                       | 206.820  | 177.260                                    | 37.500                                  | -             | -                                             |               |    |    |
| 16   |      | Hydrocarbons                   | g                                                                                                       | 0.000    | 0.000                                      | 0.000                                   | -             | -                                             |               |    |    |
| 17   |      | Total enthalpy flow            | J                                                                                                       | Unknown  | Unknown                                    | Unknown                                 | Unknown       | Unknown                                       |               |    |    |
| 18   |      | Corrosive and toxic compounds  | %w                                                                                                      | 5.210    | 5.200                                      | 2.000                                   | 1.250         | 0.000                                         |               |    |    |
| 19   |      | Solids present                 | %                                                                                                       | 0.000    | 0.000                                      | 80.000                                  | 0.000         | 100.000                                       |               |    |    |
| 20   |      | Solids particle size           | Microns                                                                                                 | -        | -                                          | Unknown                                 | -             | Unknown                                       |               |    |    |
| 21   |      | (Wet) Steam phase properties   |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 22   |      | Volumetric flow @P,T           | dm <sup>3</sup>                                                                                         | -        | -                                          | -                                       | 0.0380        | -                                             |               |    |    |
| 23   |      | Volumetric flow @(1 atm, 0°C)  | dm <sup>3</sup>                                                                                         | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 24   |      | Molecular weight               | g/mol                                                                                                   | -        | -                                          | -                                       | 22.000        | -                                             |               |    |    |
| 25   |      | Density @T                     | g/dm <sup>3</sup>                                                                                       | -        | -                                          | -                                       | 1040.000      | -                                             |               |    |    |
| 26   |      | Density @(1 atm, 0°C)          | g/dm <sup>3</sup>                                                                                       | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 27   |      | Viscosity @T                   | cP                                                                                                      | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 28   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 29   |      | Specific Heat @T               | J/(g·K)                                                                                                 | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 30   |      | Compressibility factor @P,T    | -                                                                                                       | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 31   |      | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 32   |      | Enthalpy flow                  | J                                                                                                       | -        | -                                          | -                                       | Unknown       | -                                             |               |    |    |
| 33   |      | Liquid phase properties        |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 34   |      | Volumetric flow @P,T           | dm <sup>3</sup>                                                                                         | 0.209    | 0.180                                      | 0.0380                                  | -             | -                                             |               |    |    |
| 35   |      | Volumetric flow @15°C          | dm <sup>3</sup>                                                                                         | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 36   |      | Density @T                     | g/dm <sup>3</sup>                                                                                       | 1040.000 | 1.040.000                                  | 1.040.000                               | -             | -                                             |               |    |    |
| 37   |      | Density @15°C                  | g/dm <sup>3</sup>                                                                                       | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 38   |      | Kinematic viscosity @T         | cSt                                                                                                     | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 39   |      | Kinematic viscosity @50°C      | cSt                                                                                                     | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 40   |      | Kinematic viscosity @100°C     | cSt                                                                                                     | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 41   |      | Kinematic viscosity @150°C     | cSt                                                                                                     | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 42   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 43   |      | Specific Heat @T               | J/(g·K)                                                                                                 | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 44   |      | Surface tension @P,T           | dinas/cm                                                                                                | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 45   |      | Vapor pressure                 | kg/cm <sup>2</sup> a                                                                                    | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 46   |      | Enthalpy flow                  | J                                                                                                       | Unknown  | Unknown                                    | Unknown                                 | -             | -                                             |               |    |    |
| 47   |      | Miscellaneous                  |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 48   |      |                                |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 49   |      | Notes                          |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 50   |      | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |          |                                            |                                         |               |                                               |               |    |    |
| 51   |      | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |          |                                            |                                         |               |                                               |               |    |    |
| 52   |      | 3                              | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction           |          |                                            |                                         |               |                                               |               |    |    |
| 53   |      | 4                              |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| 54   |      | 5                              |                                                                                                         |          |                                            |                                         |               |                                               |               |    |    |
| Rev. |      | by                             | 1.0                                                                                                     | SDFG     |                                            |                                         |               |                                               |               |    |    |
| Date |      | Approved                       | 29-08-25                                                                                                | PRG      |                                            |                                         |               |                                               |               |    |    |

|             |             | idener.ai                           |                                                                                                         | PROYECT | GREEN-LOOP                      |                   |    | Mass and Energy |    |    |    |  |
|-------------|-------------|-------------------------------------|---------------------------------------------------------------------------------------------------------|---------|---------------------------------|-------------------|----|-----------------|----|----|----|--|
|             |             |                                     |                                                                                                         | Process | Bio-rubber manufacture (rubber) |                   |    | Page            | 4  | of | 16 |  |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>     |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 1           |             | <b>Operational data and flows</b>   |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 2           |             | Design case                         |                                                                                                         |         |                                 | Basic engineering |    |                 |    |    |    |  |
| 3           |             | Stream n°                           |                                                                                                         |         |                                 | 1b                | 2b | 3b              | 4b | 5b |    |  |
| 4           |             | Description                         |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 5           |             |                                     |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 6           |             | Pressure                            | bar                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 7           |             | Temperature                         | °C                                                                                                      |         |                                 |                   |    |                 |    |    |    |  |
| 8           |             | Mass flow                           | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 9           |             | % Vapor                             | -                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 10          |             | Total vapor mass flow               | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 11          |             | Non condensable (N2,...)            | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 12          |             | Water steam                         | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 13          |             | Hydrocarbons                        | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 14          |             | Total liquid mass flow              | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 15          |             | Free water                          | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 16          |             | Hydrocarbons                        | g                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 17          |             | Total enthalpy flow                 | J                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 18          |             | Corrosive and toxic compounds       | %w                                                                                                      |         |                                 |                   |    |                 |    |    |    |  |
| 19          |             | Solids present                      | %                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 20          |             | Solids particle size                | Microns                                                                                                 |         |                                 |                   |    |                 |    |    |    |  |
| 21          |             | <b>(Wet) Steam phase properties</b> |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 22          |             | Volumetric flow @P,T                | dm³                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 23          |             | Volumetric flow @(1 atm, 0°C)       | dm³                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 24          |             | Molecular weight                    | g/mol                                                                                                   |         |                                 |                   |    |                 |    |    |    |  |
| 25          |             | Density @T                          | g/dm³                                                                                                   |         |                                 |                   |    |                 |    |    |    |  |
| 26          |             | Density @(1 atm, 0°C)               | g/dm³                                                                                                   |         |                                 |                   |    |                 |    |    |    |  |
| 27          |             | Viscosity @T                        | cP                                                                                                      |         |                                 |                   |    |                 |    |    |    |  |
| 28          |             | Thermal conductivity @T             | J/(s·m·K)                                                                                               |         |                                 |                   |    |                 |    |    |    |  |
| 29          |             | Specific Heat @T                    | J/(g·K)                                                                                                 |         |                                 |                   |    |                 |    |    |    |  |
| 30          |             | Compressibility factor @P,T         | -                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 31          |             | C <sub>p</sub> /C <sub>v</sub>      | -                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 32          |             | Enthalpy flow                       | J                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 33          |             | <b>Liquid phase properties</b>      |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 34          |             | Volumetric flow @P,T                | dm³                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 35          |             | Volumetric flow @15°C               | dm³                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 36          |             | Density @T                          | g/dm³                                                                                                   |         |                                 |                   |    |                 |    |    |    |  |
| 37          |             | Density @15°C                       | g/dm³                                                                                                   |         |                                 |                   |    |                 |    |    |    |  |
| 38          |             | Kinematic viscosity @T              | cSt                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 39          |             | Kinematic viscosity @50°C           | cSt                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 40          |             | Kinematic viscosity @100°C          | cSt                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 41          |             | Kinematic viscosity @150°C          | cSt                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |
| 42          |             | Thermal conductivity @T             | J/(s·m·K)                                                                                               |         |                                 |                   |    |                 |    |    |    |  |
| 43          |             | Specific Heat @T                    | J/(g·K)                                                                                                 |         |                                 |                   |    |                 |    |    |    |  |
| 44          |             | Surface tension @P,T                | dinas/cm                                                                                                |         |                                 |                   |    |                 |    |    |    |  |
| 45          |             | Vapor pressure                      | kg/cm² a                                                                                                |         |                                 |                   |    |                 |    |    |    |  |
| 46          |             | Enthalpy flow                       | J                                                                                                       |         |                                 |                   |    |                 |    |    |    |  |
| 47          |             | <b>Miscellaneous</b>                |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 48          |             |                                     |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 49          |             | <b>Notes</b>                        |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| 50          |             | 1                                   | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                 |                   |    |                 |    |    |    |  |
| 51          |             | 2                                   | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                 |                   |    |                 |    |    |    |  |
| 52          |             | 3                                   | The bio-rubber chain involves three processes. This datasheet refers to the rubber functionalisation    |         |                                 |                   |    |                 |    |    |    |  |
| 53          |             | 4                                   | Functionalisation has been removed in upscaling, so this process is no longer considered                |         |                                 |                   |    |                 |    |    |    |  |
| 54          |             | 5                                   |                                                                                                         |         |                                 |                   |    |                 |    |    |    |  |
| Rev.        | by          | 1.0                                 | SDFG                                                                                                    |         |                                 |                   |    |                 |    |    |    |  |
| Date        | Approved    | 29-08-25                            | PRG                                                                                                     |         |                                 |                   |    |                 |    |    |    |  |

|             |             |                                                                                   |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
|-------------|-------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|---------------------------------|-------------------|--|-----------------|---|----|----|
|             |             |  |                                                                                                         | PROYECT | GREEN-LOOP                      |                   |  | Mass and Energy |   |    |    |
|             |             |                                                                                   |                                                                                                         | Process | Bio-rubber manufacture (rubber) |                   |  | Page            | 5 | of | 16 |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>                                                   |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 1           |             | <b>Operational data and flows</b>                                                 |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 2           |             | Design case                                                                       |                                                                                                         |         |                                 | Basic engineering |  |                 |   |    |    |
| 3           |             | Stream n°                                                                         |                                                                                                         |         |                                 | 2                 |  |                 |   |    |    |
| 4           |             | Description                                                                       |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 5           |             |                                                                                   |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 6           |             | Pressure                                                                          | bar                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 7           |             | Temperature                                                                       | °C                                                                                                      |         |                                 |                   |  |                 |   |    |    |
| 8           |             | Mass flow                                                                         | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 9           |             | % Vapor                                                                           | -                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 10          |             | Total vapor mass flow                                                             | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 11          |             | Non condensable (N2,...)                                                          | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 12          |             | Water steam                                                                       | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 13          |             | Hydrocarbons                                                                      | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 14          |             | Total liquid mass flow                                                            | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 15          |             | Free water                                                                        | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 16          |             | Hydrocarbons                                                                      | g                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 17          |             | Total enthalpy flow                                                               | J                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 18          |             | Corrosive and toxic compounds                                                     | %w                                                                                                      |         |                                 |                   |  |                 |   |    |    |
| 19          |             | Solids present                                                                    | %                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 20          |             | Solids particle size                                                              | Microns                                                                                                 |         |                                 |                   |  |                 |   |    |    |
| 21          |             | <b>(Wet) Steam phase properties</b>                                               |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 22          |             | Volumetric flow @P,T                                                              | dm³                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 23          |             | Volumetric flow @(1 atm, 0°C)                                                     | dm³                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 24          |             | Molecular weight                                                                  | g/mol                                                                                                   |         |                                 |                   |  |                 |   |    |    |
| 25          |             | Density @T                                                                        | g/dm³                                                                                                   |         |                                 |                   |  |                 |   |    |    |
| 26          |             | Density @(1 atm, 0°C)                                                             | g/dm³                                                                                                   |         |                                 |                   |  |                 |   |    |    |
| 27          |             | Viscosity @T                                                                      | cP                                                                                                      |         |                                 |                   |  |                 |   |    |    |
| 28          |             | Thermal conductivity @T                                                           | J/(s·m·K)                                                                                               |         |                                 |                   |  |                 |   |    |    |
| 29          |             | Specific Heat @T                                                                  | J/(g·K)                                                                                                 |         |                                 |                   |  |                 |   |    |    |
| 30          |             | Compressibility factor @P,T                                                       | -                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 31          |             | C <sub>p</sub> /C <sub>v</sub>                                                    | -                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 32          |             | Enthalpy flow                                                                     | J                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 33          |             | <b>Liquid phase properties</b>                                                    |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 34          |             | Volumetric flow @P,T                                                              | dm³                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 35          |             | Volumetric flow @15°C                                                             | dm³                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 36          |             | Density @T                                                                        | g/dm³                                                                                                   |         |                                 |                   |  |                 |   |    |    |
| 37          |             | Density @15°C                                                                     | g/dm³                                                                                                   |         |                                 |                   |  |                 |   |    |    |
| 38          |             | Kinematic viscosity @T                                                            | cSt                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 39          |             | Kinematic viscosity @50°C                                                         | cSt                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 40          |             | Kinematic viscosity @100°C                                                        | cSt                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 41          |             | Kinematic viscosity @150°C                                                        | cSt                                                                                                     |         |                                 |                   |  |                 |   |    |    |
| 42          |             | Thermal conductivity @T                                                           | J/(s·m·K)                                                                                               |         |                                 |                   |  |                 |   |    |    |
| 43          |             | Specific Heat @T                                                                  | J/(g·K)                                                                                                 |         |                                 |                   |  |                 |   |    |    |
| 44          |             | Surface tension @P,T                                                              | dinas/cm                                                                                                |         |                                 |                   |  |                 |   |    |    |
| 45          |             | Vapor pressure                                                                    | kg/cm² a                                                                                                |         |                                 |                   |  |                 |   |    |    |
| 46          |             | Enthalpy flow                                                                     | J                                                                                                       |         |                                 |                   |  |                 |   |    |    |
| 47          |             | <b>Miscellaneous</b>                                                              |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 48          |             |                                                                                   |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 49          |             | <b>Notes</b>                                                                      |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| 50          |             | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                 |                   |  |                 |   |    |    |
| 51          |             | 2                                                                                 | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                 |                   |  |                 |   |    |    |
| 52          |             | 3                                                                                 | The bio-rubber chain involves three processes. This datasheet refers to the rubber functionalisation    |         |                                 |                   |  |                 |   |    |    |
| 53          |             | 4                                                                                 | Functionalisation has been removed in upscaling, so this process is no longer considered                |         |                                 |                   |  |                 |   |    |    |
| 54          |             | 5                                                                                 |                                                                                                         |         |                                 |                   |  |                 |   |    |    |
| Rev.        | by          | 1.0                                                                               | SDFG                                                                                                    |         |                                 |                   |  |                 |   |    |    |
| Date        | Approved    | 29-08-25                                                                          | PRG                                                                                                     |         |                                 |                   |  |                 |   |    |    |

|      |      | idener.ai                      |                                                                                                         | PROYECT | GREEN-LOOP                                       | Mass and Energy     |                               |           |          |   |    |    |
|------|------|--------------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------------|---------------------|-------------------------------|-----------|----------|---|----|----|
|      |      |                                |                                                                                                         | Process | Bio-rubber manufacture (rubber panel production) |                     |                               |           | Page     | 4 | of | 10 |
| Item | Rev. | MASS AND ENERGY BALANCES       |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 1    |      | Operational data and flows     |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 2    |      | Design case                    |                                                                                                         |         | Basic engineering                                |                     |                               |           |          |   |    |    |
| 3    |      | Stream n°                      |                                                                                                         |         | 1b                                               | 2b                  | 3b                            | 4b        | 5b       |   |    |    |
| 4    |      | Description                    |                                                                                                         |         | Lignin powder                                    | Devulcanized rubber | Additives (NR) <sup>(4)</sup> | Curatives | Losses   |   |    |    |
| 5    |      |                                |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 6    |      | Pressure                       | bar                                                                                                     |         | 1.000                                            | 1.000               | 1.000                         | 1.000     | 1.000    |   |    |    |
| 7    |      | Temperature                    | °C                                                                                                      |         | 25.000                                           | 25.000              | 25.000                        | 25.000    | 25.000   |   |    |    |
| 8    |      | Mass flow                      | g                                                                                                       |         | 637.00                                           | 2035.000            | 512.000                       | 233.000   | 162.000  |   |    |    |
| 9    |      | % Vapor                        | -                                                                                                       |         | 0.000                                            | 0.000               | 0.000                         | 0.000     | 0.000    |   |    |    |
| 10   |      | Total vapor mass flow          | g                                                                                                       |         | 0.000                                            | 0.000               | 0.000                         | 0.000     | 0.000    |   |    |    |
| 11   |      | Non condensable (N2,...)       | g                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 12   |      | Water steam                    | g                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 13   |      | Hydrocarbons                   | g                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 14   |      | Total liquid mass flow         | g                                                                                                       |         | 0.000                                            | 0.000               | 0.000                         | 233.000   | 11.100   |   |    |    |
| 15   |      | Free water                     | g                                                                                                       |         | 0.000                                            | 0.000               | 0.000                         | 0.000     | 0.000    |   |    |    |
| 16   |      | Hydrocarbons                   | g                                                                                                       |         | 0.000                                            | 0.000               | 0.000                         | 0.000     | 0.000    |   |    |    |
| 17   |      | Total enthalpy flow            | J                                                                                                       |         | Unknown                                          | Unknown             | Unknown                       | Unknown   | Unknown  |   |    |    |
| 18   |      | Corrosive and toxic compounds  | %w                                                                                                      |         | 0.000                                            | Unknown             | Unknown                       | Unknown   | Unknown  |   |    |    |
| 19   |      | Solids present                 | %                                                                                                       |         | 100.000                                          | 100.000             | 100.000                       | 0.000     | 93.100   |   |    |    |
| 20   |      | Solids particle size           | Microns                                                                                                 |         | Unknown                                          | Unknown             | Unknown                       | -         | Unknown  |   |    |    |
| 21   |      | (Wet) Steam phase properties   |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 22   |      | Volumetric flow @P,T           | dm³                                                                                                     |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 23   |      | Volumetric flow @(1 atm, 0°C)  | dm³                                                                                                     |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 24   |      | Molecular weight               | g/mol                                                                                                   |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 25   |      | Density @T                     | g/dm³                                                                                                   |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 26   |      | Density @(1 atm, 0°C)          | g/dm³                                                                                                   |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 27   |      | Viscosity @T                   | cP                                                                                                      |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 28   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 29   |      | Specific Heat @T               | J/(g·K)                                                                                                 |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 30   |      | Compressibility factor @P,T    | -                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 31   |      | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 32   |      | Enthalpy flow                  | J                                                                                                       |         | -                                                | -                   | -                             | -         | -        |   |    |    |
| 33   |      | Liquid phase properties        |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 34   |      | Volumetric flow @P,T           | dm³                                                                                                     |         | -                                                | -                   | -                             | 0.0633    | 0.0107   |   |    |    |
| 35   |      | Volumetric flow @15°C          | dm³                                                                                                     |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 36   |      | Density @T                     | g/dm³                                                                                                   |         | -                                                | -                   | -                             | 3680.000  | 3820.000 |   |    |    |
| 37   |      | Density @15°C                  | g/dm³                                                                                                   |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 38   |      | Kinematic viscosity @T         | cSt                                                                                                     |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 39   |      | Kinematic viscosity @50°C      | cSt                                                                                                     |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 40   |      | Kinematic viscosity @100°C     | cSt                                                                                                     |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 41   |      | Kinematic viscosity @150°C     | cSt                                                                                                     |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 42   |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 43   |      | Specific Heat @T               | J/(g·K)                                                                                                 |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 44   |      | Surface tension @P,T           | dinas/cm                                                                                                |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 45   |      | Vapor pressure                 | kg/cm² a                                                                                                |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 46   |      | Enthalpy flow                  | J                                                                                                       |         | -                                                | -                   | -                             | Unknown   | Unknown  |   |    |    |
| 47   |      | Miscellaneous                  |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 48   |      |                                |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 49   |      | Notes                          |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| 50   |      | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                                  |                     |                               |           |          |   |    |    |
| 51   |      | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                                  |                     |                               |           |          |   |    |    |
| 52   |      | 3                              | The bio-rubber chain involves three processes. This datasheet refers to the production of the rubber    |         |                                                  |                     |                               |           |          |   |    |    |
| 53   |      | 4                              | NR: Natural rubber                                                                                      |         |                                                  |                     |                               |           |          |   |    |    |
| 54   |      | 5                              |                                                                                                         |         |                                                  |                     |                               |           |          |   |    |    |
| Rev. |      | by                             | 1.0                                                                                                     | SDFG    |                                                  |                     |                               |           |          |   |    |    |
| Date |      | Approved                       | 29-08-25                                                                                                | PRG     |                                                  |                     |                               |           |          |   |    |    |

|      |      | idener.ai                     |                                                                                                         | PROYECT | GREEN-LOOP                                       | Mass and Energy    |                    |                 |                   |                 |    |    |
|------|------|-------------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------------|--------------------|--------------------|-----------------|-------------------|-----------------|----|----|
|      |      |                               |                                                                                                         | Process | Bio-rubber manufacture (rubber panel production) |                    |                    |                 | Page              | 5               | of | 10 |
| Item | Rev. | MASS AND ENERGY BALANCES      |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 1    |      | Operational data and flows    |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 2    |      | Design case                   |                                                                                                         |         |                                                  | Basic engineering  |                    |                 |                   |                 |    |    |
| 3    |      | Stream n°                     |                                                                                                         |         |                                                  | 6b                 | 7b                 | 8b              | 9b                | 10b             |    |    |
| 4    |      | Description                   |                                                                                                         |         |                                                  | Compound<br>ed mix | Compound<br>ed mix | Cured<br>rubber | Cutting<br>losses | Rubber<br>panel |    |    |
| 5    |      |                               |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 6    |      | Pressure                      | bar                                                                                                     |         | 1.000                                            | 1.000              | 1.000              | 1.000           | 1.000             |                 |    |    |
| 7    |      | Temperature                   | °C                                                                                                      |         | 40.000                                           | 25.000             | 25.000             | 25.000          | 25.000            |                 |    |    |
| 8    |      | Mass flow                     |                                                                                                         |         | 3255.000                                         | 3255.000           | 3255.000           | 155.000         | 3100.000          |                 |    |    |
| 9    |      | % Vapor                       | -                                                                                                       |         | 0.000                                            | 0.000              | 0.000              | 0.000           | 0.000             |                 |    |    |
| 10   |      | Total vapor mass flow         | g                                                                                                       |         | 0.000                                            | 0.000              | 0.000              | 0.000           | 0.000             |                 |    |    |
| 11   |      | Non condensable (N2,...)      | g                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 12   |      | Water steam                   | g                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 13   |      | Hydrocarbons                  | g                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 14   |      | Total liquid mass flow        | g                                                                                                       |         | 219.000                                          | 219.000            | 219.000            | 10.500          | 208.000           |                 |    |    |
| 15   |      | Free water                    | g                                                                                                       |         | 0.000                                            | 0.000              | 0.000              | 0.000           | 0.000             |                 |    |    |
| 16   |      | Hydrocarbons                  | g                                                                                                       |         | 0.000                                            | 0.000              | 0.000              | 0.000           | 0.000             |                 |    |    |
| 17   |      | Total enthalpy flow           | J                                                                                                       |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 18   |      | Corrosive and toxic compounds | %w                                                                                                      |         | 0.000                                            | 0.000              | 0.000              | 0.000           | 0.000             |                 |    |    |
| 19   |      | Solids present                | %                                                                                                       |         | 92.900                                           | 92.900             | 92.900             | 93.200          | 93.300            |                 |    |    |
| 20   |      | Solids particle size          | Microns                                                                                                 |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 21   |      | (Wet) Steam phase properties  |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 22   |      | Volumetric flow @P,T          | dm³                                                                                                     |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 23   |      | Volumetric flow @(1 atm, 0°C) | dm³                                                                                                     |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 24   |      | Molecular weight              | g/mol                                                                                                   |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 25   |      | Density @T                    | g/dm³                                                                                                   |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 26   |      | Density @(1 atm, 0°C)         | g/dm³                                                                                                   |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 27   |      | Viscosity @T                  | cP                                                                                                      |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 28   |      | Thermal conductivity @T       | J/(s·m·K)                                                                                               |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 29   |      | Specific Heat @T              | J/(g·K)                                                                                                 |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 30   |      | Compressibility factor @P,T   | -                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 31   |      | Cp/Cv                         | -                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 32   |      | Enthalpy flow                 | J                                                                                                       |         | -                                                | -                  | -                  | -               | -                 |                 |    |    |
| 33   |      | Liquid phase properties       |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 34   |      | Volumetric flow @P,T          | dm³                                                                                                     |         | 0.0566                                           | 0.0566             | 0.0566             | 0.00271         | 0.0538            |                 |    |    |
| 35   |      | Volumetric flow @15°C         | dm³                                                                                                     |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 36   |      | Density @T                    | g/dm³                                                                                                   |         | 3870.000                                         | 3870.000           | 3870.000           | 3880.000        | 3870.000          |                 |    |    |
| 37   |      | Density @15°C                 | g/dm³                                                                                                   |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 38   |      | Kinematic viscosity @T        | cSt                                                                                                     |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 39   |      | Kinematic viscosity @50°C     | cSt                                                                                                     |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 40   |      | Kinematic viscosity @100°C    | cSt                                                                                                     |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 41   |      | Kinematic viscosity @150°C    | cSt                                                                                                     |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 42   |      | Thermal conductivity @T       | J/(s·m·K)                                                                                               |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 43   |      | Specific Heat @T              | J/(g·K)                                                                                                 |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 44   |      | Surface tension @P,T          | dinas/cm                                                                                                |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 45   |      | Vapor pressure                | kg/cm² a                                                                                                |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 46   |      | Enthalpy flow                 | J                                                                                                       |         | Unknown                                          | Unknown            | Unknown            | Unknown         | Unknown           |                 |    |    |
| 47   |      | Miscellaneous                 |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 48   |      |                               |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 49   |      | Notes                         |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 50   |      | 1                             | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 51   |      | 2                             | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 52   |      | 3                             | The bio-rubber chain involves three processes. This datasheet refers to the production of the rubber    |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 53   |      | 4                             |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| 54   |      | 5                             |                                                                                                         |         |                                                  |                    |                    |                 |                   |                 |    |    |
| Rev. |      | by                            | 1.0                                                                                                     | SDFG    |                                                  |                    |                    |                 |                   |                 |    |    |
| Date |      | Approved                      | 29-08-25                                                                                                | PRG     |                                                  |                    |                    |                 |                   |                 |    |    |

|             |             | idener.ai                           |                                                                                                         | PROYECT | GREEN-LOOP                                       |                   |  | Mass and Energy |   |    |    |
|-------------|-------------|-------------------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------------|-------------------|--|-----------------|---|----|----|
|             |             |                                     |                                                                                                         | Process | Bio-rubber manufacture (rubber panel production) |                   |  | Page            | 8 | of | 14 |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>     |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 1           |             | <b>Operational data and flows</b>   |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 2           |             | Design case                         |                                                                                                         |         |                                                  | Basic engineering |  |                 |   |    |    |
| 3           |             | Stream n°                           |                                                                                                         |         |                                                  | 11                |  |                 |   |    |    |
| 4           |             | Description                         |                                                                                                         |         |                                                  | Rubber panel      |  |                 |   |    |    |
| 5           |             |                                     |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 6           |             | Pressure                            | bar                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 7           |             | Temperature                         | °C                                                                                                      |         |                                                  |                   |  |                 |   |    |    |
| 8           |             | Mass flow                           | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 9           |             | % Vapor                             | -                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 10          |             | Total vapor mass flow               | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 11          |             | Non condensable (N2,...)            | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 12          |             | Water steam                         | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 13          |             | Hydrocarbons                        | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 14          |             | Total liquid mass flow              | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 15          |             | Free water                          | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 16          |             | Hydrocarbons                        | g                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 17          |             | Total enthalpy flow                 | J                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 18          |             | Corrosive and toxic compounds       | %w                                                                                                      |         |                                                  |                   |  |                 |   |    |    |
| 19          |             | Solids present                      | %                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 20          |             | Solids particle size                | Microns                                                                                                 |         |                                                  |                   |  |                 |   |    |    |
| 21          |             | <b>(Wet) Steam phase properties</b> |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 22          |             | Volumetric flow @P,T                | dm³                                                                                                     | -       |                                                  |                   |  |                 |   |    |    |
| 23          |             | Volumetric flow @(1 atm, 0°C)       | dm³                                                                                                     | -       |                                                  |                   |  |                 |   |    |    |
| 24          |             | Molecular weight                    | g/mol                                                                                                   | -       |                                                  |                   |  |                 |   |    |    |
| 25          |             | Density @T                          | g/dm³                                                                                                   | -       |                                                  |                   |  |                 |   |    |    |
| 26          |             | Density @(1 atm, 0°C)               | g/dm³                                                                                                   | -       |                                                  |                   |  |                 |   |    |    |
| 27          |             | Viscosity @T                        | cP                                                                                                      | -       |                                                  |                   |  |                 |   |    |    |
| 28          |             | Thermal conductivity @T             | J/(s·m·K)                                                                                               | -       |                                                  |                   |  |                 |   |    |    |
| 29          |             | Specific Heat @T                    | J/(g·K)                                                                                                 | -       |                                                  |                   |  |                 |   |    |    |
| 30          |             | Compressibility factor @P,T         | -                                                                                                       | -       |                                                  |                   |  |                 |   |    |    |
| 31          |             | C <sub>p</sub> /C <sub>v</sub>      | -                                                                                                       | -       |                                                  |                   |  |                 |   |    |    |
| 32          |             | Enthalpy flow                       | J                                                                                                       | -       |                                                  |                   |  |                 |   |    |    |
| 33          |             | <b>Liquid phase properties</b>      |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 34          |             | Volumetric flow @P,T                | dm³                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 35          |             | Volumetric flow @15°C               | dm³                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 36          |             | Density @T                          | g/dm³                                                                                                   |         |                                                  |                   |  |                 |   |    |    |
| 37          |             | Density @15°C                       | g/dm³                                                                                                   |         |                                                  |                   |  |                 |   |    |    |
| 38          |             | Kinematic viscosity @T              | cSt                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 39          |             | Kinematic viscosity @50°C           | cSt                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 40          |             | Kinematic viscosity @100°C          | cSt                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 41          |             | Kinematic viscosity @150°C          | cSt                                                                                                     |         |                                                  |                   |  |                 |   |    |    |
| 42          |             | Thermal conductivity @T             | J/(s·m·K)                                                                                               |         |                                                  |                   |  |                 |   |    |    |
| 43          |             | Specific Heat @T                    | J/(g·K)                                                                                                 |         |                                                  |                   |  |                 |   |    |    |
| 44          |             | Surface tension @P,T                | dinas/cm                                                                                                |         |                                                  |                   |  |                 |   |    |    |
| 45          |             | Vapor pressure                      | kg/cm² a                                                                                                |         |                                                  |                   |  |                 |   |    |    |
| 46          |             | Enthalpy flow                       | J                                                                                                       |         |                                                  |                   |  |                 |   |    |    |
| 47          |             | <b>Miscellaneous</b>                |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 48          |             |                                     |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 49          |             | <b>Notes</b>                        |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 50          |             | 1                                   | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                                                  |                   |  |                 |   |    |    |
| 51          |             | 2                                   | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                                                  |                   |  |                 |   |    |    |
| 52          |             | 3                                   | The bio-rubber chain involves three processes. This datasheet refers to the production of the rubber    |         |                                                  |                   |  |                 |   |    |    |
| 53          |             | 4                                   |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| 54          |             | 5                                   |                                                                                                         |         |                                                  |                   |  |                 |   |    |    |
| Rev.        | by          | 1.0                                 | SDFG                                                                                                    |         |                                                  |                   |  |                 |   |    |    |
| Date        | Approved    | 29-08-25                            | PRG                                                                                                     |         |                                                  |                   |  |                 |   |    |    |

|          |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
|----------|----------|------------------------------------|-----------------------------------------------------------------------------------------------|---------|-------------------|--------------------------------------------|-------------------|---------|---------|-----------------|---------|---------|----|
|          |          | idener.ai                          |                                                                                               | PROYECT |                   | GREEN-LOOP                                 |                   |         |         | Mass and Energy |         |         |    |
|          |          |                                    |                                                                                               | Process |                   | Bio-rubber manufacture (lignin extraction) |                   |         |         | Page            | 6       | of      | 10 |
| Ite<br>m | Re<br>v. | MASS AND ENERGY BALANCES           |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 1        |          | Compositions                       |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 2        |          | Stream nº                          | 1a                                                                                            |         | 2a <sup>(2)</sup> |                                            | 3a <sup>(2)</sup> |         | 4a      |                 | 5a      |         |    |
| 3        |          | Componen                           | %                                                                                             | % mol   | %                 | % mol                                      | %                 | % mol   | %       | % mol           | %       | % mol   |    |
| 4        |          | Biomass                            | 100.000                                                                                       | 100.000 | 0.000             | 0.000                                      | 0.000             | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 5        |          | H <sub>2</sub> O                   | 0.000                                                                                         | 0.000   | 95.700            | 98.251                                     | 81.800            | 96.805  | 20.000  | 69.232          | 100.000 | 100.000 |    |
| 6        |          | Na <sub>2</sub> S                  | 0.000                                                                                         | 0.000   | 0.960             | 0.227                                      | 0.820             | 0.224   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 7        |          | NaOH                               | 0.000                                                                                         | 0.000   | 3.290             | 1.521                                      | 2.810             | 1.506   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 8        |          | Cellulose                          | 0.000                                                                                         | 0.000   | 0.000             | 0.000                                      | 6.950             | 0.914   | 80.000  | 30.768          | 0.000   | 0.000   |    |
| 9        |          | Hemicellul                         | 0.000                                                                                         | 0.000   | 0.000             | 0.000                                      | 3.640             | 0.517   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 10       |          | H <sub>2</sub> SO <sub>4</sub> 15% | 0.000                                                                                         | 0.000   | 0.000             | 0.000                                      | 0.000             | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 11       |          | H <sub>2</sub> SO <sub>4</sub> 5%  | 0.000                                                                                         | 0.000   | 0.000             | 0.000                                      | 0.000             | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 12       |          | Lignin                             | 0.000                                                                                         | 0.000   | 0.000             | 0.000                                      | 3.970             | 0.042   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 13       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 14       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 15       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 16       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 17       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 18       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 19       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 20       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 21       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 22       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 23       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 24       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 25       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 26       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 27       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 28       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 29       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 30       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 31       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 32       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 33       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 34       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 35       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 36       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 37       |          |                                    |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 38       |          | Total                              | 100.000                                                                                       | 100.000 | 99.950            | 100.000                                    | 99.990            | 100.008 | 100.000 | 100.000         | 100.000 | 100.000 |    |
| 39       |          | Mass dry                           |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 40       |          | flow (g)                           |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 41       |          | Molar dry                          |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 42       |          | flow (mol)                         |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 43       |          | Mass wet                           |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 44       |          | flow (g)                           |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 45       |          | Molar wet                          |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 46       |          | flow (mol)                         |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 47       |          | Notes                              |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 48       |          | 1                                  | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction |         |                   |                                            |                   |         |         |                 |         |         |    |
| 49       |          | 2                                  | Mismatch in total % is due to approximations in calculus                                      |         |                   |                                            |                   |         |         |                 |         |         |    |
| 50       |          | 3                                  |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 51       |          | 4                                  |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 52       |          | 5                                  |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 53       |          | 6                                  |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| 54       |          | 7                                  |                                                                                               |         |                   |                                            |                   |         |         |                 |         |         |    |
| Rev.     |          | by                                 | 1.0                                                                                           | SDFG    |                   |                                            |                   |         |         |                 |         |         |    |
| Date     |          | Approved                           | 29-08-25                                                                                      | PRG     |                   |                                            |                   |         |         |                 |         |         |    |

|             |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
|-------------|-------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------|---------------|--------------------------------------------|-------------------|----------------|-------------------|-----------------|----------------|----------------|----|
|             |             |  |                                                                                                       | PROYECT        |               | GREEN-LOOP                                 |                   |                |                   | Mass and Energy |                |                |    |
|             |             |                                                                                   |                                                                                                       | Process        |               | Bio-rubber manufacture (lignin extraction) |                   |                |                   | Page            | 7              | of             | 10 |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 1           |             | <b>Compositions</b>                                                               |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 2           |             | Stream nº                                                                         | 6a <sup>(2)</sup>                                                                                     |                | 7a            |                                            | 8a <sup>(2)</sup> |                | 9a <sup>(2)</sup> |                 | 10a            |                |    |
| 3           |             | Componen                                                                          | %                                                                                                     | % mol          | %             | % mol                                      | %                 | % mol          | %                 | % mol           | %              | % mol          |    |
| 4           |             | Biomass                                                                           | 0.000                                                                                                 | 0.000          | 0.000         | 0.000                                      | 0.000             | 0.000          | 0.000             | 0.000           | 0.000          | 0.000          |    |
| 5           |             | H <sub>2</sub> O                                                                  | 77.720                                                                                                | 95.314         | 0.000         | 0.000                                      | 61.440            | 79.768         | 64.500            | 79.818          | 20.000         | 96.522         |    |
| 6           |             | Na <sub>2</sub> S                                                                 | 1.630                                                                                                 | 0.461          | 0.000         | 0.000                                      | 1.290             | 0.387          | 1.350             | 0.386           | 0.000          | 0.000          |    |
| 7           |             | NaOH                                                                              | 5.570                                                                                                 | 3.077          | 0.000         | 0.000                                      | 4.400             | 2.573          | 4.610             | 2.571           | 0.000          | 0.000          |    |
| 8           |             | Cellulose                                                                         | 0.000                                                                                                 | 0.000          | 0.000         | 0.000                                      | 0.000             | 0.000          | 0.000             | 0.000           | 0.000          | 0.000          |    |
| 9           |             | Hemicellul                                                                        | 7.210                                                                                                 | 1.061          | 0.000         | 0.000                                      | 5.700             | 0.888          | 5.980             | 5.980           | 0.000          | 0.000          |    |
| 10          |             | H <sub>2</sub> SO <sub>4</sub> 15%                                                | 0.000                                                                                                 | 0.000          | 100.000       | 100.000                                    | 20.940            | 16.312         | 21.960            | 16.318          | 0.00 0         | 0.000          |    |
| 11          |             | H <sub>2</sub> SO <sub>4</sub> 5%                                                 | 0.000                                                                                                 | 0.000          | 0.000         | 0.000                                      | 0.000             | 0.000          | 0.000             | 0.000           | 0.000          | 0.000          |    |
| 12          |             | Lignin                                                                            | 7.860                                                                                                 | 0.087          | 0.000         | 0.000                                      | 6.220             | 0.0723         | 1.630             | 1.630           | 80.000         | 3.478          |    |
| 13          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 14          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 15          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 16          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 17          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 18          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 19          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 20          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 21          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 22          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 23          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 24          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 25          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 26          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 27          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 28          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 29          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 30          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 31          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 32          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 33          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 34          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 35          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 36          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 37          |             |                                                                                   |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 38          |             | <b>Total</b>                                                                      | <b>99.990</b>                                                                                         | <b>100.000</b> | <b>100.00</b> | <b>100.000</b>                             | <b>99.990</b>     | <b>100.000</b> | <b>99.980</b>     | <b>100.000</b>  | <b>100.000</b> | <b>100.000</b> |    |
| 39          |             | Mass dry                                                                          |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 40          |             | flow (g)                                                                          |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 41          |             | Molar dry                                                                         |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 42          |             | flow (mol)                                                                        |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 43          |             | Mass wet                                                                          |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 44          |             | flow (g)                                                                          |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 45          |             | Molar wet                                                                         |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 46          |             | flow (mol)                                                                        |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 47          |             | <b>Notes</b>                                                                      |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 48          |             | 1                                                                                 | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction         |                |               |                                            |                   |                |                   |                 |                |                |    |
| 49          |             | 2                                                                                 | The lack to reach 100 % weight is due to other substances from biomass, which are not included in the |                |               |                                            |                   |                |                   |                 |                |                |    |
| 50          |             | 3                                                                                 |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 51          |             | 4                                                                                 |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 52          |             | 5                                                                                 |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 53          |             | 6                                                                                 |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| 54          |             | 7                                                                                 |                                                                                                       |                |               |                                            |                   |                |                   |                 |                |                |    |
| Rev.        |             | by                                                                                | 1.0                                                                                                   | SDFG           |               |                                            |                   |                |                   |                 |                |                |    |
| Date        |             | Approved                                                                          | 29-08-25                                                                                              | PRG            |               |                                            |                   |                |                   |                 |                |                |    |

|      |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
|------|----------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|---------|---------|--------------------------------------------|---------|---------|---------|-----------------|---------|---------|----|
|      |          |  |                                                                                               | PROYECT |         | GREEN-LOOP                                 |         |         |         | Mass and Energy |         |         |    |
|      |          |                                                                                   |                                                                                               | Process |         | Bio-rubber manufacture (lignin extraction) |         |         |         | Page            | 8       | of      | 10 |
| Item | Rev.     | MASS AND ENERGY BALANCES                                                          |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 1    |          | Compositions                                                                      |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 2    |          | Stream n°                                                                         | 11a                                                                                           |         | 12a     |                                            | 13a     |         | 14a     |                 | 1b      |         |    |
| 3    |          | Componen                                                                          | %                                                                                             | % mol   | %       | % mol                                      | %       | % mol   | %       | % mol           | %       | % mol   |    |
| 4    |          | Biomass                                                                           | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 5    |          | H <sub>2</sub> O                                                                  | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 6    |          | Na <sub>2</sub> S                                                                 | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 7    |          | NaOH                                                                              | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 8    |          | Cellulose                                                                         | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 9    |          | Hemicellul                                                                        | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 10   |          | H <sub>2</sub> SO <sub>4</sub> 15%                                                | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 0.000   | 0.000   | 0.000   | 0.000           | 0.000   | 0.000   |    |
| 11   |          | H <sub>2</sub> SO <sub>4</sub> 5%                                                 | 100.000                                                                                       | 100.000 | 100.000 | 100.000                                    | 61.264  | 99.309  | 100.000 | 100.000         | 0.000   | 0.000   |    |
| 12   |          | Lignin                                                                            | 0.000                                                                                         | 0.000   | 0.000   | 0.000                                      | 38.736  | 0.691   | 0.000   | 0.000           | 100.00  | 100.00  |    |
| 13   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 14   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 15   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 16   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 17   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 18   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 19   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 20   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 21   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 22   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 23   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 24   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 25   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 26   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 27   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 28   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 29   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 30   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 31   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 32   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 33   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 34   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 35   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 36   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 37   |          |                                                                                   |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 38   |          | Total                                                                             | 100.000                                                                                       | 100.000 | 100.000 | 100.000                                    | 100.000 | 100.000 | 100.000 | 100.000         | 100.000 | 100.000 |    |
| 39   |          | Mass dry                                                                          |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 40   |          | flow (g)                                                                          |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 41   |          | Molar dry                                                                         |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 42   |          | flow (mol)                                                                        |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 43   |          | Mass wet                                                                          |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 44   |          | flow (g)                                                                          |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 45   |          | Molar wet                                                                         |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 46   |          | flow (mol)                                                                        |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 47   |          | Notes                                                                             |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 48   |          | 1                                                                                 | The bio-rubber chain involves three processes. This datasheet refers to the lignin extraction |         |         |                                            |         |         |         |                 |         |         |    |
| 49   |          | 2                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 50   |          | 3                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 51   |          | 4                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 52   |          | 5                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 53   |          | 6                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| 54   |          | 7                                                                                 |                                                                                               |         |         |                                            |         |         |         |                 |         |         |    |
| Rev. | by       | 1.0                                                                               | SDFG                                                                                          |         |         |                                            |         |         |         |                 |         |         |    |
| Date | Approved | 29-08-25                                                                          | PRG                                                                                           |         |         |                                            |         |         |         |                 |         |         |    |

|          |          | idener.ai                                                                                                 |          | PROYECT |         | GREEN-LOOP                                       |         | Mass and Energy |                   |         |                   |         |    |
|----------|----------|-----------------------------------------------------------------------------------------------------------|----------|---------|---------|--------------------------------------------------|---------|-----------------|-------------------|---------|-------------------|---------|----|
|          |          |                                                                                                           |          | Process |         | Bio-rubber manufacture (rubber panel production) |         |                 |                   | Page    | 9                 | of      | 10 |
| Ite<br>m | Re<br>v. | MASS AND ENERGY BALANCES                                                                                  |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 1        |          | Compositions                                                                                              |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 2        |          | Stream n°                                                                                                 | 1b       |         | 2b      |                                                  | 3b      |                 | 4b <sup>(6)</sup> |         | 5b <sup>(6)</sup> |         |    |
| 3        |          | Componen                                                                                                  | %        | % mol   | %       | % mol                                            | %       | % mol           | %                 | % mol   | %                 | % mol   |    |
| 4        |          | Lignin                                                                                                    | 100.000  | 100.000 | 0.000   | 0.000                                            | 0.000   | 0.000           | 0.000             | 0.000   | 18.657            | 7.787   |    |
| 5        |          | DR <sup>(2)</sup>                                                                                         | 0.000    | 0.000   | 100.000 | 100.000                                          | 0.000   | 0.000           | 0.000             | 0.000   | 59.701            | 0.091   |    |
| 6        |          | NR <sup>(3)</sup>                                                                                         | 0.000    | 0.000   | 0.000   | 0.000                                            | 100.000 | 100.000         | 0.000             | 0.000   | 14.925            | 0.023   |    |
| 7        |          | NLZO <sup>(4)</sup>                                                                                       | 0.000    | 0.000   | 0.000   | 0.000                                            | 0.000   | 0.000           | 53.300            | 42.215  | 3.731             | 38.265  |    |
| 8        |          | Stearic acid                                                                                              | 0.000    | 0.000   | 0.000   | 0.000                                            | 0.000   | 0.000           | 13.300            | 3.014   | 0.746             | 2.190   |    |
| 9        |          | MBTS-75 <sup>(5)</sup>                                                                                    | 0.000    | 0.000   | 0.000   | 0.000                                            | 0.000   | 0.000           | 6.600             | 1.280   | 0.448             | 1.124   |    |
| 10       |          | 300 MS <sup>(6)</sup>                                                                                     | 0.000    | 0.000   | 0.000   | 0.000                                            | 0.000   | 0.000           | 26.600            | 53.491  | 1.940             | 50.521  |    |
| 11       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 12       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 13       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 14       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 15       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 16       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 17       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 18       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 19       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 20       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 21       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 22       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 23       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 24       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 25       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 26       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 27       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 28       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 29       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 30       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 31       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 32       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 33       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 34       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 35       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 36       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 37       |          |                                                                                                           |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 38       |          | Total                                                                                                     | 100.000  | 100.000 | 100.000 | 100.000                                          | 100.000 | 100.000         | 99.800            | 100.000 | 100.149           | 100.000 |    |
| 39       |          | Mass dry                                                                                                  |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 40       |          | flow (g)                                                                                                  |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 41       |          | Molar dry                                                                                                 |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 42       |          | flow (mol)                                                                                                |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 43       |          | Mass wet                                                                                                  |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 44       |          | flow (g)                                                                                                  |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 45       |          | Molar wet                                                                                                 |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 46       |          | flow (mol)                                                                                                |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 47       |          | Notes                                                                                                     |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 48       |          | 1 The bio-rubber chain involves three processes. This datasheet refers to the production of rubber panels |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 49       |          | 2 Devulcanised Rubber                                                                                     |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 50       |          | 3 Natural Rubber SMR CV600                                                                                |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 51       |          | 4 Low Lead Zinc Oxide                                                                                     |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 52       |          | 5 MBTS-75 is used as accelerator during the process                                                       |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 53       |          | 6 300 Mesh Sulphur                                                                                        |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| 54       |          | 7 Mismatch in total % is due to approximations in calculus                                                |          |         |         |                                                  |         |                 |                   |         |                   |         |    |
| Rev.     |          | by                                                                                                        | 1.0      | SDFG    |         |                                                  |         |                 |                   |         |                   |         |    |
| Date     |          | Approved                                                                                                  | 29-08-25 | PRG     |         |                                                  |         |                 |                   |         |                   |         |    |

|          |          | idener.ai                |                                                                                                         | PROYECT | GREEN-LOOP                                       |         |         |         | Mass and Energy |        |         |         |  |
|----------|----------|--------------------------|---------------------------------------------------------------------------------------------------------|---------|--------------------------------------------------|---------|---------|---------|-----------------|--------|---------|---------|--|
|          |          |                          |                                                                                                         | Process | Bio-rubber manufacture (rubber panel production) |         |         |         | Page            | 10     | of      | 10      |  |
| Ite<br>m | Re<br>v. | MASS AND ENERGY BALANCES |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 1        |          | Compositions             |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 2        |          | Stream n°                | 6b                                                                                                      |         | 7b                                               |         | 8b      |         | 9b              |        | 10b     |         |  |
| 3        |          | Componen                 | %                                                                                                       | % mol   | %                                                | % mol   | %       | % mol   | %               | % mol  | %       | % mol   |  |
| 4        |          | Lignin                   | 18.657                                                                                                  | 7.947   | 18.657                                           | 7.947   | 18.657  | 7.947   | 18.668          | 7.996  | 18.652  | 7.958   |  |
| 5        |          | DR <sup>(2)</sup>        | 59.701                                                                                                  | 0.092   | 59.701                                           | 0.092   | 59.701  | 0.092   | 59.669          | 0.093  | 59.701  | 0.093   |  |
| 6        |          | NR <sup>(3)</sup>        | 14.925                                                                                                  | 0.023   | 14.925                                           | 0.023   | 14.925  | 0.023   | 14.876          | 0.023  | 14.927  | 0.023   |  |
| 7        |          | NLZO <sup>(4)</sup>      | 3.731                                                                                                   | 39.053  | 3.731                                            | 39.053  | 3.731   | 39.053  | 3.802           | 39.990 | 3.734   | 39.143  |  |
| 8        |          | Stearic acid             | 0.746                                                                                                   | 2.235   | 0.746                                            | 2.235   | 0.746   | 2.235   | 0.826           | 2.487  | 0.749   | 2.245   |  |
| 9        |          | MBTS-75 <sup>(5)</sup>   | 0.377                                                                                                   | 0.966   | 0.377                                            | 0.966   | 0.377   | 0.966   | 0.331           | 0.851  | 0.374   | 0.961   |  |
| 10       |          | 300 MS <sup>(6)</sup>    | 1.870                                                                                                   | 49.682  | 1.870                                            | 49.682  | 1.870   | 49.682  | 1.818           | 48.559 | 1.863   | 49.577  |  |
| 11       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 12       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 13       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 14       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 15       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 16       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 17       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 18       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 19       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 20       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 21       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 22       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 23       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 24       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 25       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 26       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 27       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 28       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 29       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 30       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 31       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 32       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 33       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 34       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 35       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 36       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 37       |          |                          |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 38       |          | Total                    | 100.000                                                                                                 | 100.000 | 100.000                                          | 100.000 | 100.000 | 100.000 | 0.000           | 0.000  | 100.000 | 100.000 |  |
| 39       |          | Mass dry                 |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 40       |          | flow (g)                 |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 41       |          | Molar dry                |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 42       |          | flow (mol)               |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 43       |          | Mass wet                 |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 44       |          | flow (g)                 |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 45       |          | Molar wet                |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 46       |          | flow (mol)               |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 47       |          | Notes                    |                                                                                                         |         |                                                  |         |         |         |                 |        |         |         |  |
| 48       |          | 1                        | The bio-rubber chain involves three processes. This datasheet refers to the production of rubber panels |         |                                                  |         |         |         |                 |        |         |         |  |
| 49       |          | 2                        | Devulcanised Rubber                                                                                     |         |                                                  |         |         |         |                 |        |         |         |  |
| 50       |          | 3                        | Natural Rubber SMR CV600                                                                                |         |                                                  |         |         |         |                 |        |         |         |  |
| 51       |          | 4                        | Low Lead Zinc Oxide                                                                                     |         |                                                  |         |         |         |                 |        |         |         |  |
| 52       |          | 5                        | MBTS-75 is used as accelerator during the process                                                       |         |                                                  |         |         |         |                 |        |         |         |  |
| 53       |          | 6                        | 300 Mesh Sulphur                                                                                        |         |                                                  |         |         |         |                 |        |         |         |  |
| 54       |          | 7                        | Mismatch in total % is due to approximations in calculus                                                |         |                                                  |         |         |         |                 |        |         |         |  |
| Rev.     | by       | 1.0                      | SDFG                                                                                                    |         |                                                  |         |         |         |                 |        |         |         |  |
| Date     | Approved | 29-08-25                 | PRG                                                                                                     |         |                                                  |         |         |         |                 |        |         |         |  |

|      |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
|------|----------|----------------------------------|---------------------------------------------------------------------------------------------------------|---------|------------------------|--|-------------------|-----------------|-------|----|---|
|      |          | idener.ai                        |                                                                                                         | PROYECT | GREEN-LOOP             |  |                   | Plant Utilities |       |    |   |
|      |          |                                  |                                                                                                         | Process | Bio-rubber manufacture |  |                   | Page            | 1     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (COOLING DEMAND) |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 1    |          | Design case                      |                                                                                                         |         |                        |  | Basic engineering |                 |       |    |   |
| 2    |          | Equipment                        | Description                                                                                             |         |                        |  | Demand (kJ)       |                 | Notes |    |   |
| 3    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 4    |          | Pulping                          | Cooling of the reaction mixture                                                                         |         |                        |  | 450.000           |                 | (2)   |    |   |
| 5    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 6    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 7    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 8    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 9    |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 10   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 11   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 12   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 13   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 14   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 15   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 16   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 17   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 18   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 19   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 20   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 21   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 22   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 23   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 24   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 25   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 26   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 27   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 28   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 29   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 30   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 31   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 32   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 33   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 34   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 35   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 36   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 37   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 38   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 39   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 40   |          |                                  |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 41   |          | Total                            |                                                                                                         |         |                        |  | 450.000           |                 |       |    |   |
| 42   |          | Notes                            |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 43   |          | 1                                | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                        |  |                   |                 |       |    |   |
| 44   |          | 2                                | To cool down the reaction mixture from 175 to 25 °C in 60 min                                           |         |                        |  |                   |                 |       |    |   |
| 45   |          | 3                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 46   |          | 4                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 47   |          | 5                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 48   |          | 6                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 49   |          | 7                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 50   |          | 8                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 51   |          | 9                                |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 52   |          | 10                               |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 53   |          | 11                               |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| 54   |          | 12                               |                                                                                                         |         |                        |  |                   |                 |       |    |   |
| Rev. | by       | 1.0                              | SDFG                                                                                                    |         |                        |  |                   |                 |       |    |   |
| Date | Approved | 29-08-25                         | PRG                                                                                                     |         |                        |  |                   |                 |       |    |   |

|      |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
|------|----------|---------------------------------|---------------------------------------------------------------------------------------------------------|---------|------------------------|-------------------|------------|-----------------|-------|----|---|
|      |          | idener.ai                       |                                                                                                         | PROYECT | GREEN-LOOP             |                   |            | Plant Utilities |       |    |   |
|      |          |                                 |                                                                                                         | Process | Bio-rubber manufacture |                   |            | Page            | 2     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (COOLING WATER) |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 1    |          | Design case                     |                                                                                                         |         |                        | Basic engineering |            |                 |       |    |   |
| 2    |          | Equipment                       | Description                                                                                             |         |                        |                   | Flow (dm³) |                 | Notes |    |   |
| 3    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 4    |          | Pulping                         | Cooling of the reaction mixture. Ratio flow: 0.18                                                       |         |                        |                   | 10.800     |                 | (3)   |    |   |
| 5    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 6    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 7    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 8    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 9    |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 10   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 11   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 12   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 13   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 14   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 15   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 16   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 17   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 18   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 19   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 20   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 21   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 22   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 23   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 24   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 25   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 26   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 27   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 28   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 29   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 30   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 31   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 32   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 33   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 34   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 35   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 36   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 37   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 38   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 39   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 40   |          |                                 |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 41   |          | Total                           |                                                                                                         |         |                        |                   |            | 10.8000         |       |    |   |
| 42   |          | Notes                           |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 43   |          | 1                               | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                        |                   |            |                 |       |    |   |
| 44   |          | 2                               | The flow values with positive sign are positive cooling water flows with the ΔT of the design           |         |                        |                   |            |                 |       |    |   |
| 45   |          |                                 | specification, indicate if the ΔT is different in any case including it on the notes of this datasheet  |         |                        |                   |            |                 |       |    |   |
| 46   |          | 3                               | To cool down the reaction mixture from 175 to 25 °C in 60 min                                           |         |                        |                   |            |                 |       |    |   |
| 47   |          | 4                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 48   |          | 5                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 49   |          | 6                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 50   |          | 7                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 51   |          | 8                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 52   |          | 9                               |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 53   |          | 10                              |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| 54   |          | 11                              |                                                                                                         |         |                        |                   |            |                 |       |    |   |
| Rev. | by       | 1.0                             | SDFG                                                                                                    |         |                        |                   |            |                 |       |    |   |
| Date | Approved | 29-08-25                        | PRG                                                                                                     |         |                        |                   |            |                 |       |    |   |

|      |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
|------|----------|----------------------------------|---------------------------------------------------------------------------------------------------------|---------|------------------------|-------------------|-------------|-----------------|-------|----|---|
|      |          | idener.ai                        |                                                                                                         | PROYECT | GREEN-LOOP             |                   |             | Plant Utilities |       |    |   |
|      |          |                                  |                                                                                                         | Process | Bio-rubber manufacture |                   |             | Page            | 3     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (HEATING DEMAND) |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 1    |          | Design case                      |                                                                                                         |         |                        | Basic engineering |             |                 |       |    |   |
| 2    |          | Equipment                        | Description                                                                                             |         |                        |                   | Demand (kJ) |                 | Notes |    |   |
| 3    |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 4    |          | Pulping                          | Heating of the reaction mixture                                                                         |         |                        |                   | 540         |                 | (2)   |    |   |
| 5    |          | Drying oven                      | Drying of lignin                                                                                        |         |                        |                   | 43200       |                 | (3)   |    |   |
| 6    |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 7    |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 8    |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 9    |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 10   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 11   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 12   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 13   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 14   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 15   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 16   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 17   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 18   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 19   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 20   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 21   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 22   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 23   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 24   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 25   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 26   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 27   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 28   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 29   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 30   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 31   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 32   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 33   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 34   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 35   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 36   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 37   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 38   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 39   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 40   |          |                                  |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 41   |          | Total                            |                                                                                                         |         |                        |                   |             | 43740.000       |       |    |   |
| 42   |          | Notes                            |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 43   |          | 1                                | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                        |                   |             |                 |       |    |   |
| 44   |          | 2                                | To heat the reaction mixture from 25 to 175 °C in 60 min                                                |         |                        |                   |             |                 |       |    |   |
| 45   |          | 3                                | To heat up to 40 °C and keep the temperature for 24h                                                    |         |                        |                   |             |                 |       |    |   |
| 46   |          | 4                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 47   |          | 5                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 48   |          | 6                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 49   |          | 7                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 50   |          | 8                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 51   |          | 9                                |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 52   |          | 10                               |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 53   |          | 11                               |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| 54   |          | 12                               |                                                                                                         |         |                        |                   |             |                 |       |    |   |
| Rev. | by       | 1.0                              | SDFG                                                                                                    |         |                        |                   |             |                 |       |    |   |
| Date | Approved | 29-08-25                         | PRG                                                                                                     |         |                        |                   |             |                 |       |    |   |

|             |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
|-------------|-------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|--------------------|--|--------------------------------------|-------------|-----------------|-------|-----|---|----|---|
|             |             |  |                                                                                                         | PROYECT<br>Process |  | GREEN-LOOP<br>Bio-rubber manufacture |             | Plant Utilities |       | Pag | 4 | of | 5 |
| <b>Item</b> | <b>Rev.</b> | <b>PLANT UTILITIES (FUEL CONSUMPTION)</b>                                         |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 1           |             | Design case                                                                       |                                                                                                         |                    |  | Basic engineering                    |             |                 |       |     |   |    |   |
| 2           |             | Equipment                                                                         |                                                                                                         | Description        |  | Fuel consumption (m³/h)              |             |                 | Notes |     |   |    |   |
| 3           | Fuel oil    |                                                                                   |                                                                                                         |                    |  | Fuel gas                             | Natural gas |                 |       |     |   |    |   |
| 4           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 5           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 6           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 7           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 8           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 9           |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 10          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 11          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 12          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 13          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 14          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 15          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 16          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 17          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 18          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 19          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 20          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 21          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 22          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 23          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 24          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 25          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 26          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 27          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 28          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 29          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 30          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 31          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 32          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 33          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 34          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 35          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 36          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 37          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 38          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 39          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 40          |             |                                                                                   |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 41          |             | <b>Total</b>                                                                      |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 42          |             | <b>Notes</b>                                                                      |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 43          |             | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                    |  |                                      |             |                 |       |     |   |    |   |
| 44          |             | 2                                                                                 | Positive values are consumptions; negative values are by-products of the process                        |                    |  |                                      |             |                 |       |     |   |    |   |
| 45          |             | 3                                                                                 |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 46          |             | 4                                                                                 |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 47          |             | 5                                                                                 |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 48          |             | 6                                                                                 |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 49          |             | 11                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 50          |             | 12                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 51          |             | 13                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 52          |             | 14                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 53          |             | 15                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| 54          |             | 16                                                                                |                                                                                                         |                    |  |                                      |             |                 |       |     |   |    |   |
| Rev.        | by          | 1.0                                                                               | SDFG                                                                                                    |                    |  |                                      |             |                 |       |     |   |    |   |
| Date        | Approved    | 29-08-25                                                                          | PRG                                                                                                     |                    |  |                                      |             |                 |       |     |   |    |   |

|          |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
|----------|----------|-------------------------------|---------------------------------------------------------------------------------------------------------|---------|------------------------|--|-------------------|-----------------|-----------|----|---|
|          |          | idener.ai                     |                                                                                                         | PROYECT | GREEN-LOOP             |  |                   | Plant Utilities |           |    |   |
|          |          |                               |                                                                                                         | Process | Bio-rubber manufacture |  |                   | Pag             | 5         | of | 5 |
| Ite<br>m | Rev<br>. | PLANT UTILITIES (ELECTRICITY) |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 1        |          | Design case                   |                                                                                                         |         |                        |  | Basic engineering |                 |           |    |   |
| 2        |          | Equipment                     | Description                                                                                             |         |                        |  | Consumption (kJ)  |                 | Notes     |    |   |
| 3        |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 4        |          | Pulping                       | Cooling and heating of the reaction mixture                                                             |         |                        |  | 39109.809         |                 | (4)(8)(9) |    |   |
| 5        |          | Drying oven                   | Drying of lignin                                                                                        |         |                        |  | 43200.000         |                 | (5)(9)    |    |   |
| 6        |          | Compounding                   | Mixing of rubber formulation                                                                            |         |                        |  | 3850.276          |                 | (6)       |    |   |
| 7        |          | CM <sup>(3)</sup>             | Hot pressing of rubber formulation                                                                      |         |                        |  | 177644.880        |                 | (7)(8)    |    |   |
| 8        |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 9        |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 10       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 11       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 12       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 13       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 14       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 15       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 16       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 17       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 18       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 19       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 20       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 21       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 22       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 23       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 24       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 25       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 26       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 27       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 28       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 29       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 30       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 31       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 32       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 33       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 34       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 35       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 36       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 37       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 38       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 39       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 40       |          |                               |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 41       |          | Total                         |                                                                                                         |         |                        |  |                   | 225685.156      |           |    |   |
| 42       |          | Notes                         |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 43       |          | 1                             | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                        |  |                   |                 |           |    |   |
| 44       |          | 2                             | Positive values are consumptions; negative values are by-products of the process                        |         |                        |  |                   |                 |           |    |   |
| 45       |          | 3                             | Compression moulding                                                                                    |         |                        |  |                   |                 |           |    |   |
| 46       |          | 4                             | To heat the reaction mixture from 25 to 175 °C in 60 min                                                |         |                        |  |                   |                 |           |    |   |
| 47       |          | 5                             | To heat up to 40 °C and keep the temperature for 24h                                                    |         |                        |  |                   |                 |           |    |   |
| 48       |          | 6                             | Consumption per mass unit: 0.313 kWh/kg                                                                 |         |                        |  |                   |                 |           |    |   |
| 49       |          | 7                             | Consumption per mass unit: 15.16 kWh/kg                                                                 |         |                        |  |                   |                 |           |    |   |
| 50       |          | 8                             | Total consumption, including pressing, heating and cooling                                              |         |                        |  |                   |                 |           |    |   |
| 51       |          | 9                             | Equipment consumption negligible compared to pulping and oven, so only these components are             |         |                        |  |                   |                 |           |    |   |
| 52       |          | 10                            |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 53       |          | 11                            |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| 54       |          | 12                            |                                                                                                         |         |                        |  |                   |                 |           |    |   |
| Rev.     | by       | 1.0                           | SDFG                                                                                                    |         |                        |  |                   |                 |           |    |   |
| Date     | Approved | 29-08-25                      | PRG                                                                                                     |         |                        |  |                   |                 |           |    |   |

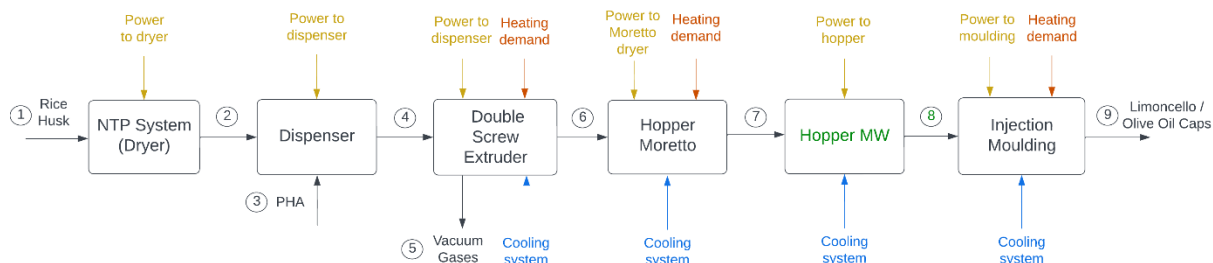
|      |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
|------|----------|-----------------------------------------------------------------------------------|-----------------------------------------------------|---------|------------------------|-------------------|---------------|--------|-------|----|---|
|      |          |  |                                                     | PROYECT | GREEN-LOOP             |                   |               | Wastes |       |    |   |
|      |          |                                                                                   |                                                     | Process | Bio-rubber manufacture |                   |               | Pag    | 1     | of | 3 |
| Item | Rev.     | WASTES (SOLIDS)                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 1    |          | Design case                                                                       |                                                     |         |                        | Basic engineering |               |        |       |    |   |
| 2    |          | Equipment                                                                         | Description                                         |         |                        |                   | Mass Flow (g) |        | Notes |    |   |
| 3    |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 4    |          | Compounding                                                                       | Wastes involved in losses within compounding        |         |                        |                   | 162           |        | (1)   |    |   |
| 5    |          | Cutting                                                                           | Wastes involved in losses within cutting            |         |                        |                   | 155           |        | (1)   |    |   |
| 6    |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 7    |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 8    |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 9    |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 10   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 11   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 12   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 13   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 14   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 15   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 16   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 17   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 18   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 19   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 20   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 21   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 22   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 23   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 24   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 25   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 26   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 27   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 28   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 29   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 30   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 31   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 32   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 33   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 34   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 35   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 36   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 37   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 38   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 39   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 40   |          |                                                                                   |                                                     |         |                        |                   |               |        |       |    |   |
| 41   |          | Total                                                                             |                                                     |         |                        |                   | 317.000       |        |       |    |   |
| 42   |          | Notes                                                                             |                                                     |         |                        |                   |               |        |       |    |   |
| 43   |          | 1                                                                                 | Solid wastes for PFD III detailed in 'losses' lines |         |                        |                   |               |        |       |    |   |
| 44   |          | 2                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 45   |          | 3                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 46   |          | 4                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 47   |          | 5                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 48   |          | 6                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 49   |          | 7                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 50   |          | 8                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 51   |          | 9                                                                                 |                                                     |         |                        |                   |               |        |       |    |   |
| 52   |          | 10                                                                                |                                                     |         |                        |                   |               |        |       |    |   |
| 53   |          | 11                                                                                |                                                     |         |                        |                   |               |        |       |    |   |
| 54   |          | 12                                                                                |                                                     |         |                        |                   |               |        |       |    |   |
| Rev. | by       | 1.0                                                                               | SDFG                                                |         |                        |                   |               |        |       |    |   |
| Date | Approved | 29-08-25                                                                          | PRG                                                 |         |                        |                   |               |        |       |    |   |

|             |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
|-------------|-------------|-----------------------------------------------------------------------------------|--------------------------------------------------|------------------------|--|-------------------|--|-------|--|
|             |             |  |                                                  | PROYECT GREEN-LOOP     |  | Wastes            |  |       |  |
|             |             | Process                                                                           |                                                  | Bio-rubber manufacture |  | Pag 2             |  | of 3  |  |
| <b>Item</b> | <b>Rev.</b> | <b>WASTES (LIQUIDS)</b>                                                           |                                                  |                        |  |                   |  |       |  |
| 1           |             | Design case                                                                       |                                                  |                        |  | Basic engineering |  |       |  |
| 2           |             | Equipment                                                                         | Description                                      |                        |  | Flow (dm³)        |  | Notes |  |
| 3           |             | Filter press                                                                      | Filtration of the precipitated and washed lignin |                        |  | Unknown           |  |       |  |
| 4           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 5           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 6           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 7           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 8           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 9           |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 10          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 11          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 12          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 13          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 14          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 15          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 16          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 17          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 18          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 19          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 20          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 21          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 22          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 23          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 24          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 25          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 26          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 27          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 28          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 29          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 30          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 31          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 32          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 33          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 34          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 35          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 36          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 37          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 38          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 39          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 40          |             |                                                                                   |                                                  |                        |  |                   |  |       |  |
| 41          |             | <b>Total</b>                                                                      |                                                  |                        |  | <b>Unknown</b>    |  |       |  |
| 42          |             | <b>Notes</b>                                                                      |                                                  |                        |  |                   |  |       |  |
| 43          |             | 1                                                                                 |                                                  |                        |  |                   |  |       |  |
| 44          |             | 2                                                                                 |                                                  |                        |  |                   |  |       |  |
| 45          |             | 3                                                                                 |                                                  |                        |  |                   |  |       |  |
| 46          |             | 4                                                                                 |                                                  |                        |  |                   |  |       |  |
| 47          |             | 5                                                                                 |                                                  |                        |  |                   |  |       |  |
| 48          |             | 6                                                                                 |                                                  |                        |  |                   |  |       |  |
| 49          |             | 7                                                                                 |                                                  |                        |  |                   |  |       |  |
| 50          |             | 8                                                                                 |                                                  |                        |  |                   |  |       |  |
| 51          |             | 9                                                                                 |                                                  |                        |  |                   |  |       |  |
| 52          |             | 10                                                                                |                                                  |                        |  |                   |  |       |  |
| 53          |             | 11                                                                                |                                                  |                        |  |                   |  |       |  |
| 54          |             | 12                                                                                |                                                  |                        |  |                   |  |       |  |
| Rev.        | by          | 1.0                                                                               | SDFG                                             |                        |  |                   |  |       |  |
| Date        | Approved    | 29-08-25                                                                          | PRG                                              |                        |  |                   |  |       |  |

|      |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
|------|----------|----------------------------|----------------------------------------------------------------------------|---------|------------------------|-------------------|------------|--------|-------|----|---|
|      |          | idener.ai                  |                                                                            | PROYECT | GREEN-LOOP             |                   |            | Wastes |       |    |   |
|      |          |                            |                                                                            | Process | Bio-rubber manufacture |                   |            | Pag    | 3     | of | 3 |
| Item | Rev.     | WASTES (GASES AND VAPOURS) |                                                                            |         |                        |                   |            |        |       |    |   |
| 1    |          | Design case                |                                                                            |         |                        | Basic engineering |            |        |       |    |   |
| 2    |          | Equipment                  | Description                                                                |         |                        |                   | Flow (dm³) |        | Notes |    |   |
| 3    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 4    |          | Pulping                    | Heating of the reaction mixture                                            |         |                        |                   | N/A        |        | (2)   |    |   |
| 5    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 6    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 7    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 8    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 9    |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 10   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 11   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 12   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 13   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 14   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 15   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 16   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 17   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 18   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 19   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 20   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 21   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 22   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 23   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 24   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 25   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 26   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 27   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 28   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 29   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 30   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 31   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 32   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 33   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 34   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 35   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 36   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 37   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 38   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 39   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 40   |          |                            |                                                                            |         |                        |                   |            |        |       |    |   |
| 41   |          | Total                      |                                                                            |         |                        |                   | N/A        |        |       |    |   |
| 42   |          | Notes                      |                                                                            |         |                        |                   |            |        |       |    |   |
| 43   |          | 1                          | Vapours are released upon opening the reactor, no flow could be identified |         |                        |                   |            |        |       |    |   |
| 44   |          | 2                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 45   |          | 3                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 46   |          | 4                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 47   |          | 5                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 48   |          | 6                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 49   |          | 7                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 50   |          | 8                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 51   |          | 9                          |                                                                            |         |                        |                   |            |        |       |    |   |
| 52   |          | 10                         |                                                                            |         |                        |                   |            |        |       |    |   |
| 53   |          | 11                         |                                                                            |         |                        |                   |            |        |       |    |   |
| 54   |          | 12                         |                                                                            |         |                        |                   |            |        |       |    |   |
| Rev. | by       | 1.0                        | SDFG                                                                       |         |                        |                   |            |        |       |    |   |
| Date | Approved | 29-08-25                   | PRG                                                                        |         |                        |                   |            |        |       |    |   |

| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-plastic | WP4 | T6.3 | GUALA     | MYX and TDZ         |

## PFDs:



## Process description:

Two kinds of formulations have been tested in upscaling: PHBH modified extreme MFI formula (harder material) and scPHA aPHA blend + rice husk (softer material), which both are compounded by 80 % PHA + 20 % rice husk. Nevertheless, official tests have been performed considering the PHPB modified, so the process has been analysed taking this formulation into consideration.

During the process, the rice husk is dried and mixed with the PHA formula in the dispenser. Next, the formulation is extruded, dispensed in a hopper and finally moulded to give as results the bio-plastic caps. There are two different products depending on the machinery involved in the process: i) limoncello caps: the “Baby Pressa” moulder is used during injection moulding; and ii) olive oil caps: the selected moulder is the JSW55, and the hopper MW is introduced in addition to the hopper Moretto.

|      |          |                                                                                   |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
|------|----------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|-------------------------|-------------------|-----------------|-----------|-----------------|---------------------|----|---|
|      |          |  |                                                                                                         | PROYECT | GREEN-LOOP              |                   |                 |           | Mass and Energy |                     |    |   |
|      |          |                                                                                   |                                                                                                         | Process | Bio-plastic manufacture |                   |                 |           | Page            | 1                   | of | 4 |
| Item | Rev.     | MASS AND ENERGY BALANCES                                                          |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 1    |          | Operational data and flows                                                        |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 2    |          | Design case                                                                       |                                                                                                         |         |                         | Basic engineering |                 |           |                 |                     |    |   |
| 3    |          | Stream n°                                                                         |                                                                                                         |         |                         | 1                 | 2               | 3         | 4               | 5 <sup>(4)(5)</sup> |    |   |
| 4    |          | Description                                                                       |                                                                                                         |         |                         | Rice husk         | Exsiccated rice | PHA       | Inlet mixture   | Vacuum gases        |    |   |
| 5    |          |                                                                                   |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 6    |          | Pressure                                                                          | bar                                                                                                     |         |                         | 1.000             | 1.000           | 1.000     | 1.000           | 1.500 / 2.500       |    |   |
| 7    |          | Temperature                                                                       | °C                                                                                                      |         |                         | 25.000            | 25.000          | 25.000    | 25.000          | 135.000             |    |   |
| 8    |          | Mass flow                                                                         | g                                                                                                       |         |                         | 5000.000          | 5000.000        | 20000.000 | 25000.000       | Unknown             |    |   |
| 9    |          | % Vapor                                                                           | -                                                                                                       |         |                         | 5.000             | 5.000           | 0.000     | 0.200           | 100.000             |    |   |
| 10   |          | Total vapor mass flow                                                             | g                                                                                                       |         |                         | 2500.000          | 2500.000        | 0.000     | 50.000          | Unknown             |    |   |
| 11   |          | Non condensable (N2,...)                                                          | g                                                                                                       |         |                         | -                 | -               | -         | -               | -                   |    |   |
| 12   |          | Water steam                                                                       | g                                                                                                       |         |                         | 250.000           | 250.000         | -         | 50.000          | Unknown             |    |   |
| 13   |          | Hydrocarbons                                                                      | g                                                                                                       |         |                         | -                 | -               | -         | -               | -                   |    |   |
| 14   |          | Total liquid mass flow                                                            | g                                                                                                       |         |                         | 0.000             | 0.000           | 0.000     | 20.000          | 0.000               |    |   |
| 15   |          | Free water                                                                        | g                                                                                                       |         |                         | -                 | -               | -         | 20.000          | -                   |    |   |
| 16   |          | Hydrocarbons                                                                      | g                                                                                                       |         |                         | -                 | -               | -         | -               | -                   |    |   |
| 17   |          | Total enthalpy flow                                                               | J                                                                                                       |         |                         | Unknown           | Unknown         | Unknown   | 6250000.00      | Unknown             |    |   |
| 18   |          | Corrosive and toxic compounds                                                     | %w                                                                                                      |         |                         | -                 | -               | -         | -               | -                   |    |   |
| 19   |          | Solids present                                                                    | %                                                                                                       |         |                         | 95.000            | 95.000          | 100.000   | 99.700          | 0.000               |    |   |
| 20   |          | Solids particle size                                                              | Microns                                                                                                 |         |                         | 150.000           | 150.000         | 3000.000  | 3000.000        | -                   |    |   |
| 21   |          | (Wet) Steam phase properties                                                      |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 22   |          | Volumetric flow @P,T                                                              | dm³                                                                                                     |         |                         | 0.370             | 0.370           | 0.000     | 70.000          | Unknown             |    |   |
| 23   |          | Volumetric flow @(1 atm, 0°C)                                                     | dm³                                                                                                     |         |                         | Unknown           | Unknown         | Unknown   | Unknown         | Unknown             |    |   |
| 24   |          | Molecular weight                                                                  | g/mol                                                                                                   |         |                         | 588.000           | 588.000         | 525000.00 | 419000.000      | Unknown             |    |   |
| 25   |          | Density @T                                                                        | g/dm³                                                                                                   |         |                         | 675.000           | 675.000         | 1180.000  | 700.000         | Unknown             |    |   |
| 26   |          | Density @(1 atm, 0°C)                                                             | g/dm³                                                                                                   |         |                         | Unknown           | Unknown         | Unknown   | Unknown         | Unknown             |    |   |
| 27   |          | Viscosity @T                                                                      | cP                                                                                                      |         |                         | Unknown           | Unknown         | Unknown   | 650.000         | Unknown             |    |   |
| 28   |          | Thermal conductivity @T                                                           | J/(s·m·K)                                                                                               |         |                         | 0.125             | 0.125           | 0.180     | 0.0250          | Unknown             |    |   |
| 29   |          | Specific Heat @T                                                                  | J/(g·K)                                                                                                 |         |                         | 1.400             | 1.400           | 1.600     | 1.550           | Unknown             |    |   |
| 30   |          | Compressibility factor @P,T                                                       | -                                                                                                       |         |                         | Unknown           | Unknown         | Unknown   | Unknown         | Unknown             |    |   |
| 31   |          | C <sub>p</sub> /C <sub>v</sub>                                                    | -                                                                                                       |         |                         | Unknown           | Unknown         | Unknown   | Unknown         | Unknown             |    |   |
| 32   |          | Enthalpy flow                                                                     | J                                                                                                       |         |                         | Unknown           | Unknown         | Unknown   | Unknown         | Unknown             |    |   |
| 33   |          | Liquid phase properties                                                           |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 34   |          | Volumetric flow @P,T                                                              | dm³                                                                                                     |         |                         | -                 | -               | 0.0180    | 0.0180          | -                   |    |   |
| 35   |          | Volumetric flow @15°C                                                             | dm³                                                                                                     |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 36   |          | Density @T                                                                        | g/dm³                                                                                                   |         |                         | -                 | -               | 1.100     | 1.100           | -                   |    |   |
| 37   |          | Density @15°C                                                                     | g/dm³                                                                                                   |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 38   |          | Kinematic viscosity @T                                                            | cSt                                                                                                     |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 39   |          | Kinematic viscosity @50°C                                                         | cSt                                                                                                     |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 40   |          | Kinematic viscosity @100°C                                                        | cSt                                                                                                     |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 41   |          | Kinematic viscosity @150°C                                                        | cSt                                                                                                     |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 42   |          | Thermal conductivity @T                                                           | J/(s·m·K)                                                                                               |         |                         | -                 | -               | 0.200     | 0.200           | -                   |    |   |
| 43   |          | Specific Heat @T                                                                  | J/(g·K)                                                                                                 |         |                         | -                 | -               | 2.000     | 2.000           | -                   |    |   |
| 44   |          | Surface tension @P,T                                                              | dinas/cm                                                                                                |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 45   |          | Vapor pressure                                                                    | kg/cm² a                                                                                                |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 46   |          | Enthalpy flow                                                                     | J                                                                                                       |         |                         | -                 | -               | Unknown   | Unknown         | -                   |    |   |
| 47   |          | Miscellaneous                                                                     |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 48   |          |                                                                                   |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 49   |          | Notes                                                                             |                                                                                                         |         |                         |                   |                 |           |                 |                     |    |   |
| 50   |          | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                         |                   |                 |           |                 |                     |    |   |
| 51   |          | 2                                                                                 | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                         |                   |                 |           |                 |                     |    |   |
| 52   |          | 3                                                                                 | Data correspond to limoncello and olive oil manufactures, since both present the same formulation       |         |                         |                   |                 |           |                 |                     |    |   |
| 53   |          | 4                                                                                 | 1.5 bar and 2.5 bar in limoncello and olive oil processes, respectively                                 |         |                         |                   |                 |           |                 |                     |    |   |
| 54   |          | 5                                                                                 | Remaining gases from the dryer at inlet, not considered within the 5 kg of rice husk                    |         |                         |                   |                 |           |                 |                     |    |   |
| Rev. | by       | 1.0                                                                               | SDFG                                                                                                    |         |                         |                   |                 |           |                 |                     |    |   |
| Date | Approved | 29-08-25                                                                          | PRG                                                                                                     |         |                         |                   |                 |           |                 |                     |    |   |

|      |          |                                |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
|------|----------|--------------------------------|---------------------------------------------------------------------------------------------------------|---------|-------------------------|--------------------|-----------------------|------------------|------------------------|----|---|
|      |          | idener.ai                      |                                                                                                         | PROYECT | GREEN-LOOP              |                    |                       | Mass and Energy  |                        |    |   |
|      |          |                                |                                                                                                         | Process | Bio-plastic manufacture |                    |                       | Page             | 2                      | of | 4 |
| Item | Rev.     | MASS AND ENERGY BALANCES       |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 1    |          | Operational data and flows     |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 2    |          | Design case                    |                                                                                                         |         |                         | Basic engineering  |                       |                  |                        |    |   |
| 3    |          | Stream n°                      |                                                                                                         |         |                         | 6 <sup>(4)</sup>   | 7 <sup>(4)</sup>      | 8 <sup>(5)</sup> | 9 <sup>(4)</sup>       |    |   |
| 4    |          | Description                    |                                                                                                         |         |                         | Plastic formulatio | Exsiccated formulatio | Olive oil        | Limoncello / olive oil |    |   |
| 5    |          |                                |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 6    |          | Pressure                       | bar                                                                                                     |         | 1.500 /                 | 1.500 /            | 2.500                 | 1.500 /          |                        |    |   |
| 7    |          | Temperature                    | °C                                                                                                      |         | 135.000                 | 60.000             | 160.000               | 175.000          |                        |    |   |
| 8    |          | Mass flow                      | g                                                                                                       |         | 25000.000               | 25000.000          | 25000.000             | 25000.000        |                        |    |   |
| 9    |          | % Vapor                        | -                                                                                                       |         | 0.200                   | 0.200              | 0.200                 | 0.200            |                        |    |   |
| 10   |          | Total vapor mass flow          | g                                                                                                       |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 11   |          | Non condensable (N2,...)       | g                                                                                                       |         | -                       | -                  | -                     | -                |                        |    |   |
| 12   |          | Water steam                    | g                                                                                                       |         | 50.000                  | 50.000             | 50.000                | 50.000           |                        |    |   |
| 13   |          | Hydrocarbons                   | g                                                                                                       |         | -                       | -                  | -                     | -                |                        |    |   |
| 14   |          | Total liquid mass flow         | g                                                                                                       |         | 20.000                  | 20.000             | 20.000                | 20.000           |                        |    |   |
| 15   |          | Free water                     | g                                                                                                       |         | 20.000                  | 20.000             | 20.000                | 20.000           |                        |    |   |
| 16   |          | Hydrocarbons                   | g                                                                                                       |         | -                       | -                  | -                     | -                |                        |    |   |
| 17   |          | Total enthalpy flow            | J                                                                                                       |         | 6250000.0               | 6250000.0          | 6250000.0             | 6250000.00       |                        |    |   |
| 18   |          | Corrosive and toxic compounds  | %w                                                                                                      |         | -                       | -                  | -                     | -                |                        |    |   |
| 19   |          | Solids present                 | %                                                                                                       |         | 99.700                  | 99.700             | 99.700                | 99.700           |                        |    |   |
| 20   |          | Solids particle size           | Microns                                                                                                 |         | 3000.000                | 3000.000           | 3000.000              | 3000.000         |                        |    |   |
| 21   |          | (Wet) Steam phase properties   |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 22   |          | Volumetric flow @P,T           | dm³                                                                                                     |         | 70.000                  | 70.000             | 70.000                | 70.000           |                        |    |   |
| 23   |          | Volumetric flow @(1 atm, 0°C)  | dm³                                                                                                     |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 24   |          | Molecular weight               | g/mol                                                                                                   |         | 419000.00               | 419000.00          | 419000.00             | 419000.000       |                        |    |   |
| 25   |          | Density @T                     | g/dm³                                                                                                   |         | 700.000                 | 700.000            | 700.000               | 700.000          |                        |    |   |
| 26   |          | Density @(1 atm, 0°C)          | g/dm³                                                                                                   |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 27   |          | Viscosity @T                   | cP                                                                                                      |         | 650.000                 | 650.000            | 650.000               | 650.000          |                        |    |   |
| 28   |          | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | 0.0250                  | 0.0250             | 0.0250                | 0.0250           |                        |    |   |
| 29   |          | Specific Heat @T               | J/(g·K)                                                                                                 |         | 1.550                   | 1.550              | 1.550                 | 1.550            |                        |    |   |
| 30   |          | Compressibility factor @P,T    | -                                                                                                       |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 31   |          | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 32   |          | Enthalpy flow                  | J                                                                                                       |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 33   |          | Liquid phase properties        |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 34   |          | Volumetric flow @P,T           | dm³                                                                                                     |         | 0.0180                  | 0.0180             | 0.0180                | 0.0180           |                        |    |   |
| 35   |          | Volumetric flow @15°C          | dm³                                                                                                     |         | Unkown                  | Unkown             | Unkown                | Unkown           |                        |    |   |
| 36   |          | Density @T                     | g/dm³                                                                                                   |         | 1.100                   | 1.100              | 1.100                 | 1.100            |                        |    |   |
| 37   |          | Density @15°C                  | g/dm³                                                                                                   |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 38   |          | Kinematic viscosity @T         | cSt                                                                                                     |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 39   |          | Kinematic viscosity @50°C      | cSt                                                                                                     |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 40   |          | Kinematic viscosity @100°C     | cSt                                                                                                     |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 41   |          | Kinematic viscosity @150°C     | cSt                                                                                                     |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 42   |          | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | 0.200                   | 0.200              | 0.200                 | 0.200            |                        |    |   |
| 43   |          | Specific Heat @T               | J/(g·K)                                                                                                 |         | 2.000                   | 2.000              | 2.000                 | 2.000            |                        |    |   |
| 44   |          | Surface tension @P,T           | dinas/cm                                                                                                |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 45   |          | Vapor pressure                 | kg/cm² a                                                                                                |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 46   |          | Enthalpy flow                  | J                                                                                                       |         | Unknown                 | Unknown            | Unknown               | Unknown          |                        |    |   |
| 47   |          | Miscellaneous                  |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 48   |          |                                |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 49   |          | Notes                          |                                                                                                         |         |                         |                    |                       |                  |                        |    |   |
| 50   |          | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                         |                    |                       |                  |                        |    |   |
| 51   |          | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                         |                    |                       |                  |                        |    |   |
| 52   |          | 3                              | Data correspond to limoncello and olive oil manufactures, since both present the same formulation       |         |                         |                    |                       |                  |                        |    |   |
| 53   |          | 4                              | 1.5 bar and 2.5 bar in limoncello and olive oil processes, respectively                                 |         |                         |                    |                       |                  |                        |    |   |
| 54   |          | 5                              | Hopper MW is only applied within olive oil manufacturing process                                        |         |                         |                    |                       |                  |                        |    |   |
| Rev. | by       | 1.0                            | SDFG                                                                                                    |         |                         |                    |                       |                  |                        |    |   |
| Date | Approved | 29-08-25                       | PRG                                                                                                     |         |                         |                    |                       |                  |                        |    |   |

|             |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
|-------------|-------------|-----------------------------------------------------------------------------------|---------------------|----------------|----------------|-------------------------|----------------|----------------|----------------|-----------------|----------------|----------------|---|
|             |             |  |                     | PROYECT        |                | GREEN-LOOP              |                |                |                | Mass and Energy |                |                |   |
|             |             |                                                                                   |                     | Process        |                | Bio-plastic manufacture |                |                |                | Page            | 3              | of             | 4 |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 1           |             | <b>Compositions</b>                                                               |                     |                |                |                         |                |                |                |                 |                |                |   |
| 2           |             | Stream nº                                                                         | 1                   |                | 2              |                         | 3              |                | 4              |                 | 5              |                |   |
| 3           |             | Componen                                                                          | %                   | % mol          | %              | % mol                   | %              | % mol          | %              | % mol           | %              | % mol          |   |
| 4           |             | Rice husk                                                                         | 95.000              | 35.648         | 95.000         | 35.648                  | 0.000          | 0.000          | 19.944         | 67.284          | 19.944         | 67.284         |   |
| 5           |             | PHA <sup>(1)</sup>                                                                | 0.000               | 0.000          | 0.000          | 0.000                   | 100.000        | 100.000        | 79.776         | 0.317           | 79.776         | 0.317          |   |
| 6           |             | Water                                                                             | 5.000               | 64.352         | 5.000          | 64.352                  | 0.000          | 0.000          | 0.280          | 32.400          | 0.280          | 32.400         |   |
| 7           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 8           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 9           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 10          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 11          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 12          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 13          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 14          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 15          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 16          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 17          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 18          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 19          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 20          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 21          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 22          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 23          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 24          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 25          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 26          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 27          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 28          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 29          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 30          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 31          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 32          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 33          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 34          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 35          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 36          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 37          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |                |                |   |
| 38          |             | <b>Total</b>                                                                      | <b>100.000</b>      | <b>100.000</b> | <b>100.000</b> | <b>100.000</b>          | <b>100.000</b> | <b>100.000</b> | <b>100.000</b> | <b>100.000</b>  | <b>100.000</b> | <b>100.000</b> |   |
| 39          |             | Mass dry                                                                          |                     |                |                |                         |                |                |                |                 |                |                |   |
| 40          |             | flow (g)                                                                          |                     |                |                |                         |                |                |                |                 |                |                |   |
| 41          |             | Molar dry                                                                         |                     |                |                |                         |                |                |                |                 |                |                |   |
| 42          |             | flow (mol)                                                                        |                     |                |                |                         |                |                |                |                 |                |                |   |
| 43          |             | Mass wet                                                                          |                     |                |                |                         |                |                |                |                 |                |                |   |
| 44          |             | flow (g)                                                                          |                     |                |                |                         |                |                |                |                 |                |                |   |
| 45          |             | Molar wet                                                                         |                     |                |                |                         |                |                |                |                 |                |                |   |
| 46          |             | flow (mol)                                                                        |                     |                |                |                         |                |                |                |                 |                |                |   |
| 47          |             | <b>Notes</b>                                                                      |                     |                |                |                         |                |                |                |                 |                |                |   |
| 48          |             | 1                                                                                 | 100 % PHBH modified |                |                |                         |                |                |                |                 |                |                |   |
| 49          |             | 2                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| 50          |             | 3                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| 51          |             | 4                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| 52          |             | 5                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| 53          |             | 6                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| 54          |             | 7                                                                                 |                     |                |                |                         |                |                |                |                 |                |                |   |
| Rev.        | by          | 1.0                                                                               | SDFG                |                |                |                         |                |                |                |                 |                |                |   |
| Date        | Approved    | 29-08-25                                                                          | PRG                 |                |                |                         |                |                |                |                 |                |                |   |

|             |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
|-------------|-------------|-----------------------------------------------------------------------------------|---------------------|----------------|----------------|-------------------------|----------------|----------------|----------------|-----------------|---|-------|---|
|             |             |  |                     | PROYECT        |                | GREEN-LOOP              |                |                |                | Mass and Energy |   |       |   |
|             |             |                                                                                   |                     | Process        |                | Bio-plastic manufacture |                |                |                | Page            | 4 | of    | 4 |
| <b>Item</b> | <b>Rev.</b> | <b>MASS AND ENERGY BALANCES</b>                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 1           |             | <b>Compositions</b>                                                               |                     |                |                |                         |                |                |                |                 |   |       |   |
| 2           |             | Stream n°                                                                         | 6                   |                | 7              |                         | 8              |                | 9              |                 |   |       |   |
| 3           |             | Componen                                                                          | %                   | % mol          | %              | % mol                   | %              | % mol          | %              | % mol           | % | % mol |   |
| 4           |             | Rice husk                                                                         | Unknow              | Unknow         | 19.944         | 67.284                  | 19.944         | 67.284         | 19.944         | 67.284          |   |       |   |
| 5           |             | PHA <sup>(1)</sup>                                                                | 0.000               | 0.000          | 79.776         | 0.317                   | 79.776         | 0.317          | 79.776         | 0.317           |   |       |   |
| 6           |             | Water                                                                             | Unknow              | Unknow         | 0.280          | 32.400                  | 0.280          | 32.400         | 0.280          | 32.400          |   |       |   |
| 7           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 8           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 9           |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 10          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 11          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 12          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 13          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 14          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 15          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 16          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 17          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 18          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 19          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 20          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 21          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 22          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 23          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 24          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 25          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 26          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 27          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 28          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 29          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 30          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 31          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 32          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 33          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 34          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 35          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 36          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 37          |             |                                                                                   |                     |                |                |                         |                |                |                |                 |   |       |   |
| 38          |             | <b>Total</b>                                                                      | <b>Unkno</b>        | <b>Unknown</b> | <b>100.000</b> | <b>100.000</b>          | <b>100.000</b> | <b>100.000</b> | <b>100.000</b> | <b>100.000</b>  |   |       |   |
| 39          |             | Mass dry                                                                          |                     |                |                |                         |                |                |                |                 |   |       |   |
| 40          |             | flow (g)                                                                          |                     |                |                |                         |                |                |                |                 |   |       |   |
| 41          |             | Molar dry                                                                         |                     |                |                |                         |                |                |                |                 |   |       |   |
| 42          |             | flow (mol)                                                                        |                     |                |                |                         |                |                |                |                 |   |       |   |
| 43          |             | Mass wet                                                                          |                     |                |                |                         |                |                |                |                 |   |       |   |
| 44          |             | flow (g)                                                                          |                     |                |                |                         |                |                |                |                 |   |       |   |
| 45          |             | Molar wet                                                                         |                     |                |                |                         |                |                |                |                 |   |       |   |
| 46          |             | flow (mol)                                                                        |                     |                |                |                         |                |                |                |                 |   |       |   |
| 47          |             | <b>Notes</b>                                                                      |                     |                |                |                         |                |                |                |                 |   |       |   |
| 48          |             | 1                                                                                 | 100 % PHBH modified |                |                |                         |                |                |                |                 |   |       |   |
| 49          |             | 2                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| 50          |             | 3                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| 51          |             | 4                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| 52          |             | 5                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| 53          |             | 6                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| 54          |             | 7                                                                                 |                     |                |                |                         |                |                |                |                 |   |       |   |
| Rev.        | by          | 1.0                                                                               | SDFG                |                |                |                         |                |                |                |                 |   |       |   |
| Date        | Approved    | 29-08-25                                                                          | PRG                 |                |                |                         |                |                |                |                 |   |       |   |

|      |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
|------|----------|----------------------------------|---------------------------------------------------------------------------------------------------------|---------|-------------------------|-------------------|--|-----------------|---|----|---|
|      |          | idener.ai                        |                                                                                                         | PROYECT | GREEN-LOOP              |                   |  | Plant Utilities |   |    |   |
|      |          |                                  |                                                                                                         | Process | Bio-plastic manufacture |                   |  | Page            | 1 | of | 5 |
| Item | Rev.     | PLANT UTILITIES (COOLING DEMAND) |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 1    |          | Design case                      |                                                                                                         |         |                         | Basic engineering |  |                 |   |    |   |
| 2    |          | Equipment                        | Description                                                                                             |         |                         | Demand (kJ)       |  | Notes           |   |    |   |
| 3    |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 4    |          | NTP MIX                          | No cooling demand                                                                                       |         |                         | -                 |  | (2)             |   |    |   |
| 5    |          | Dispenser MIX                    | No cooling demand                                                                                       |         |                         | -                 |  | (2)             |   |    |   |
| 6    |          | Double extruder                  | Cooling needed to maintain the extruder temperature                                                     |         |                         | Unknown           |  | (2)             |   |    |   |
| 7    |          | Hopper MW                        | The system has a water chiller that runs to maintain                                                    |         |                         | 3960              |  | (3)             |   |    |   |
| 8    |          | Hopper Moretto                   | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,                                                              |         |                         | 200               |  | (4)             |   |    |   |
| 9    |          | JSW55                            | JSW 55, ANNO 2015, VOLT 400 Power 60-90 kw                                                              |         |                         | 2500              |  | (4)             |   |    |   |
| 10   |          | Baby Pressa                      | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER                                                           |         |                         | 800               |  | (4)             |   |    |   |
| 11   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 12   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 13   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 14   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 15   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 16   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 17   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 18   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 19   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 20   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 21   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 22   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 23   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 24   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 25   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 26   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 27   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 28   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 29   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 30   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 31   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 32   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 33   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 34   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 35   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 36   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 37   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 38   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 39   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 40   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 41   |          | Total                            |                                                                                                         |         |                         | 7460.000          |  |                 |   |    |   |
| 42   |          | Notes                            |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 43   |          | 1                                | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                         |                   |  |                 |   |    |   |
| 44   |          | 2                                | Data provided by MIXCYCLING                                                                             |         |                         |                   |  |                 |   |    |   |
| 45   |          | 3                                | Data provided by IDENER                                                                                 |         |                         |                   |  |                 |   |    |   |
| 46   |          | 4                                | Data provided by GUALA                                                                                  |         |                         |                   |  |                 |   |    |   |
| 47   |          | 5                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 48   |          | 6                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 49   |          | 7                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 50   |          | 8                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 51   |          | 9                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 52   |          | 10                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 53   |          | 11                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 54   |          | 12                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| Rev. | by       | 1.0                              | SDFG                                                                                                    |         |                         |                   |  |                 |   |    |   |
| Date | Approved | 29-08-25                         | PRG                                                                                                     |         |                         |                   |  |                 |   |    |   |

|      |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
|------|----------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|-------------------------|-------------------|------------|-----------------|-------|----|---|
|      |          |  |                                                                                                         | PROYECT | GREEN-LOOP              |                   |            | Plant Utilities |       |    |   |
|      |          |                                                                                   |                                                                                                         | Process | Bio-plastic manufacture |                   |            | Page            | 2     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (COOLING WATER)                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 1    |          | Design case                                                                       |                                                                                                         |         |                         | Basic engineering |            |                 |       |    |   |
| 2    |          | Equipment                                                                         | Description                                                                                             |         |                         |                   | Flow (dm³) |                 | Notes |    |   |
| 3    |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 4    |          | NTP MIX                                                                           | No cooling water                                                                                        |         |                         |                   | -          |                 | (3)   |    |   |
| 5    |          | Dispenser MIX                                                                     | No cooling water                                                                                        |         |                         |                   | -          |                 | (3)   |    |   |
| 6    |          | Double extruder                                                                   | Cooling needed to maintain the extruder temperature                                                     |         |                         |                   | 50         |                 | (3)   |    |   |
| 7    |          | Hopper MW                                                                         | The system has a water chiller that runs to maintain                                                    |         |                         |                   | 0          |                 | (4)   |    |   |
| 8    |          | Hopper Moretto                                                                    | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,                                                              |         |                         |                   | 15         |                 | (5)   |    |   |
| 9    |          | JSW55                                                                             | JSW 55, ANNO 2015, VOLT 400 Power 60-90 kw                                                              |         |                         |                   | 180        |                 | (5)   |    |   |
| 10   |          | Baby Pressa                                                                       | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER                                                           |         |                         |                   | 60         |                 | (5)   |    |   |
| 11   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 12   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 13   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 14   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 15   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 16   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 17   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 18   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 19   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 20   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 21   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 22   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 23   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 24   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 25   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 26   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 27   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 28   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 29   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 30   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 31   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 32   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 33   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 34   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 35   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 36   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 37   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 38   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 39   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 40   |          |                                                                                   |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 41   |          | Total                                                                             |                                                                                                         |         |                         |                   | 305.000    |                 |       |    |   |
| 42   |          | Notes                                                                             |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 43   |          | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                         |                   |            |                 |       |    |   |
| 44   |          | 2                                                                                 | The flow values with positive sign are positive cooling water flows with the ΔT of the design           |         |                         |                   |            |                 |       |    |   |
| 45   |          |                                                                                   | specification, indicate if the ΔT is different in any case including it on the notes of this datasheet  |         |                         |                   |            |                 |       |    |   |
| 46   |          | 3                                                                                 | Data provided by MIXCYCLING                                                                             |         |                         |                   |            |                 |       |    |   |
| 47   |          | 4                                                                                 | Data provided by IDENER                                                                                 |         |                         |                   |            |                 |       |    |   |
| 48   |          | 5                                                                                 | Data provided by GUALA                                                                                  |         |                         |                   |            |                 |       |    |   |
| 49   |          | 6                                                                                 |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 50   |          | 7                                                                                 |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 51   |          | 8                                                                                 |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 52   |          | 9                                                                                 |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 53   |          | 10                                                                                |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| 54   |          | 11                                                                                |                                                                                                         |         |                         |                   |            |                 |       |    |   |
| Rev. | by       | 1.0                                                                               | SDFG                                                                                                    |         |                         |                   |            |                 |       |    |   |
| Date | Approved | 29-08-25                                                                          | PRG                                                                                                     |         |                         |                   |            |                 |       |    |   |

|      |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
|------|----------|----------------------------------|---------------------------------------------------------------------------------------------------------|---------|-------------------------|-------------------|--|-----------------|---|----|---|
|      |          | idener.ai                        |                                                                                                         | PROYECT | GREEN-LOOP              |                   |  | Plant Utilities |   |    |   |
|      |          |                                  |                                                                                                         | Process | Bio-plastic manufacture |                   |  | Page            | 3 | of | 5 |
| Item | Rev.     | PLANT UTILITIES (HEATING DEMAND) |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 1    |          | Design case                      |                                                                                                         |         |                         | Basic engineering |  |                 |   |    |   |
| 2    |          | Equipment                        | Description                                                                                             |         |                         | Demand (kJ)       |  | Notes           |   |    |   |
| 3    |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 4    |          | NTP MIX                          | No cooling water                                                                                        |         |                         | -                 |  | (2)             |   |    |   |
| 5    |          | Dispenser MIX                    | No cooling water                                                                                        |         |                         | -                 |  | (2)             |   |    |   |
| 6    |          | Double extruder                  | Cooling needed to maintain the extruder temperature                                                     |         |                         | 54000             |  | (2)             |   |    |   |
| 7    |          | Hopper MW                        | The system has a water chiller that runs to maintain                                                    |         |                         | 0                 |  | (3)             |   |    |   |
| 8    |          | Hopper Moretto                   | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,                                                              |         |                         | 1000              |  | (4)             |   |    |   |
| 9    |          | JSW55                            | JSW 55, ANNO 2015, VOLT 400 Power 60-90 kw                                                              |         |                         | 3200              |  | (4)             |   |    |   |
| 10   |          | Baby Pressa                      | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER                                                           |         |                         | 1500              |  | (4)             |   |    |   |
| 11   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 12   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 13   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 14   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 15   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 16   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 17   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 18   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 19   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 20   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 21   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 22   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 23   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 24   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 25   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 26   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 27   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 28   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 29   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 30   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 31   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 32   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 33   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 34   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 35   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 36   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 37   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 38   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 39   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 40   |          |                                  |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 41   |          | Total                            |                                                                                                         |         |                         | 59700.000         |  |                 |   |    |   |
| 42   |          | Notes                            |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 43   |          | 1                                | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                         |                   |  |                 |   |    |   |
| 44   |          | 2                                | Data provided by MIXCYCLING                                                                             |         |                         |                   |  |                 |   |    |   |
| 45   |          | 3                                | Data provided by IDENER                                                                                 |         |                         |                   |  |                 |   |    |   |
| 46   |          | 4                                | Data provided by GUALA                                                                                  |         |                         |                   |  |                 |   |    |   |
| 47   |          | 5                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 48   |          | 6                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 49   |          | 7                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 50   |          | 8                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 51   |          | 9                                |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 52   |          | 10                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 53   |          | 11                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| 54   |          | 12                               |                                                                                                         |         |                         |                   |  |                 |   |    |   |
| Rev. | by       | 1.0                              | SDFG                                                                                                    |         |                         |                   |  |                 |   |    |   |
| Date | Approved | 29-08-25                         | PRG                                                                                                     |         |                         |                   |  |                 |   |    |   |

|      |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
|------|----------|------------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------|-------------------------|-------------|-----------------|-----|---|----|---|
|      |          | idener.a                           |                                                                                                         | PROYECT                 | GREEN-LOOP              |             | Plant Utilities |     |   |    |   |
|      |          |                                    |                                                                                                         | Process                 | Bio-plastic manufacture |             |                 | Pag | 4 | of | 5 |
| Item | Rev.     | PLANT UTILITIES (FUEL CONSUMPTION) |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 1    |          | Design case                        |                                                                                                         |                         | Basic engineering       |             |                 |     |   |    |   |
| 2    |          | Equipment                          | Description                                                                                             | Fuel consumption (m³/h) |                         |             | Notes           |     |   |    |   |
| 3    |          |                                    |                                                                                                         | Fuel oil                | Fuel gas                | Natural gas |                 |     |   |    |   |
| 4    |          | NTP MIX                            | No fuel use                                                                                             | -                       | -                       | -           | (3)             |     |   |    |   |
| 5    |          | Dispenser MIX                      | No fuel use                                                                                             | -                       | -                       | -           | (3)             |     |   |    |   |
| 6    |          | Double extruder                    | No fuel use                                                                                             | -                       | -                       | -           | (3)             |     |   |    |   |
| 7    |          | Hopper MW                          | No fuel use                                                                                             | -                       | -                       | -           | (4)             |     |   |    |   |
| 8    |          | Hopper Moretto                     | No fuel use                                                                                             | -                       | -                       | -           | (5)             |     |   |    |   |
| 9    |          | JSW55                              | No fuel use                                                                                             | -                       | -                       | -           | (5)             |     |   |    |   |
| 10   |          | Baby Pressa                        | No fuel use                                                                                             | -                       | -                       | -           | (5)             |     |   |    |   |
| 11   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 12   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 13   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 14   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 15   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 16   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 17   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 18   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 19   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 20   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 21   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 22   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 23   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 24   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 25   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 26   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 27   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 28   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 29   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 30   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 31   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 32   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 33   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 34   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 35   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 36   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 37   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 38   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 39   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 40   |          |                                    |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 41   |          | Total                              |                                                                                                         | -                       | -                       | -           |                 |     |   |    |   |
| 42   |          | Notes                              |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 43   |          | 1                                  | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                         |                         |             |                 |     |   |    |   |
| 44   |          | 2                                  | Positive values are consumptions; negative values are by-products of the process                        |                         |                         |             |                 |     |   |    |   |
| 45   |          | 3                                  | Data provided by MIXCYCLING                                                                             |                         |                         |             |                 |     |   |    |   |
| 46   |          | 4                                  | Data provided by IDENER                                                                                 |                         |                         |             |                 |     |   |    |   |
| 47   |          | 5                                  | Data provided by GUALA                                                                                  |                         |                         |             |                 |     |   |    |   |
| 48   |          | 6                                  |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 49   |          | 11                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 50   |          | 12                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 51   |          | 13                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 52   |          | 14                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 53   |          | 15                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| 54   |          | 16                                 |                                                                                                         |                         |                         |             |                 |     |   |    |   |
| Rev. | by       | 1.0                                | SDFG                                                                                                    |                         |                         |             |                 |     |   |    |   |
| Date | Approved | 29-08-25                           | PRG                                                                                                     |                         |                         |             |                 |     |   |    |   |

|      |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
|------|----------|-------------------------------|---------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-------------------------|-------------------|--|------------------|---|-------------|---|
|      |          | idener.ai                     |                                                                                                         | PROYECT                                                | GREEN-LOOP              |                   |  | Plant Utilities  |   |             |   |
|      |          |                               |                                                                                                         | Process                                                | Bio-plastic manufacture |                   |  | Pag              | 5 | of          | 5 |
| Item | Rev      | PLANT UTILITIES (ELECTRICITY) |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 1    |          | Design case                   |                                                                                                         |                                                        |                         | Basic engineering |  |                  |   |             |   |
| 2    |          | Equipment                     |                                                                                                         | Description                                            |                         |                   |  | Consumption (kJ) |   | Notes       |   |
| 3    |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 4    |          | NTP MIX                       |                                                                                                         | For 5 kg of rice husk                                  |                         |                   |  | 10800.000        |   | (3)         |   |
| 5    |          | Dispenser MIX                 |                                                                                                         | For 25 kg of compound                                  |                         |                   |  | 1879.200         |   | (3)         |   |
| 6    |          | Double extruder               |                                                                                                         | For 25 kg of compound                                  |                         |                   |  | 75060.000        |   | (3)(6)      |   |
| 7    |          | Hopper MW                     |                                                                                                         | 1 kg of material was heated to 60 °C in 150 seconds at |                         |                   |  | 8460.000         |   | (4)(7)(11)  |   |
| 8    |          | Hopper Moretto                |                                                                                                         | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,             |                         |                   |  | 3600.000         |   | (5)(8)      |   |
| 9    |          | JSW55                         |                                                                                                         | JSW 55, ANNO 2015, VOLT 400, Power 60-90 kw            |                         |                   |  | 270000.000       |   | (5)(9)(12)  |   |
| 10   |          | Baby Pressa                   |                                                                                                         | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER          |                         |                   |  | 10800.000        |   | (5)(10)(12) |   |
| 11   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 12   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 13   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 14   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 15   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 16   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 17   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 18   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 19   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 20   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 21   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 22   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 23   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 24   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 25   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 26   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 27   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 28   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 29   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 30   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 31   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 32   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 33   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 34   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 35   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 36   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 37   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 38   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 39   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 40   |          |                               |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 41   |          | Total                         |                                                                                                         |                                                        |                         |                   |  | 380599.200       |   |             |   |
| 42   |          | Notes                         |                                                                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 43   |          | 1                             | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                                                        |                         |                   |  |                  |   |             |   |
| 44   |          | 2                             | Positive values are consumptions; negative values are by-products of the process                        |                                                        |                         |                   |  |                  |   |             |   |
| 45   |          | 3                             | Data provided by MIXCYCLING                                                                             |                                                        |                         |                   |  |                  |   |             |   |
| 46   |          | 4                             | Data provided by IDENER                                                                                 |                                                        |                         |                   |  |                  |   |             |   |
| 47   |          | 5                             | Data provided by GUALA                                                                                  |                                                        |                         |                   |  |                  |   |             |   |
| 48   |          | 6                             | Total consumption in extruder, including extrusion, heating and cooling                                 |                                                        |                         |                   |  |                  |   |             |   |
| 49   |          | 7                             | Total consumption in hopper MW, including microwaves and chiller                                        |                                                        |                         |                   |  |                  |   |             |   |
| 50   |          | 8                             | Total consumption in hopper Moretto, including drying, heating and cooling                              |                                                        |                         |                   |  |                  |   |             |   |
| 51   |          | 9                             | Total consumption in JSW55, including pressing, heating and cooling                                     |                                                        |                         |                   |  |                  |   |             |   |
| 52   |          | 10                            | Total consumption in Baby Pressa, including pressing, heating and cooling                               |                                                        |                         |                   |  |                  |   |             |   |
| 53   |          | 11                            | Hopper MW is only used in olive oil manufacture                                                         |                                                        |                         |                   |  |                  |   |             |   |
| 54   |          | 12                            | Injection moulding Baby Pressa corresponds to limoncello manufacture, whereas JSW55 is so to olive      |                                                        |                         |                   |  |                  |   |             |   |
| Rev. | by       | 1.0                           | SDFG                                                                                                    |                                                        |                         |                   |  |                  |   |             |   |
| Date | Approved | 29-08-25                      | PRG                                                                                                     |                                                        |                         |                   |  |                  |   |             |   |

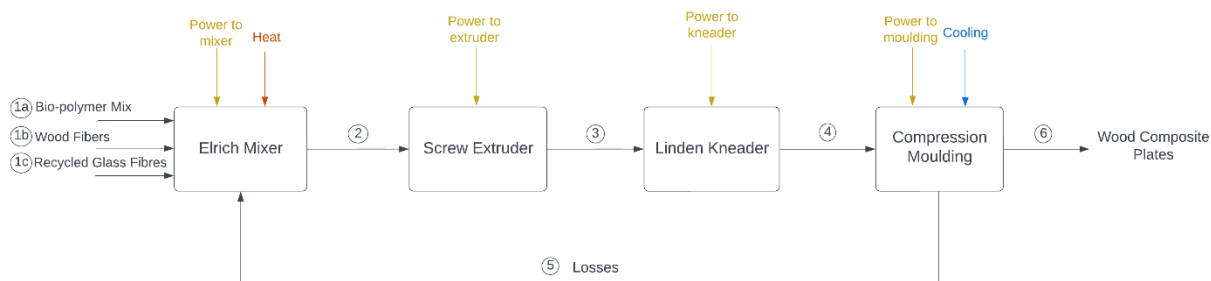
|      |          | idener.ai       |                             | PROYECT                                       | GREEN-LOOP              | Wastes            |               |     |       |    |   |
|------|----------|-----------------|-----------------------------|-----------------------------------------------|-------------------------|-------------------|---------------|-----|-------|----|---|
|      |          |                 |                             | Process                                       | Bio-plastic manufacture |                   |               | Pag | 1     | of | 3 |
| Item | Rev.     | WASTES (SOLIDS) |                             |                                               |                         |                   |               |     |       |    |   |
| 1    |          | Design case     |                             |                                               |                         | Basic engineering |               |     |       |    |   |
| 2    |          | Equipment       |                             | Description                                   |                         |                   | Mass Flow (g) |     | Notes |    |   |
| 3    |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 4    |          | NTP MIX         |                             | No waste                                      |                         |                   | -             |     | (1)   |    |   |
| 5    |          | Dispenser MIX   |                             | No waste                                      |                         |                   | -             |     | (1)   |    |   |
| 6    |          | Double extruder |                             | No waste                                      |                         |                   | -             |     | (1)   |    |   |
| 7    |          | Hopper MW       |                             | No waste                                      |                         |                   | -             |     | (2)   |    |   |
| 8    |          | Hopper Moretto  |                             | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,    |                         |                   | 1875          |     | (3)   |    |   |
| 9    |          | JSW55           |                             | JSW 55, ANNO 2015, VOLT 400, Power 60-90 kw   |                         |                   | 1875          |     | (3)   |    |   |
| 10   |          | Baby Pressa     |                             | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER |                         |                   | 1875          |     | (3)   |    |   |
| 11   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 12   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 13   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 14   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 15   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 16   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 17   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 18   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 19   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 20   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 21   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 22   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 23   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 24   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 25   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 26   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 27   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 28   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 29   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 30   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 31   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 32   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 33   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 34   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 35   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 36   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 37   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 38   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 39   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 40   |          |                 |                             |                                               |                         |                   |               |     |       |    |   |
| 41   |          | Total           |                             |                                               |                         |                   | 5625.000      |     |       |    |   |
| 42   |          | Notes           |                             |                                               |                         |                   |               |     |       |    |   |
| 43   |          | 1               | Data provided by MIXCYCLING |                                               |                         |                   |               |     |       |    |   |
| 44   |          | 2               | Data provided by IDENER     |                                               |                         |                   |               |     |       |    |   |
| 45   |          | 3               | Data provided by GUALA      |                                               |                         |                   |               |     |       |    |   |
| 46   |          | 4               |                             |                                               |                         |                   |               |     |       |    |   |
| 47   |          | 5               |                             |                                               |                         |                   |               |     |       |    |   |
| 48   |          | 6               |                             |                                               |                         |                   |               |     |       |    |   |
| 49   |          | 7               |                             |                                               |                         |                   |               |     |       |    |   |
| 50   |          | 8               |                             |                                               |                         |                   |               |     |       |    |   |
| 51   |          | 9               |                             |                                               |                         |                   |               |     |       |    |   |
| 52   |          | 10              |                             |                                               |                         |                   |               |     |       |    |   |
| 53   |          | 11              |                             |                                               |                         |                   |               |     |       |    |   |
| 54   |          | 12              |                             |                                               |                         |                   |               |     |       |    |   |
| Rev. | by       | 1.0             | SDFG                        |                                               |                         |                   |               |     |       |    |   |
| Date | Approved | 29-08-25        | PRG                         |                                               |                         |                   |               |     |       |    |   |

|      |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
|------|-----|------------------|--------------------------------------------------------|---------|-------------------------|-------------------|------------|--------|-------|----|---|
|      |     | idener.ai        |                                                        | PROYECT | GREEN-LOOP              |                   |            | Wastes |       |    |   |
|      |     |                  |                                                        | Process | Bio-plastic manufacture |                   |            | Pag    | 2     | of | 3 |
| Item | Rev | WASTES (LIQUIDS) |                                                        |         |                         |                   |            |        |       |    |   |
| 1    |     | Design case      |                                                        |         |                         | Basic engineering |            |        |       |    |   |
| 2    |     | Equipment        | Description                                            |         |                         |                   | Flow (dm³) |        | Notes |    |   |
| 3    |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 4    |     | NTP MIX          | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 5    |     | Dispenser MIX    | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 6    |     | Double extruder  | Closed circuit, no water waste. Total capacity of 50 l |         |                         |                   | -          |        |       |    |   |
| 7    |     | Hopper MW        | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 8    |     | Hopper Moretto   | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 9    |     | JSW55            | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 10   |     | Baby Pressa      | No waste                                               |         |                         |                   | -          |        |       |    |   |
| 11   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 12   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 13   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 14   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 15   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 16   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 17   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 18   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 19   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 20   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 21   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 22   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 23   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 24   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 25   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 26   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 27   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 28   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 29   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 30   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 31   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 32   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 33   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 34   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 35   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 36   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 37   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 38   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 39   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 40   |     |                  |                                                        |         |                         |                   |            |        |       |    |   |
| 41   |     | Total            |                                                        |         |                         |                   | -          |        |       |    |   |
| 42   |     | Notes            |                                                        |         |                         |                   |            |        |       |    |   |
| 43   |     | 1                | Data provided by MIXCYCLING                            |         |                         |                   |            |        |       |    |   |
| 44   |     | 2                | Data provided by IDENER                                |         |                         |                   |            |        |       |    |   |
| 45   |     | 3                | Data provided by GUALA                                 |         |                         |                   |            |        |       |    |   |
| 46   |     | 4                |                                                        |         |                         |                   |            |        |       |    |   |
| 47   |     | 5                |                                                        |         |                         |                   |            |        |       |    |   |
| 48   |     | 6                |                                                        |         |                         |                   |            |        |       |    |   |
| 49   |     | 7                |                                                        |         |                         |                   |            |        |       |    |   |
| 50   |     | 8                |                                                        |         |                         |                   |            |        |       |    |   |
| 51   |     | 9                |                                                        |         |                         |                   |            |        |       |    |   |
| 52   |     | 10               |                                                        |         |                         |                   |            |        |       |    |   |
| 53   |     | 11               |                                                        |         |                         |                   |            |        |       |    |   |
| 54   |     | 12               |                                                        |         |                         |                   |            |        |       |    |   |
| Rev. |     | by               | 1.0                                                    | SDFG    |                         |                   |            |        |       |    |   |
| Date |     | Approved         | 29-08-25                                               | PRG     |                         |                   |            |        |       |    |   |

|          |          |                            |                                               |         |                         |  |                   |            |   |        |   |
|----------|----------|----------------------------|-----------------------------------------------|---------|-------------------------|--|-------------------|------------|---|--------|---|
|          |          | idener.ai                  |                                               | PROYECT | GREEN-LOOP              |  |                   | Wastes     |   |        |   |
|          |          |                            |                                               | Process | Bio-plastic manufacture |  |                   | Pag        | 3 | of     | 3 |
| Ite<br>m | Rev<br>. | WASTES (GASES AND VAPOURS) |                                               |         |                         |  |                   |            |   |        |   |
| 1        |          | Design case                |                                               |         |                         |  | Basic engineering |            |   |        |   |
| 2        |          | Equipment                  | Description                                   |         |                         |  |                   | Flow (dm³) |   | Notes  |   |
| 3        |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 4        |          | NTP MIX                    | -                                             |         |                         |  |                   | -          |   | (1)    |   |
| 5        |          | Dispenser MIX              | -                                             |         |                         |  |                   | -          |   | (1)    |   |
| 6        |          | Double extruder            | -                                             |         |                         |  |                   | -          |   | (1)    |   |
| 7        |          | Hopper MW                  | -                                             |         |                         |  |                   | -          |   | (2)    |   |
| 8        |          | Hopper Moretto             | HOPPER DEHUMIDIFYING, ANNO 2019, VOLT 230,    |         |                         |  |                   | 10         |   | (3)(4) |   |
| 9        |          | JSW55                      | JSW 55, ANNO 2015, VOLT 400, Power 60-90 kw   |         |                         |  |                   | 5          |   | (3)(4) |   |
| 10       |          | Baby Pressa                | MEGATECH H10/18-1, ANNO 2018, VOLT 400, POWER |         |                         |  |                   | 5          |   | (3)(5) |   |
| 11       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 12       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 13       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 14       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 15       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 16       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 17       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 18       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 19       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 20       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 21       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 22       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 23       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 24       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 25       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 26       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 27       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 28       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 29       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 30       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 31       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 32       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 33       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 34       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 35       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 36       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 37       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 38       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 39       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 40       |          |                            |                                               |         |                         |  |                   |            |   |        |   |
| 41       |          | Total                      |                                               |         |                         |  |                   | 20.000     |   |        |   |
| 42       |          | Notes                      |                                               |         |                         |  |                   |            |   |        |   |
| 43       |          | 1                          | Data provided by MIXCYCLING                   |         |                         |  |                   |            |   |        |   |
| 44       |          | 2                          | Data provided by IDENER                       |         |                         |  |                   |            |   |        |   |
| 45       |          | 3                          | Data provided by GUALA                        |         |                         |  |                   |            |   |        |   |
| 46       |          | 4                          | Gases wasted during humidification            |         |                         |  |                   |            |   |        |   |
| 47       |          | 5                          | Gases wasted during venting                   |         |                         |  |                   |            |   |        |   |
| 48       |          | 6                          |                                               |         |                         |  |                   |            |   |        |   |
| 49       |          | 7                          |                                               |         |                         |  |                   |            |   |        |   |
| 50       |          | 8                          |                                               |         |                         |  |                   |            |   |        |   |
| 51       |          | 9                          |                                               |         |                         |  |                   |            |   |        |   |
| 52       |          | 10                         |                                               |         |                         |  |                   |            |   |        |   |
| 53       |          | 11                         |                                               |         |                         |  |                   |            |   |        |   |
| 54       |          | 12                         |                                               |         |                         |  |                   |            |   |        |   |
| Rev.     | by       | 1.0                        | SDFG                                          |         |                         |  |                   |            |   |        |   |
| Date     | Approved | 29-08-25                   | PRG                                           |         |                         |  |                   |            |   |        |   |

| Value chain     | WP  | Task | WP Leader | Consortium partners |
|-----------------|-----|------|-----------|---------------------|
| Wood composites | WP5 | T6.4 | FHF       | GUALA               |

## PFDs:



## Process description:

Glass fibres (FG 400/100) are recycled in the manufacturing of wood composites whereas the rest of inlet materials have biological origins -bio-polymer mix and wood fibres (ARBOCEL C400)-. After mixing in the elrich mixer, the species are extruded and kneaded at 473 K to generate the final product, which is taken in samples of 60 g to produce the plates in the compression moulding. From these samples, 10 g are wasted (i. e., 1/6 of samples): after the process, the 1/6 fraction of the compound is used in the input of the next batch process.

|                              |      | idener.ai                      |                                                                                                         | PROYECT | GREEN-LOOP                  | Mass and Energy   |             |                       |                  |                  |   |
|------------------------------|------|--------------------------------|---------------------------------------------------------------------------------------------------------|---------|-----------------------------|-------------------|-------------|-----------------------|------------------|------------------|---|
|                              |      |                                |                                                                                                         | Process | Wood composites manufacture |                   |             | Page                  | 1                | of               | 4 |
| Item                         | Rev. | MASS AND ENERGY BALANCES       |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| Operational data and flows   |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 1                            |      |                                |                                                                                                         |         |                             | Basic engineering |             |                       |                  |                  |   |
| 2                            |      | Design case                    |                                                                                                         |         |                             | 1a                | 1b          | 1c                    | 2 <sup>(3)</sup> | 3                |   |
| 3                            |      | Stream n°                      |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 4                            |      | Description                    |                                                                                                         |         |                             | Bio-polymer       | Wood fibres | Recycled glass fibres | Outlet mixture   | Extruded mixture |   |
| 5                            |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 6                            |      | Pressure                       | bar                                                                                                     |         | 1.000                       | 1.000             | 1.000       | 1.000                 | 1.000            |                  |   |
| 7                            |      | Temperature                    | °C                                                                                                      |         | 25.000                      | 25.00             | 25.00       | 200.00                | 200.00           |                  |   |
| 8                            |      | Mass flow                      | g                                                                                                       |         | 1000.000                    | 430.100           | 524.900     | 1955.000              | 1955.000         |                  |   |
| 9                            |      | % Vapor                        | -                                                                                                       |         | 0.000                       | 0.000             | 0.000       | 0.000                 | 0.000            |                  |   |
| 10                           |      | Total vapor mass flow          | g                                                                                                       |         | 0.000                       | 0.000             | 0.000       | 0.000                 | 0.000            |                  |   |
| 11                           |      | Non condensable (N2,...)       | g                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 12                           |      | Water steam                    | g                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 13                           |      | Hydrocarbons                   | g                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 14                           |      | Total liquid mass flow         | g                                                                                                       |         | 0.000                       | 0.000             | 0.000       | 0.000                 | 0.000            |                  |   |
| 15                           |      | Free water                     | g                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 16                           |      | Hydrocarbons                   | g                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 17                           |      | Total enthalpy flow            | J                                                                                                       |         | Unknown                     | Unknown           | Unknown     | Unknown               | Unknown          |                  |   |
| 18                           |      | Corrosive and toxic compounds  | %w                                                                                                      |         | Unknown                     | Unknown           | Unknown     | Unknown               | Unknown          |                  |   |
| 19                           |      | Solids present                 | %                                                                                                       |         | 100.000                     | 100.000           | 100.000     | 100.000               | 100.000          |                  |   |
| 20                           |      | Solids particle size           | Microns                                                                                                 |         | Unknown                     | Unknown           | Unknown     | Unknown               | Unknown          |                  |   |
| (Wet) Steam phase properties |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 22                           |      | Volumetric flow @P,T           | dm³                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 23                           |      | Volumetric flow @(1 atm, 0°C)  | dm³                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 24                           |      | Molecular weight               | g/mol                                                                                                   |         | -                           | -                 | -           | -                     | -                |                  |   |
| 25                           |      | Density @T                     | g/dm³                                                                                                   |         | -                           | -                 | -           | -                     | -                |                  |   |
| 26                           |      | Density @(1 atm, 0°C)          | g/dm³                                                                                                   |         | -                           | -                 | -           | -                     | -                |                  |   |
| 27                           |      | Viscosity @T                   | cP                                                                                                      |         | -                           | -                 | -           | -                     | -                |                  |   |
| 28                           |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | -                           | -                 | -           | -                     | -                |                  |   |
| 29                           |      | Specific Heat @T               | J/(g·K)                                                                                                 |         | -                           | -                 | -           | -                     | -                |                  |   |
| 30                           |      | Compressibility factor @P,T    | -                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 31                           |      | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| 32                           |      | Enthalpy flow                  | J                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| Liquid phase properties      |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 34                           |      | Volumetric flow @P,T           | dm³                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 35                           |      | Volumetric flow @15°C          | dm³                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 36                           |      | Density @T                     | g/dm³                                                                                                   |         | -                           | -                 | -           | -                     | -                |                  |   |
| 37                           |      | Density @15°C                  | g/dm³                                                                                                   |         | -                           | -                 | -           | -                     | -                |                  |   |
| 38                           |      | Kinematic viscosity @T         | cSt                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 39                           |      | Kinematic viscosity @50°C      | cSt                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 40                           |      | Kinematic viscosity @100°C     | cSt                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 41                           |      | Kinematic viscosity @150°C     | cSt                                                                                                     |         | -                           | -                 | -           | -                     | -                |                  |   |
| 42                           |      | Thermal conductivity @T        | J/(s·m·K)                                                                                               |         | -                           | -                 | -           | -                     | -                |                  |   |
| 43                           |      | Specific Heat @T               | J/(g·K)                                                                                                 |         | -                           | -                 | -           | -                     | -                |                  |   |
| 44                           |      | Surface tension @P,T           | dinas/cm                                                                                                |         | -                           | -                 | -           | -                     | -                |                  |   |
| 45                           |      | Vapor pressure                 | kg/cm² a                                                                                                |         | -                           | -                 | -           | -                     | -                |                  |   |
| 46                           |      | Enthalpy flow                  | J                                                                                                       |         | -                           | -                 | -           | -                     | -                |                  |   |
| Miscellaneous                |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 47                           |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 48                           |      |                                |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 49                           |      | Notes                          |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 50                           |      | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                             |                   |             |                       |                  |                  |   |
| 51                           |      | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |         |                             |                   |             |                       |                  |                  |   |
| 52                           |      | 3                              | The losses of step 5 are reused in compound to obtain the mixture                                       |         |                             |                   |             |                       |                  |                  |   |
| 53                           |      | 4                              |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| 54                           |      | 5                              |                                                                                                         |         |                             |                   |             |                       |                  |                  |   |
| Rev.                         |      | by                             | 1.0                                                                                                     | SDFG    |                             |                   |             |                       |                  |                  |   |
| Date                         |      | Approved                       | 29-08-25                                                                                                | PRG     |                             |                   |             |                       |                  |                  |   |

|          |          | idener.ai                      |                                                                                                         | PROYECT        | GREEN-LOOP                  | Mass and Energy   |   |    |   |
|----------|----------|--------------------------------|---------------------------------------------------------------------------------------------------------|----------------|-----------------------------|-------------------|---|----|---|
|          |          |                                |                                                                                                         | Process        | Wood composites manufacture | Page              | 2 | of | 4 |
| Ite<br>m | Rev      | MASS AND ENERGY BALANCES       |                                                                                                         |                |                             |                   |   |    |   |
| 1        |          | Operational data and flows     |                                                                                                         |                |                             |                   |   |    |   |
| 2        |          | Design case                    |                                                                                                         |                |                             | Basic engineering |   |    |   |
| 3        |          | Stream n°                      |                                                                                                         | 4              | 5 <sup>(3)</sup>            | 6 <sup>(4)</sup>  |   |    |   |
| 4        |          | Description                    |                                                                                                         | Cut<br>mixture | Losses                      | WC plates         |   |    |   |
| 5        |          |                                |                                                                                                         |                |                             |                   |   |    |   |
| 6        |          | Pressure                       | bar                                                                                                     | 1.000          | 1.000                       | 1.000             |   |    |   |
| 7        |          | Temperature                    | °C                                                                                                      | 200.00         | 200.00                      | 200.00            |   |    |   |
| 8        |          | Mass flow                      | g                                                                                                       | 1955.000       | 325.833                     | 1629.170          |   |    |   |
| 9        |          | % Vapor                        | -                                                                                                       | 0.000          | 0.000                       | 0.000             |   |    |   |
| 10       |          | Total vapor mass flow          | g                                                                                                       | 0.000          | 0.000                       | 0.000             |   |    |   |
| 11       |          | Non condensable (N2,...)       | g                                                                                                       | -              | -                           | -                 |   |    |   |
| 12       |          | Water steam                    | g                                                                                                       | -              | -                           | -                 |   |    |   |
| 13       |          | Hydrocarbons                   | g                                                                                                       | -              | -                           | -                 |   |    |   |
| 14       |          | Total liquid mass flow         | g                                                                                                       | 0.000          | 0.000                       | 0.000             |   |    |   |
| 15       |          | Free water                     | g                                                                                                       | -              | -                           | -                 |   |    |   |
| 16       |          | Hydrocarbons                   | g                                                                                                       | -              | -                           | -                 |   |    |   |
| 17       |          | Total enthalpy flow            | J                                                                                                       | Unknown        | Unknown                     | Unknown           |   |    |   |
| 18       |          | Corrosive and toxic compounds  | %w                                                                                                      | Unknown        | Unknown                     | Unknown           |   |    |   |
| 19       |          | Solids present                 | %                                                                                                       | 100.000        | 100.000                     | 100.000           |   |    |   |
| 20       |          | Solids particle size           | Microns                                                                                                 | Unknown        | Unknown                     | Unknown           |   |    |   |
| 21       |          | (Wet) Steam phase properties   |                                                                                                         |                |                             |                   |   |    |   |
| 22       |          | Volumetric flow @P,T           | dm³                                                                                                     | -              | -                           | -                 |   |    |   |
| 23       |          | Volumetric flow @(1 atm, 0°C)  | dm³                                                                                                     | -              | -                           | -                 |   |    |   |
| 24       |          | Molecular weight               | g/mol                                                                                                   | -              | -                           | -                 |   |    |   |
| 25       |          | Density @T                     | g/dm³                                                                                                   | -              | -                           | -                 |   |    |   |
| 26       |          | Density @(1 atm, 0°C)          | g/dm³                                                                                                   | -              | -                           | -                 |   |    |   |
| 27       |          | Viscosity @T                   | cP                                                                                                      | -              | -                           | -                 |   |    |   |
| 28       |          | Thermal conductivity @T        | J/(s·m·K)                                                                                               | -              | -                           | -                 |   |    |   |
| 29       |          | Specific Heat @T               | J/(g·K)                                                                                                 | -              | -                           | -                 |   |    |   |
| 30       |          | Compressibility factor @P,T    | -                                                                                                       | -              | -                           | -                 |   |    |   |
| 31       |          | C <sub>p</sub> /C <sub>v</sub> | -                                                                                                       | -              | -                           | -                 |   |    |   |
| 32       |          | Enthalpy flow                  | J                                                                                                       | -              | -                           | -                 |   |    |   |
| 33       |          | Liquid phase properties        |                                                                                                         |                |                             |                   |   |    |   |
| 34       |          | Volumetric flow @P,T           | dm³                                                                                                     | -              | -                           | -                 |   |    |   |
| 35       |          | Volumetric flow @15°C          | dm³                                                                                                     | -              | -                           | -                 |   |    |   |
| 36       |          | Density @T                     | g/dm³                                                                                                   | -              | -                           | -                 |   |    |   |
| 37       |          | Density @15°C                  | g/dm³                                                                                                   | -              | -                           | -                 |   |    |   |
| 38       |          | Kinematic viscosity @T         | cSt                                                                                                     | -              | -                           | -                 |   |    |   |
| 39       |          | Kinematic viscosity @50°C      | cSt                                                                                                     | -              | -                           | -                 |   |    |   |
| 40       |          | Kinematic viscosity @100°C     | cSt                                                                                                     | -              | -                           | -                 |   |    |   |
| 41       |          | Kinematic viscosity @150°C     | cSt                                                                                                     | -              | -                           | -                 |   |    |   |
| 42       |          | Thermal conductivity @T        | J/(s·m·K)                                                                                               | -              | -                           | -                 |   |    |   |
| 43       |          | Specific Heat @T               | J/(g·K)                                                                                                 | -              | -                           | -                 |   |    |   |
| 44       |          | Surface tension @P,T           | dinas/cm                                                                                                | -              | -                           | -                 |   |    |   |
| 45       |          | Vapor pressure                 | kg/cm² a                                                                                                | -              | -                           | -                 |   |    |   |
| 46       |          | Enthalpy flow                  | J                                                                                                       | -              | -                           | -                 |   |    |   |
| 47       |          | Miscellaneous                  |                                                                                                         |                |                             |                   |   |    |   |
| 48       |          |                                |                                                                                                         |                |                             |                   |   |    |   |
| 49       |          | Notes                          |                                                                                                         |                |                             |                   |   |    |   |
| 50       |          | 1                              | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                |                             |                   |   |    |   |
| 51       |          | 2                              | Process variables not known are marked as "Unknown", if they do not apply to the process stream, they   |                |                             |                   |   |    |   |
| 52       |          | 3                              | A 1/6 fraction of compound is reused within mixing                                                      |                |                             |                   |   |    |   |
| 53       |          | 4                              | WD: Wood Composites                                                                                     |                |                             |                   |   |    |   |
| 54       |          | 5                              |                                                                                                         |                |                             |                   |   |    |   |
| Rev.     | by       | 1.0                            | SDFG                                                                                                    |                |                             |                   |   |    |   |
| Date     | Approved | 29-08-25                       | PRG                                                                                                     |                |                             |                   |   |    |   |

|      |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
|------|------|--------------------------|----------------------------------------------------------------------------------------|---------|-----------------------------|---------|---------|---------|-----------------|---------|---------|---------|
|      |      | idener.ai                |                                                                                        | PROYECT | GREEN-LOOP                  |         |         |         | Mass and Energy |         |         |         |
|      |      |                          |                                                                                        | Process | Wood composites manufacture |         |         |         | Page            | 3       | of      | 4       |
| Item | Rev. | MASS AND ENERGY BALANCES |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 1    |      | Compositions             |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 2    |      | Stream nº                | 1a                                                                                     |         | 1b                          |         | 1c      |         | 2               |         | 3       |         |
| 3    |      | Componen                 | %                                                                                      | % mol   | %                           | % mol   | %       | % mol   | %               | % mol   | %       | % mol   |
| 4    |      | Bio-                     | 100.000                                                                                | 100.000 | 0.000                       | 0.000   | 0.000   | 0.000   | 51.150          | 0.0798  | 51.150  | 0.0798  |
| 5    |      | Wood                     | 0.000                                                                                  | 0.000   | 100.000                     | 100.000 | 0.000   | 0.000   | 22.000          | 23.271  | 22.000  | 23.271  |
| 6    |      | Glass                    | 0.000                                                                                  | 0.000   | 0.000                       | 0.000   | 100.000 | 100.000 | 26.850          | 76.649  | 26.850  | 76.649  |
| 7    |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 8    |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 9    |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 10   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 11   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 12   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 13   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 14   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 15   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 16   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 17   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 18   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 19   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 20   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 21   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 22   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 23   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 24   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 25   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 26   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 27   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 28   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 29   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 30   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 31   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 32   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 33   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 34   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 35   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 36   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 37   |      |                          |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 38   |      | Total                    | 100,000                                                                                | 100,000 | 100,000                     | 100,000 | 100,000 | 100,000 | 100,000         | 100,000 | 100,000 | 100,000 |
| 39   |      | Mass dry                 |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 40   |      | flow (g)                 |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 41   |      | Molar dry                |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 42   |      | flow (mol)               |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 43   |      | Mass wet                 |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 44   |      | flow (g)                 |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 45   |      | Molar wet                |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 46   |      | flow (mol)               |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 47   |      | Notes                    |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 48   |      | 1                        | ARBOBLEND® 224IX is used as bio-polymer mix, which is composed by PLA polymer, lignin, |         |                             |         |         |         |                 |         |         |         |
| 49   |      | 2                        | ARBOCEL C400 is used as 100 % cellulose fibre                                          |         |                             |         |         |         |                 |         |         |         |
| 50   |      | 3                        | FG 400/100 is used as 100 % glass fibre                                                |         |                             |         |         |         |                 |         |         |         |
| 51   |      | 4                        |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 52   |      | 5                        |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 53   |      | 6                        |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| 54   |      | 7                        |                                                                                        |         |                             |         |         |         |                 |         |         |         |
| Rev. |      | by                       | 1.0                                                                                    | SDFG    |                             |         |         |         |                 |         |         |         |
| Date |      | Approved                 | 29-08-25                                                                               | PRG     |                             |         |         |         |                 |         |         |         |

|          |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
|----------|----------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|---------|---------|-----------------------------|---------|-----------------|---|-------|---|-------|---|
|          |          |  |                                                                                        | PROYECT |         | GREEN-LOOP                  |         | Mass and Energy |   |       |   |       |   |
|          |          |                                                                                   |                                                                                        | Process |         | Wood composites manufacture |         |                 |   | Page  | 4 | of    | 4 |
| Ite<br>m | Re<br>v. | MASS AND ENERGY BALANCES                                                          |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 1        |          | Compositions                                                                      |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 2        |          | Stream nº                                                                         | 4                                                                                      |         | 5       |                             | 6       |                 |   |       |   |       |   |
| 3        |          | Componen                                                                          | %                                                                                      | % mol   | %       | % mol                       | %       | % mol           | % | % mol | % | % mol |   |
| 4        |          | Bio-                                                                              | 51.150                                                                                 | 0.0798  | 51.150  | 0.0798                      | 51.150  | 0.0798          |   |       |   |       |   |
| 5        |          | Wood                                                                              | 22.000                                                                                 | 23.271  | 22.000  | 23.271                      | 22.000  | 23.271          |   |       |   |       |   |
| 6        |          | Glass                                                                             | 26.850                                                                                 | 76.649  | 26.850  | 76.649                      | 26.850  | 76.649          |   |       |   |       |   |
| 7        |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 8        |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 9        |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 10       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 11       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 12       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 13       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 14       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 15       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 16       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 17       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 18       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 19       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 20       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 21       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 22       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 23       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 24       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 25       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 26       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 27       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 28       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 29       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 30       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 31       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 32       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 33       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 34       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 35       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 36       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 37       |          |                                                                                   |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 38       |          | Total                                                                             | 100.000                                                                                | 100.000 | 100.000 | 100.000                     | 100.000 | 100.000         |   |       |   |       |   |
| 39       |          | Mass dry                                                                          |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 40       |          | flow (g)                                                                          |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 41       |          | Molar dry                                                                         |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 42       |          | flow (mol)                                                                        |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 43       |          | Mass wet                                                                          |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 44       |          | flow (g)                                                                          |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 45       |          | Molar wet                                                                         |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 46       |          | flow (mol)                                                                        |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 47       |          | Notes                                                                             |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 48       |          | 1                                                                                 | ARBOBLEND® 2241X is used as bio-polymer mix, which is composed by PLA polymer, lignin, |         |         |                             |         |                 |   |       |   |       |   |
| 49       |          | 2                                                                                 | ARBOCEL C400 is used as 100 % cellulose fibre                                          |         |         |                             |         |                 |   |       |   |       |   |
| 50       |          | 3                                                                                 | FG 400/100 is used as 100 % glass fibre                                                |         |         |                             |         |                 |   |       |   |       |   |
| 51       |          | 4                                                                                 |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 52       |          | 5                                                                                 |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 53       |          | 6                                                                                 |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| 54       |          | 7                                                                                 |                                                                                        |         |         |                             |         |                 |   |       |   |       |   |
| Rev.     | by       | 1.0                                                                               | SDFG                                                                                   |         |         |                             |         |                 |   |       |   |       |   |
| Date     | Approved | 29-08-25                                                                          | PRG                                                                                    |         |         |                             |         |                 |   |       |   |       |   |

|      |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
|------|----------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-----------------------------|------------|-------------------|-----------------|------|-------|----|---|
|      |          |  |                                                                                                         | PROYECT                     | GREEN-LOOP |                   | Plant Utilities |      |       |    |   |
|      |          | Process                                                                           |                                                                                                         | Wood composites manufacture |            |                   |                 | Page | 1     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (COOLING DEMAND)                                                  |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 1    |          | Design case                                                                       |                                                                                                         |                             |            | Basic engineering |                 |      |       |    |   |
| 2    |          | Equipment                                                                         | Description                                                                                             |                             |            |                   | Demand (kJ)     |      | Notes |    |   |
| 3    |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 4    |          | Elrich mixer                                                                      | No cooling needed                                                                                       |                             |            |                   | -               |      |       |    |   |
| 5    |          | Screw extruder                                                                    | No cooling needed                                                                                       |                             |            |                   | -               |      |       |    |   |
| 6    |          | Linden kneader                                                                    | No cooling needed                                                                                       |                             |            |                   | -               |      |       |    |   |
| 7    |          | CM <sup>(2)</sup>                                                                 | Cooling needed                                                                                          |                             |            |                   | Unknown         |      |       |    |   |
| 8    |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 9    |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 10   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 11   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 12   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 13   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 14   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 15   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 16   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 17   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 18   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 19   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 20   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 21   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 22   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 23   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 24   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 25   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 26   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 27   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 28   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 29   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 30   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 31   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 32   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 33   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 34   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 35   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 36   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 37   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 38   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 39   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 40   |          |                                                                                   |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 41   |          | Total                                                                             |                                                                                                         |                             |            |                   |                 | -    |       |    |   |
| 42   |          | Notes                                                                             |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 43   |          | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                             |            |                   |                 |      |       |    |   |
| 44   |          | 2                                                                                 | CM: Compression Moulding                                                                                |                             |            |                   |                 |      |       |    |   |
| 45   |          | 3                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 46   |          | 4                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 47   |          | 5                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 48   |          | 6                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 49   |          | 7                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 50   |          | 8                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 51   |          | 9                                                                                 |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 52   |          | 10                                                                                |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 53   |          | 11                                                                                |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| 54   |          | 12                                                                                |                                                                                                         |                             |            |                   |                 |      |       |    |   |
| Rev. | by       | 1.0                                                                               | SDFG                                                                                                    |                             |            |                   |                 |      |       |    |   |
| Date | Approved | 29-08-25                                                                          | PRG                                                                                                     |                             |            |                   |                 |      |       |    |   |

|          |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
|----------|----------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|-----------------------------|-------------------|------------|-----------------|-------|----|---|
|          |          |  |                                                                                                         | PROYECT | GREEN-LOOP                  |                   |            | Plant Utilities |       |    |   |
|          |          |                                                                                   |                                                                                                         | Process | Wood composites manufacture |                   |            | Page            | 2     | of | 5 |
| Ite<br>m | Re<br>v. | PLANT UTILITIES (COOLING WATER)                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 1        |          | Design case                                                                       |                                                                                                         |         |                             | Basic engineering |            |                 |       |    |   |
| 2        |          | Equipment                                                                         | Description                                                                                             |         |                             |                   | Flow (dm³) |                 | Notes |    |   |
| 3        |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 4        |          | Elrich mixer                                                                      | No cooling water needed                                                                                 |         |                             |                   | -          |                 |       |    |   |
| 5        |          | Screw extruder                                                                    | No cooling water needed                                                                                 |         |                             |                   | -          |                 |       |    |   |
| 6        |          | Linden kneader                                                                    | No cooling water needed                                                                                 |         |                             |                   | -          |                 |       |    |   |
| 7        |          | CM <sup>(3)</sup>                                                                 | Cooling water needed                                                                                    |         |                             |                   | 200.000    |                 | (4)   |    |   |
| 8        |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 9        |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 10       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 11       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 12       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 13       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 14       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 15       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 16       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 17       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 18       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 19       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 20       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 21       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 22       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 23       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 24       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 25       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 26       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 27       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 28       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 29       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 30       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 31       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 32       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 33       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 34       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 35       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 36       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 37       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 38       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 39       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 40       |          |                                                                                   |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 41       |          | Total                                                                             |                                                                                                         |         |                             |                   |            | 200.000         |       |    |   |
| 42       |          | Notes                                                                             |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 43       |          | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                             |                   |            |                 |       |    |   |
| 44       |          | 2                                                                                 | The flow values with positive sign are positive cooling water flows with the ΔT of the design           |         |                             |                   |            |                 |       |    |   |
| 45       |          |                                                                                   | specification, indicate if the ΔT is different in any case including it on the notes of this datasheet  |         |                             |                   |            |                 |       |    |   |
| 46       |          | 3                                                                                 | CM: Compression Moulding                                                                                |         |                             |                   |            |                 |       |    |   |
| 47       |          | 4                                                                                 | 10 l/min for 20 minutes                                                                                 |         |                             |                   |            |                 |       |    |   |
| 48       |          | 5                                                                                 |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 49       |          | 6                                                                                 |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 50       |          | 7                                                                                 |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 51       |          | 8                                                                                 |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 52       |          | 9                                                                                 |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 53       |          | 10                                                                                |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| 54       |          | 11                                                                                |                                                                                                         |         |                             |                   |            |                 |       |    |   |
| Rev.     |          | by                                                                                | 1.0                                                                                                     | SDFG    |                             |                   |            |                 |       |    |   |
| Date     |          | Approved                                                                          | 29-08-25                                                                                                | PRG     |                             |                   |            |                 |       |    |   |

|      |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
|------|----------|----------------------------------|---------------------------------------------------------------------------------------------------------|---------|-----------------------------|-------------------|-------------|-----------------|-------|----|---|
|      |          | idener.ai                        |                                                                                                         | PROYECT | GREEN-LOOP                  |                   |             | Plant Utilities |       |    |   |
|      |          |                                  |                                                                                                         | Process | Wood composites manufacture |                   |             | Page            | 3     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (HEATING DEMAND) |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 1    |          | Design case                      |                                                                                                         |         |                             | Basic engineering |             |                 |       |    |   |
| 2    |          | Equipment                        | Description                                                                                             |         |                             |                   | Demand (kJ) |                 | Notes |    |   |
| 3    |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 4    |          | Elrich mixer                     | Extra heating needed                                                                                    |         |                             |                   | 3600        |                 |       |    |   |
| 5    |          | Screw extruder                   | No extra heating needed                                                                                 |         |                             |                   | -           |                 |       |    |   |
| 6    |          | Linden kneader                   | No extra heating needed                                                                                 |         |                             |                   | -           |                 |       |    |   |
| 7    |          | CM <sup>(2)</sup>                | No extra heating needed                                                                                 |         |                             |                   | -           |                 |       |    |   |
| 8    |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 9    |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 10   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 11   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 12   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 13   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 14   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 15   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 16   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 17   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 18   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 19   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 20   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 21   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 22   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 23   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 24   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 25   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 26   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 27   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 28   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 29   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 30   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 31   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 32   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 33   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 34   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 35   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 36   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 37   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 38   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 39   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 40   |          |                                  |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 41   |          | Total                            |                                                                                                         |         |                             |                   | 3600        |                 |       |    |   |
| 42   |          | Notes                            |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 43   |          | 1                                | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                             |                   |             |                 |       |    |   |
| 44   |          | 2                                | CM: Compression Moulding                                                                                |         |                             |                   |             |                 |       |    |   |
| 45   |          | 3                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 46   |          | 4                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 47   |          | 5                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 48   |          | 6                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 49   |          | 7                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 50   |          | 8                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 51   |          | 9                                |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 52   |          | 10                               |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 53   |          | 11                               |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| 54   |          | 12                               |                                                                                                         |         |                             |                   |             |                 |       |    |   |
| Rev. | by       | 1.0                              | SDFG                                                                                                    |         |                             |                   |             |                 |       |    |   |
| Date | Approved | 29-08-25                         | PRG                                                                                                     |         |                             |                   |             |                 |       |    |   |

|      |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
|------|----------|------------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------|-----------------------------|-------------|-----------------|---|----|---|
|      |          | idener.a                           |                                                                                                         | PROYECT                 | GREEN-LOOP                  |             | Plant Utilities |   |    |   |
|      |          |                                    |                                                                                                         | Process                 | Wood composites manufacture |             | Pag             | 4 | of | 5 |
| Item | Rev.     | PLANT UTILITIES (FUEL CONSUMPTION) |                                                                                                         |                         |                             |             |                 |   |    |   |
| 1    |          | Design case                        |                                                                                                         |                         | Basic engineering           |             |                 |   |    |   |
| 2    |          | Equipment                          | Description                                                                                             | Fuel consumption (m³/h) |                             |             | Notes           |   |    |   |
| 3    |          |                                    |                                                                                                         | Fuel oil                | Fuel gas                    | Natural gas |                 |   |    |   |
| 4    |          | Elrich mixer                       | No fuel needed                                                                                          | -                       | -                           | -           |                 |   |    |   |
| 5    |          | Screw extruder                     | No fuel needed                                                                                          | -                       | -                           | -           |                 |   |    |   |
| 6    |          | Linden kneader                     | No fuel needed                                                                                          | -                       | -                           | -           |                 |   |    |   |
| 7    |          | CM <sup>(3)</sup>                  | No fuel needed                                                                                          | -                       | -                           | -           |                 |   |    |   |
| 8    |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 9    |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 10   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 11   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 12   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 13   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 14   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 15   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 16   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 17   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 18   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 19   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 20   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 21   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 22   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 23   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 24   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 25   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 26   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 27   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 28   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 29   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 30   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 31   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 32   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 33   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 34   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 35   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 36   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 37   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 38   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 39   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 40   |          |                                    |                                                                                                         |                         |                             |             |                 |   |    |   |
| 41   |          | Total                              |                                                                                                         | -                       | -                           | -           |                 |   |    |   |
| 42   |          | Notes                              |                                                                                                         |                         |                             |             |                 |   |    |   |
| 43   |          | 1                                  | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |                         |                             |             |                 |   |    |   |
| 44   |          | 2                                  | Positive values are consumptions; negative values are by-products of the process                        |                         |                             |             |                 |   |    |   |
| 45   |          | 3                                  | CM: Compression Moulding                                                                                |                         |                             |             |                 |   |    |   |
| 46   |          | 4                                  |                                                                                                         |                         |                             |             |                 |   |    |   |
| 47   |          | 5                                  |                                                                                                         |                         |                             |             |                 |   |    |   |
| 48   |          | 6                                  |                                                                                                         |                         |                             |             |                 |   |    |   |
| 49   |          | 11                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| 50   |          | 12                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| 51   |          | 13                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| 52   |          | 14                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| 53   |          | 15                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| 54   |          | 16                                 |                                                                                                         |                         |                             |             |                 |   |    |   |
| Rev. | by       | 1.0                                | SDFG                                                                                                    |                         |                             |             |                 |   |    |   |
| Date | Approved | 29-08-25                           | PRG                                                                                                     |                         |                             |             |                 |   |    |   |

|      |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
|------|----------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|---------|-----------------------------|-------------------|------------------|-----------------|-------|----|---|
|      |          |  |                                                                                                         | PROYECT | GREEN-LOOP                  |                   |                  | Plant Utilities |       |    |   |
|      |          |                                                                                   |                                                                                                         | Process | Wood composites manufacture |                   |                  | Pag             | 5     | of | 5 |
| Item | Rev.     | PLANT UTILITIES (ELECTRICITY)                                                     |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 1    |          | Design case                                                                       |                                                                                                         |         |                             | Basic engineering |                  |                 |       |    |   |
| 2    |          | Equipment                                                                         | Description                                                                                             |         |                             |                   | Consumption (kJ) |                 | Notes |    |   |
| 3    |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 4    |          | Elrich mixer                                                                      | 1kWh for the Eirich Mixer + 1kWh for the heater                                                         |         |                             |                   | 7200.000         |                 | (4)   |    |   |
| 5    |          | Screw extruder                                                                    | 1kWh consumption for 1h extrusion and ca. 1000g                                                         |         |                             |                   | 7038.000         |                 | (5)   |    |   |
| 6    |          | Linden kneader                                                                    | 0.5kWh for 1 hour and ca. 1000g material                                                                |         |                             |                   | 3519.000         |                 | (4)   |    |   |
| 7    |          | CM <sup>(5)</sup>                                                                 | 2kWh for 1 hour and ca. 50g material                                                                    |         |                             |                   | 281520.000       |                 | (4)   |    |   |
| 8    |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 9    |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 10   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 11   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 12   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 13   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 14   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 15   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 16   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 17   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 18   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 19   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 20   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 21   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 22   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 23   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 24   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 25   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 26   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 27   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 28   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 29   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 30   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 31   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 32   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 33   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 34   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 35   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 36   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 37   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 38   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 39   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 40   |          |                                                                                   |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 41   |          | Total                                                                             |                                                                                                         |         |                             |                   | 299277.000       |                 |       |    |   |
| 42   |          | Notes                                                                             |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 43   |          | 1                                                                                 | The process operates in a non-steady state, therefore the values considered are not rates, but absolute |         |                             |                   |                  |                 |       |    |   |
| 44   |          | 2                                                                                 | Positive values are consumptions; negative values are by-products of the process                        |         |                             |                   |                  |                 |       |    |   |
| 45   |          | 3                                                                                 | CM: Compression Moulding                                                                                |         |                             |                   |                  |                 |       |    |   |
| 46   |          | 4                                                                                 | Estimated value                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 47   |          | 5                                                                                 | Measured value                                                                                          |         |                             |                   |                  |                 |       |    |   |
| 48   |          | 6                                                                                 |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 49   |          | 7                                                                                 |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 50   |          | 8                                                                                 |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 51   |          | 9                                                                                 |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 52   |          | 10                                                                                |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 53   |          | 11                                                                                |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| 54   |          | 12                                                                                |                                                                                                         |         |                             |                   |                  |                 |       |    |   |
| Rev. | by       | 1.0                                                                               | SDFG                                                                                                    |         |                             |                   |                  |                 |       |    |   |
| Date | Approved | 29-08-25                                                                          | PRG                                                                                                     |         |                             |                   |                  |                 |       |    |   |

|      |          | idener.ai         |                          | PROYECT GREEN-LOOP          |  | Wastes            |   |       |   |
|------|----------|-------------------|--------------------------|-----------------------------|--|-------------------|---|-------|---|
|      |          | Process           |                          | Wood composites manufacture |  | Pag               | 1 | of    | 3 |
| Item | Rev.     | WASTES (SOLIDS)   |                          |                             |  |                   |   |       |   |
| 1    |          | Design case       |                          |                             |  | Basic engineering |   |       |   |
| 2    |          | Equipment         |                          | Description                 |  | Mass Flow (g)     |   | Notes |   |
| 3    |          |                   |                          |                             |  |                   |   |       |   |
| 4    |          | Elrich mixer      |                          | No waste as solids          |  | -                 |   |       |   |
| 5    |          | Screw extruder    |                          | No waste as solids          |  | -                 |   |       |   |
| 6    |          | Linden kneader    |                          | No waste as solids          |  | -                 |   |       |   |
| 7    |          | CM <sup>(1)</sup> |                          | No waste as solids          |  | -                 |   |       |   |
| 8    |          |                   |                          |                             |  |                   |   |       |   |
| 9    |          |                   |                          |                             |  |                   |   |       |   |
| 10   |          |                   |                          |                             |  |                   |   |       |   |
| 11   |          |                   |                          |                             |  |                   |   |       |   |
| 12   |          |                   |                          |                             |  |                   |   |       |   |
| 13   |          |                   |                          |                             |  |                   |   |       |   |
| 14   |          |                   |                          |                             |  |                   |   |       |   |
| 15   |          |                   |                          |                             |  |                   |   |       |   |
| 16   |          |                   |                          |                             |  |                   |   |       |   |
| 17   |          |                   |                          |                             |  |                   |   |       |   |
| 18   |          |                   |                          |                             |  |                   |   |       |   |
| 19   |          |                   |                          |                             |  |                   |   |       |   |
| 20   |          |                   |                          |                             |  |                   |   |       |   |
| 21   |          |                   |                          |                             |  |                   |   |       |   |
| 22   |          |                   |                          |                             |  |                   |   |       |   |
| 23   |          |                   |                          |                             |  |                   |   |       |   |
| 24   |          |                   |                          |                             |  |                   |   |       |   |
| 25   |          |                   |                          |                             |  |                   |   |       |   |
| 26   |          |                   |                          |                             |  |                   |   |       |   |
| 27   |          |                   |                          |                             |  |                   |   |       |   |
| 28   |          |                   |                          |                             |  |                   |   |       |   |
| 29   |          |                   |                          |                             |  |                   |   |       |   |
| 30   |          |                   |                          |                             |  |                   |   |       |   |
| 31   |          |                   |                          |                             |  |                   |   |       |   |
| 32   |          |                   |                          |                             |  |                   |   |       |   |
| 33   |          |                   |                          |                             |  |                   |   |       |   |
| 34   |          |                   |                          |                             |  |                   |   |       |   |
| 35   |          |                   |                          |                             |  |                   |   |       |   |
| 36   |          |                   |                          |                             |  |                   |   |       |   |
| 37   |          |                   |                          |                             |  |                   |   |       |   |
| 38   |          |                   |                          |                             |  |                   |   |       |   |
| 39   |          |                   |                          |                             |  |                   |   |       |   |
| 40   |          |                   |                          |                             |  |                   |   |       |   |
| 41   |          | <b>Total</b>      |                          |                             |  | -                 |   |       |   |
| 42   |          | <b>Notes</b>      |                          |                             |  |                   |   |       |   |
| 43   |          | 1                 | CM: Compression Moulding |                             |  |                   |   |       |   |
| 44   |          | 2                 |                          |                             |  |                   |   |       |   |
| 45   |          | 3                 |                          |                             |  |                   |   |       |   |
| 46   |          | 4                 |                          |                             |  |                   |   |       |   |
| 47   |          | 5                 |                          |                             |  |                   |   |       |   |
| 48   |          | 6                 |                          |                             |  |                   |   |       |   |
| 49   |          | 7                 |                          |                             |  |                   |   |       |   |
| 50   |          | 8                 |                          |                             |  |                   |   |       |   |
| 51   |          | 9                 |                          |                             |  |                   |   |       |   |
| 52   |          | 10                |                          |                             |  |                   |   |       |   |
| 53   |          | 11                |                          |                             |  |                   |   |       |   |
| 54   |          | 12                |                          |                             |  |                   |   |       |   |
| Rev. | by       | 1.0               | SDFG                     |                             |  |                   |   |       |   |
| Date | Approved | 29-08-25          | PRG                      |                             |  |                   |   |       |   |

|             |             |                                                                                   |                          |                             |  |                   |  |       |  |
|-------------|-------------|-----------------------------------------------------------------------------------|--------------------------|-----------------------------|--|-------------------|--|-------|--|
|             |             |  |                          | PROYECT GREEN-LOOP          |  | Wastes            |  |       |  |
|             |             | Process                                                                           |                          | Wood composites manufacture |  | Pag 2             |  | of 3  |  |
| <b>Item</b> | <b>Rev.</b> | <b>WASTES (LIQUIDS)</b>                                                           |                          |                             |  |                   |  |       |  |
| 1           |             | Design case                                                                       |                          |                             |  | Basic engineering |  |       |  |
| 2           |             | Equipment                                                                         |                          | Description                 |  | Flow (dm³)        |  | Notes |  |
| 3           |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 4           |             | Elrich mixer                                                                      |                          | No waste as liquids         |  | -                 |  |       |  |
| 5           |             | Screw extruder                                                                    |                          | No waste as liquids         |  | -                 |  |       |  |
| 6           |             | Linden kneader                                                                    |                          | No waste as liquids         |  | -                 |  |       |  |
| 7           |             | CM <sup>(1)</sup>                                                                 |                          | No waste as liquids         |  | -                 |  |       |  |
| 8           |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 9           |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 10          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 11          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 12          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 13          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 14          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 15          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 16          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 17          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 18          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 19          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 20          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 21          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 22          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 23          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 24          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 25          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 26          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 27          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 28          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 29          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 30          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 31          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 32          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 33          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 34          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 35          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 36          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 37          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 38          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 39          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 40          |             |                                                                                   |                          |                             |  |                   |  |       |  |
| 41          |             | <b>Total</b>                                                                      |                          |                             |  | -                 |  |       |  |
| 42          |             | <b>Notes</b>                                                                      |                          |                             |  |                   |  |       |  |
| 43          |             | 1                                                                                 | CM: Compression Moulding |                             |  |                   |  |       |  |
| 44          |             | 2                                                                                 |                          |                             |  |                   |  |       |  |
| 45          |             | 3                                                                                 |                          |                             |  |                   |  |       |  |
| 46          |             | 4                                                                                 |                          |                             |  |                   |  |       |  |
| 47          |             | 5                                                                                 |                          |                             |  |                   |  |       |  |
| 48          |             | 6                                                                                 |                          |                             |  |                   |  |       |  |
| 49          |             | 7                                                                                 |                          |                             |  |                   |  |       |  |
| 50          |             | 8                                                                                 |                          |                             |  |                   |  |       |  |
| 51          |             | 9                                                                                 |                          |                             |  |                   |  |       |  |
| 52          |             | 10                                                                                |                          |                             |  |                   |  |       |  |
| 53          |             | 11                                                                                |                          |                             |  |                   |  |       |  |
| 54          |             | 12                                                                                |                          |                             |  |                   |  |       |  |
| Rev.        | by          | 1.0                                                                               | SDFG                     |                             |  |                   |  |       |  |
| Date        | Approved    | 29-08-25                                                                          | PRG                      |                             |  |                   |  |       |  |

|             |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
|-------------|-------------|-----------------------------------------------------------------------------------|--------------------------|-------------------------------|-----------------------------|-------------------|--|------------|--------|-------|----|---|
|             |             |  |                          | PROYECT                       | GREEN-LOOP                  |                   |  |            | Wastes |       |    |   |
|             |             |                                                                                   |                          | Process                       | Wood composites manufacture |                   |  |            | Pag    | 3     | of | 3 |
| <b>Item</b> | <b>Rev.</b> | <b>WASTES (GASES AND VAPOURS)</b>                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 1           |             | Design case                                                                       |                          |                               |                             | Basic engineering |  |            |        |       |    |   |
| 2           |             | Equipment                                                                         |                          | Description                   |                             |                   |  | Flow (dm³) |        | Notes |    |   |
| 3           |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 4           |             | Elrich mixer                                                                      |                          | No waste as gases and vapours |                             |                   |  | -          |        |       |    |   |
| 5           |             | Screw extruder                                                                    |                          | No waste as gases and vapours |                             |                   |  | -          |        |       |    |   |
| 6           |             | Linden kneader                                                                    |                          | No waste as gases and vapours |                             |                   |  | -          |        |       |    |   |
| 7           |             | CM <sup>(1)</sup>                                                                 |                          | No waste as gases and vapours |                             |                   |  | -          |        |       |    |   |
| 8           |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 9           |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 10          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 11          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 12          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 13          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 14          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 15          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 16          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 17          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 18          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 19          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 20          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 21          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 22          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 23          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 24          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 25          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 26          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 27          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 28          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 29          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 30          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 31          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 32          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 33          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 34          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 35          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 36          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 37          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 38          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 39          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 40          |             |                                                                                   |                          |                               |                             |                   |  |            |        |       |    |   |
| 41          |             | <b>Total</b>                                                                      |                          |                               |                             |                   |  | -          |        |       |    |   |
| 42          |             | <b>Notes</b>                                                                      |                          |                               |                             |                   |  |            |        |       |    |   |
| 43          |             | 1                                                                                 | CM: Compression Moulding |                               |                             |                   |  |            |        |       |    |   |
| 44          |             | 2                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 45          |             | 3                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 46          |             | 4                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 47          |             | 5                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 48          |             | 6                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 49          |             | 7                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 50          |             | 8                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 51          |             | 9                                                                                 |                          |                               |                             |                   |  |            |        |       |    |   |
| 52          |             | 10                                                                                |                          |                               |                             |                   |  |            |        |       |    |   |
| 53          |             | 11                                                                                |                          |                               |                             |                   |  |            |        |       |    |   |
| 54          |             | 12                                                                                |                          |                               |                             |                   |  |            |        |       |    |   |
| Rev.        | by          | 1.0                                                                               | SDFG                     |                               |                             |                   |  |            |        |       |    |   |
| Date        | Approved    | 29-08-25                                                                          | PRG                      |                               |                             |                   |  |            |        |       |    |   |

## Annex 2: Supplementary material from the LCA

| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-rubber  | WP3 | T6.2 | NCC       | UBRIS, NIC and ZAG  |

Table 52. LCI for the manufacturing of lignin powder.

| Lignin powder production |                                                                                                                                              |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Material                 | <b>Ecoinvent dataset</b>                                                                                                                     |
| Distilled water          | Water, ultrapure {RER}  market for water, ultrapure   Cut-off, U                                                                             |
| Sodium sulfide           | Sodium sulfide {GLO}  market for sodium sulfide   Cut-off, U                                                                                 |
| Sodium hydroxide         | Sodium hydroxide, without water, in 50% solution state {RER}  market for sodium hydroxide, without water, in 50% solution state   Cut-off, U |
| Lignocelullose Biomass   | Wood chips, wet, measured as dry mass {Europe without Switzerland}  wood chips production, softwood, at sawmill   Cut-off, U                 |
| Sulfuric Acid 98%        | Sulfuric acid {RER}  market for sulfuric acid   Cut-off, U                                                                                   |
| Distilled water          | Water, ultrapure {RER}  market for water, ultrapure   Cut-off, U                                                                             |
| Energy                   | <b>Ecoinvent dataset</b>                                                                                                                     |
| Electricity              | Electricity, medium voltage {SI}  market for electricity, medium voltage   Cut-off, U                                                        |
| Waste                    | <b>Ecoinvent dataset</b>                                                                                                                     |
| Acid liquor              | Sulfuric acid {RER}  market for sulfuric acid   Cut-off, U    Water, ultrapure {RER}  market for water, ultrapure   Cut-off, U               |
| Cellulose rich waste     | Waste paper, unsorted {RoW}  market for waste paper, unsorted   Cut-off, U                                                                   |

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Table 53. LCI for the manufacture of a synthetic rubber panel benchmark.

| Synthetic rubber panel benchmark production |                                                 |
|---------------------------------------------|-------------------------------------------------|
| Material                                    | <b>Ecoinvent dataset</b>                        |
| Virgin synthetic rubber                     | Synthetic rubber {GLO}  market for   Cut-Off, U |
| Lignin power                                | Lignin powder                                   |
| Low Lead Zinc Oxide                         | Zinc oxide {GLO}  market for   Cut-Off, U       |
| Stearic acid                                | Stearic acid {GLO}  market for   Cut-Off, U     |
| MBTS-75                                     | Dimethyl sulfide {GLO}  market for   Cut-Off, U |

|                  |                                                                                                        |
|------------------|--------------------------------------------------------------------------------------------------------|
| 300 Mesh Sulphur | Sulphur {GLO}  market for   Cut-Off, U                                                                 |
| Energy           | <b>Ecoinvent dataset</b>                                                                               |
| Electricity      | Electricity, medium voltage {EwS}  market group for   Cut-Off, U                                       |
| Waste            | <b>Ecoinvent dataset</b>                                                                               |
| Polymer off-cuts | Waste plastic, mixture {GLO}  treatment of waste plastic, mixture, municipal incineration   Cut-off, U |

Table 54. LCI for the manufacture of a bio-rubber panel with 20% lignin.

| Synthetic rubber panel benchmark production |                                                                                                                 |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| Material                                    | <b>Ecoinvent dataset</b>                                                                                        |
| TDP-B                                       | Electricity, medium voltage {GLO}  market group for electricity, medium voltage   Cut-off, U                    |
| Lignin power                                | Lignin powder                                                                                                   |
| Natural rubber                              | Acrylonitrile {GLO}  market for acrylonitrile   Cut-off, U   Butadiene {RER}  market for butadiene   Cut-off, U |
| Low Lead Zinc Oxide                         | Zinc oxide {GLO}  market for   Cut-Off, U                                                                       |
| Stearic acid                                | Stearic acid {GLO}  market for   Cut-Off, U                                                                     |
| MBTS-75                                     | Dimethyl sulfide {GLO}  market for   Cut-Off, U                                                                 |
| 300 Mesh Sulphur                            | Sulphur {GLO}  market for   Cut-Off, U                                                                          |
| Energy                                      | <b>Ecoinvent dataset</b>                                                                                        |
| Electricity                                 | Electricity, medium voltage {EwS}  market group for   Cut-Off, U                                                |
| Waste                                       | <b>Ecoinvent dataset</b>                                                                                        |
| Polymer off-cuts                            | Mixed plastics (waste treatment) {GLO}  recycling of mixed plastics   Cut-off, U                                |

Table 55. LCI for the manufacture of a bio-rubber panel with 0% lignin.

| Synthetic rubber panel benchmark production |                                                                                                                 |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| Material                                    | <b>Ecoinvent dataset</b>                                                                                        |
| TDP-B                                       | Electricity, medium voltage {GLO}  market group for electricity, medium voltage   Cut-off, U                    |
| Natural rubber                              | Acrylonitrile {GLO}  market for acrylonitrile   Cut-off, U   Butadiene {RER}  market for butadiene   Cut-off, U |
| Low Lead Zinc Oxide                         | Zinc oxide {GLO}  market for   Cut-Off, U                                                                       |
| Stearic acid                                | Stearic acid {GLO}  market for   Cut-Off, U                                                                     |
| MBTS-75                                     | Dimethyl sulfide {GLO}  market for   Cut-Off, U                                                                 |
| 300 Mesh Sulphur                            | Sulphur {GLO}  market for   Cut-Off, U                                                                          |
| Energy                                      | <b>Ecoinvent dataset</b>                                                                                        |

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Electricity

Electricity, medium voltage {EwS}| market group  
for | Cut-Off, U

Waste

**Ecoinvent dataset**

Polymer off-cuts

Waste plastic, mixture {GLO}| treatment of waste  
plastic, mixture, municipal incineration | Cut-off,  
U



| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-plastic | WP4 | T6.3 | GUALA     | MYX and TDZ         |

Table 56. Ecoinvent LCI for BB solutions\* (VC2) from T6.3.

| BB solutions (Bioplastic VC2) |                                                                                                            |
|-------------------------------|------------------------------------------------------------------------------------------------------------|
| Material                      | <b>Ecoinvent dataset</b>                                                                                   |
| PHA                           | Polyester-complexed starch biopolymer {RER}  polyester-complexed starch biopolymer production   Cut-off, U |
| Rice Husk                     | Rice husk, dry, at farm (proxy)                                                                            |
| Energy                        | <b>Ecoinvent dataset</b>                                                                                   |
| Electricity                   | Electricity, medium voltage {IT}  market for electricity, medium voltage   Cut-off, U                      |

\*The inputs for the olive oil and limoncello closures are the same because they use the same raw materials and the same type of electricity; what differs is the quantity.

Table 57. Ecoinvent LCI for Olive Oil current (VC2) from T6.3.

| Olive Oil current (Bioplastic - VC2) |                                                                                                          |
|--------------------------------------|----------------------------------------------------------------------------------------------------------|
| Material                             | <b>Ecoinvent dataset</b>                                                                                 |
| LDPE                                 | Polyethylene, low density, granulate {GLO}  market for polyethylene, low density, granulate   Cut-off, U |
| Energy                               | <b>Ecoinvent dataset</b>                                                                                 |
| Electricity                          | Electricity, medium voltage {IT}  market for electricity, medium voltage   Cut-off, U                    |

Table 58. Ecoinvent LCI for Limoncello current (VC2) from T6.3.

| Limoncello current (Bioplastic - VC2) |                                                                                       |
|---------------------------------------|---------------------------------------------------------------------------------------|
| Material                              | <b>Ecoinvent dataset</b>                                                              |
| PP                                    | Polypropylene, granulate {RER}  polypropylene production, granulate   Cut-off, U      |
| Energy                                | <b>Ecoinvent dataset</b>                                                              |
| Electricity                           | Electricity, medium voltage {IT}  market for electricity, medium voltage   Cut-off, U |

| Value chain     | WP  | Task | WP Leader | Consortium partners |
|-----------------|-----|------|-----------|---------------------|
| Wood composites | WP5 | T6.4 | FHF       | GUALA               |

Table 59. Ecoinvent LCI for SBS1 (Wood composite without glass fibre) from T6.4.

| SBS1 (Wood composite without glass fibre – VC3) |                                                                                       |
|-------------------------------------------------|---------------------------------------------------------------------------------------|
| Material                                        | <b>Ecoinvent dataset</b>                                                              |
| ARBOBLEND 2241x                                 | Polylactic acid, granulate {GLO}  market for   Cut-Off, U                             |
| Natural Wood Fibre                              | Bark chips, wet, measured as dry mass {EwS}  market for fibreboard, hard   Cut-off, U |
| Energy                                          | <b>Ecoinvent dataset</b>                                                              |
| Electricity                                     | Electricity, medium voltage {DE}  market for   Cut-Off, U                             |

Table 60. Ecoinvent LCI for SBS2 (Wood composite with glass fibre) from T6.4.

| SBS2 (Wood composite with glass fibre – VC3) |                                                                                       |
|----------------------------------------------|---------------------------------------------------------------------------------------|
| Material                                     | <b>Ecoinvent dataset</b>                                                              |
| ARBOBLEND 2241x                              | Polylactic acid, granulate {GLO}  market for   Cut-Off, U                             |
| Natural Wood Fibre                           | Bark chips, wet, measured as dry mass {EwS}  market for fibreboard, hard   Cut-off, U |
| Glass Fibre Filler                           | Glass fibre {GLO}  market for glass fibre   Cut-off, U                                |
| Energy                                       | <b>Ecoinvent dataset</b>                                                              |
| Electricity                                  | Electricity, medium voltage {DE}  market for   Cut-Off, U                             |

Table 61. Ecoinvent LCI for metal benchmark from T6.4.

| Metallic Benchmark Sliding Bearing |                                                                                                      |
|------------------------------------|------------------------------------------------------------------------------------------------------|
| <b>Material</b>                    | <b>Ecoinvent dataset</b>                                                                             |
| Copper                             | Copper, cathode {GLO}  market for copper, cathode   Cut-off, U                                       |
| Cast iron                          | Cast iron {GLO}  market for cast iron   Cut-off, U                                                   |
| Zinc                               | Zinc {GLO}  market for zinc   Cut-off, U                                                             |
| Aluminium                          | Aluminium, primary, ingot {IAI Area, EU27 & EFTA}  market for aluminium, primary, ingot   Cut-off, U |
| Energy                             | <b>Ecoinvent dataset</b>                                                                             |
| Electricity                        | Electricity, medium voltage {DE}  market for   Cut-Off, U                                            |
| Waste                              | <b>Ecoinvent dataset</b>                                                                             |

*Metallic off-cuts*

Scrap copper {EwS}| treatment of scrap copper, municipal incineration | Cut-off, U  
 Scrap aluminium {CH}| treatment of scrap aluminium, municipal incineration FAE | Cut-off, U  
 Scrap steel {CH}| treatment of scrap steel, municipal incineration FAE | Cut-off, U  
 Hazardous waste, for incineration {EwS}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U

Table 62. Ecoinvent LCI for PBP benchmark from T6.4.

| <b>PBP Benchmark Sliding Bearing</b> |                                                                                                        |
|--------------------------------------|--------------------------------------------------------------------------------------------------------|
| Material                             | <b>Ecoinvent dataset</b>                                                                               |
| PA                                   | Nylon 6-6 {RER}  market for nylon 6-6   Cut-off, U                                                     |
| POM                                  | Ecoinvent proxy                                                                                        |
| HDPE                                 | Polyethylene, high density, granulate {GLO}  market for   Cut-off, U                                   |
| Energy                               | <b>Ecoinvent dataset</b>                                                                               |
| Electricity                          | Electricity, medium voltage {DE}  market for   Cut-Off, U                                              |
| Waste                                | <b>Ecoinvent dataset</b>                                                                               |
| Polymer off-cuts                     | Waste plastic, mixture {GLO}  treatment of waste plastic, mixture, municipal incineration   Cut-off, U |

Table 63. LCA for Experts database datasets for transport in road, water and rail. Air transport was not considered due to being insignificant in all cases. In all the cases, the first entry is the dataset to represent the transport media, the second is the fuel and the third (if exists) represents the electricity.

| <b>Transports in the LCA for Experts database</b> |                                                                                                                                                       |
|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Media                                             | <b>LCA for Experts dataset</b>                                                                                                                        |
| Road                                              | GLO: Truck, Euro 0-6 mix, 20 – 26 t gross weight / 17,3t payload capacity<br>RER: Diesel mix at filling station <sup>18</sup>                         |
| Water                                             | GLO: Bulk commodity carrier, 1.000 to 250.000 dwt payload capacity, deep sea<br>RER: Heavy fuel oil at refinery (1wt.% S) <sup>18</sup>               |
| Rail                                              | GLO: Rail transport cargo - average, light train, gross tonne weight 500t / 363t payload capacity<br>RER: Diesel mix at filling station <sup>18</sup> |

<sup>18</sup> Fuel and electricity for transport are geographically located as RER since it is the most generic location provided by LCA for Experts database.

Table 64. LCA for Experts LCI for SBS1 (Wood composite without glass fibre) from T6.4.

| <b>SBS1 (Wood composite without glass fibre)</b> |                                                                                                                                           |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Material</b>                                  | <b>LCA for Experts dataset</b>                                                                                                            |
| ARBOBLEND 2241x                                  | US: Ingeo Polylactide (PLA) biopolymer production                                                                                         |
| Natural Wood                                     | RER: Lightweight wood fibre panel (EN15804 A1-A3                                                                                          |
| Fibre                                            | Transport in LCA for Experts database (Table 63)                                                                                          |
| Transports                                       | Distances from "Plastics", "Veneer sheets and wood-based panels" and "Glass and glass fibre products" <b>Error! Bookmark not defined.</b> |
| <b>Energy</b>                                    | <b>LCA for Experts dataset</b>                                                                                                            |
| Electricity                                      | DE: Electricity grid mix 1 kV -60kV                                                                                                       |

Table 65. LCA for Experts LCI for SBS2 (Wood composite with glass fibre) from T6.4.

| <b>SBS2 (Wood composite with glass fibre)</b> |                                                                     |
|-----------------------------------------------|---------------------------------------------------------------------|
| <b>Material</b>                               | <b>LCA for Experts dataset</b>                                      |
| ARBOBLEND 2241x                               | US: Ingeo Polylactide (PLA) biopolymer production                   |
| Natural Wood                                  | RER : Lightweight wood fibre panel (EN15804 A1-A3                   |
| Fibre                                         | DE: Glass fibres                                                    |
| Glass Fibre Filler                            | Transport in LCA for Experts database (Table 63)                    |
| Transports                                    | Distances from "Plastics" and "Veneer sheets and wood-based panels" |
| <b>Energy</b>                                 | <b>LCA for Experts dataset</b>                                      |
| Electricity                                   | DE: Electricity grid mix 1 kV -60kV                                 |

Table 66. LCA for Experts LCI for metal benchmark from T6.4

| <b>Metallic Benchmark Sliding Bearing</b> |                                                  |
|-------------------------------------------|--------------------------------------------------|
| <b>Material</b>                           | <b>LCA for Experts dataset</b>                   |
| Copper                                    | GLO: Copper (99.99% cathode) ICA                 |
| Cast iron                                 | DE: Cast iron component (EN15804)                |
| Zinc                                      | RER: Special high grade zinc only from Zn        |
| Aluminium                                 | RER: Aluminium ingot mix Sphera                  |
| Transports                                | Transport in LCA for Experts database (Table 63) |

Energy  
Electricity  
Waste  
Metallic off-cuts

Distances from “Articles of base metal”

Error! Bookmark not defined.

## LCA for Experts dataset

DE: Electricity grid mix 1 kV -60kV

## LCA for Experts dataset

DE: Municipal waste in waste incineration plant

Table 67. LCA for Experts LCI for PBP benchmark from T6.4

### PBP Benchmark Sliding Bearing

Material

## LCA for Experts dataset

PA

RER: Polyamide 6.6

POM

RER: Polyoxymethylene (POM)

HDPE

RER: polyethylene high density granulate (HLDPE/PE-HD)

Transports

Transport in LCA for Experts database (Table 63)

Distances from “Plastics”

Energy

## LCA for Experts dataset

Electricity

DE: Electricity grid mix 1 kV -60kV

Waste

## LCA for Experts dataset

Polymer off-cuts

DE: Municipal waste in waste incineration plant

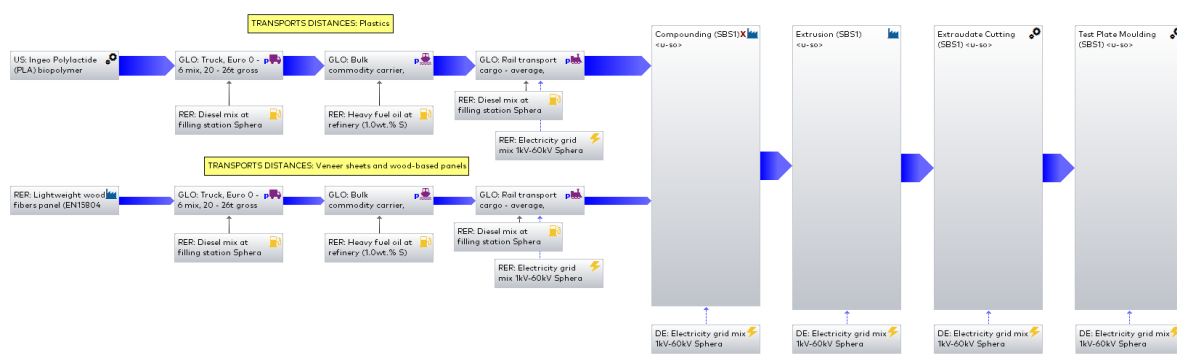


Figure 42. LCA for Experts model for SBS1 from T6.4

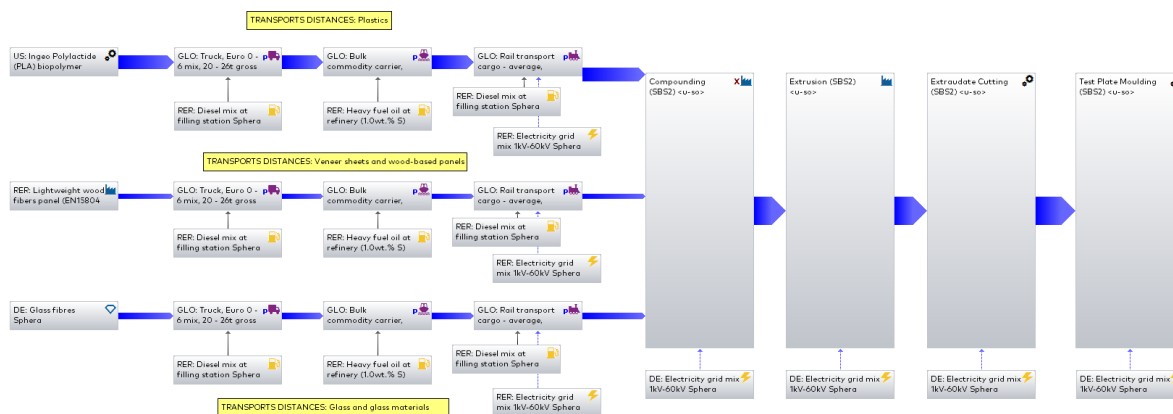


Figure 43. LCA for Experts model for SBS2 from T6.4

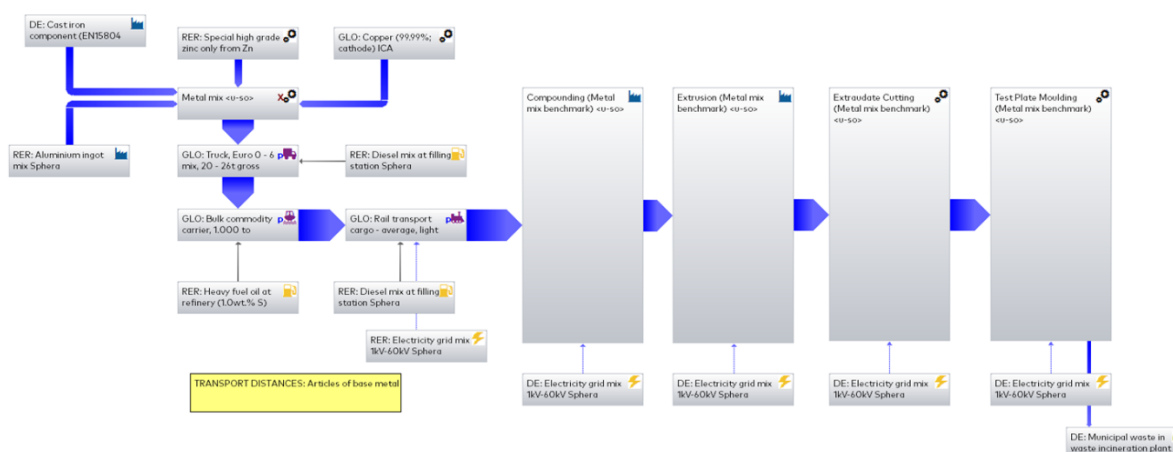


Figure 44. LCA for Experts model for the MM benchmark from T6.4

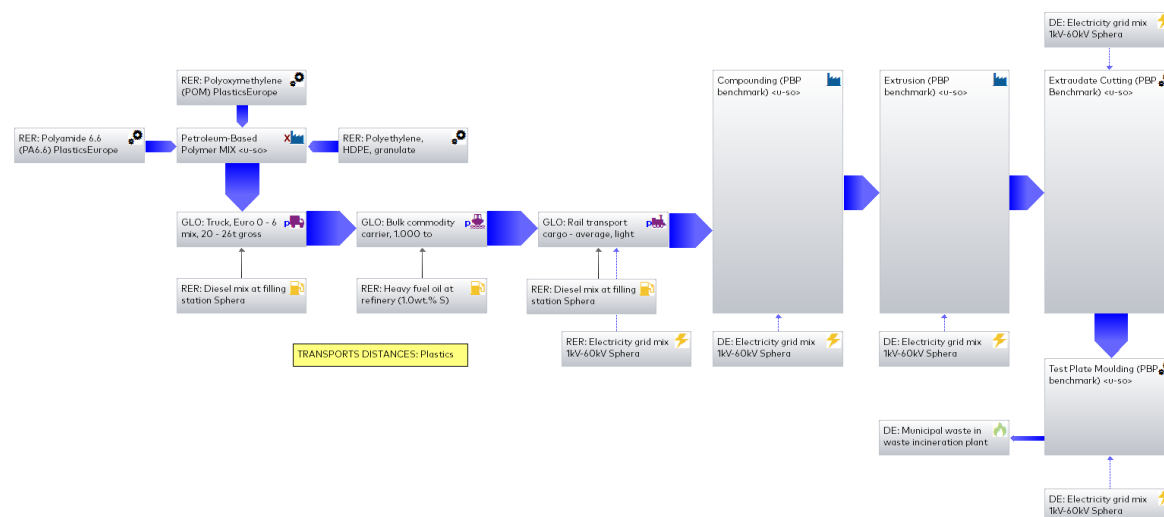


Figure 45. LCA for Experts model for the PBP benchmark from T6.4

## Annex 3: Supplementary material from the s-LCA

| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-rubber  | WP3 | T6.2 | NCC       | UBRIS, NIC and ZAG  |

Table 68. LCI for Lignin recovery step from T6.2.

### STEP 1 - Lignin Recovery

|                              |                                                                                                                                                     |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Material                     | <b>PSILCA process</b>                                                                                                                               |
| Distilled water              | Commodities - Collection, purification and distribution of water - SVN                                                                              |
| Sodium sulphide              | Commodities - Manufacture of chemical products - USA                                                                                                |
| Sodium hydroxide             | Commodities - Manufacture of chemical products - USA                                                                                                |
| Lignocellulose biomass       | Commodities - Manufacture of wood and of products of wood and cork, except furniture, manufacture of articles of straw and plaiting materials - SVN |
| Sulfuric acid (5% in water)  | Commodities - Manufacture of chemical products - USA                                                                                                |
| Sulfuric acid (15% in water) | Commodities - Manufacture of chemical products - USA                                                                                                |
| Energy                       | <b>PSILCA process</b>                                                                                                                               |
| Batch Reactor                | Commodities - Electrical energy, gas, steam and hot water - SVN                                                                                     |
| Material                     | <b>PSILCA process</b>                                                                                                                               |
| Lignin Powder                | Industries - Manufacture of rubber and plastic products - SVN                                                                                       |

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Table 69. LCI for bio-rubber panel manufacture from T6.2.

### STEP 2 – Bio-rubber panel production

|                     |                                                      |
|---------------------|------------------------------------------------------|
| Material            | <b>PSILCA process</b>                                |
| Lignin Powder       | Step 1 (Table 68)                                    |
| TDP                 | Commodities - Manufacture of rubber products - DEU   |
| Natural rubber      | Commodities - Agricultural products other - MYS      |
| Low Lead Zinc Oxide | Commodities - Manufacture of chemical products - USA |
| Stearic acid        | Commodities - Manufacture of chemical products - USA |
| MBTS-75             | Commodities - Manufacture of chemical products - USA |
| 300 Mesh Sulphur    | Commodities - Manufacture of chemical products - USA |

|                  |                                                                    |
|------------------|--------------------------------------------------------------------|
| Energy           | <b>PSILCA process</b>                                              |
| Internal mixer   | Commodities - Transmission of electricity - GBR                    |
| Press            | Commodities - Transmission of electricity - GBR                    |
| Material         | <b>PSILCA process</b>                                              |
| Bio-rubber panel | Industries - Manufacture of rubber products, tyres and tubes - GBR |

Table 70. LCI for rubber panel production benchmark from T6.2. Raw materials provided from outside Europe.

Benchmark: Rubber panel production (NON-EU)

|                     |                                                                    |
|---------------------|--------------------------------------------------------------------|
| Material            | <b>PSILCA process</b>                                              |
| Lignin Powder       | Step 1 (Table 68)                                                  |
| Synthetic rubber    | Commodities - Manufacture of rubber products - CHN                 |
| Low Lead Zinc Oxide | Commodities - Manufacture of chemical products - USA               |
| Stearic acid        | Commodities - Manufacture of chemical products - USA               |
| MBTS-75             | Commodities - Manufacture of chemical products - USA               |
| 300 Mesh Sulphur    | Commodities - Manufacture of chemical products - USA               |
| Energy              | <b>PSILCA process</b>                                              |
| Internal mixer      | Commodities - Transmission of electricity - GBR                    |
| Press               | Commodities - Transmission of electricity - GBR                    |
| Material            | <b>PSILCA process</b>                                              |
| Bio-rubber panel    | Industries - Manufacture of rubber products, tyres and tubes - GBR |

Table 71. LCI for rubber panel production benchmark from T6.2. Raw materials provided from Europe.

Benchmark: Rubber panel production (EU)

|                     |                                                                |
|---------------------|----------------------------------------------------------------|
| Material            | <b>PSILCA process</b>                                          |
| Lignin Powder       | Step 1 (Table 68)                                              |
| Synthetic rubber    | Commodities - Manufacture of rubber and plastic products - POL |
| Low Lead Zinc Oxide | Commodities - Manufacture of chemical products - USA           |
| Stearic acid        | Commodities - Manufacture of chemical products - USA           |
| MBTS-75             | Commodities - Manufacture of chemical products - USA           |
| 300 Mesh Sulphur    | Commodities - Manufacture of chemical products - USA           |
| Energy              | <b>PSILCA process</b>                                          |
| Internal mixer      | Commodities - Transmission of electricity - GBR                |
| Press               | Commodities - Transmission of electricity - GBR                |
| Material            | <b>PSILCA process</b>                                          |



| Value chain | WP  | Task | WP Leader | Consortium partners |
|-------------|-----|------|-----------|---------------------|
| Bio-plastic | WP4 | T6.3 | GUALA     | MYX and TDZ         |

Table 72. LCI for the bioplastic olive oil closure from T6.3.

## BIOPLASTIC OLIVE OIL CLOSURE (BP OO)

|                             |                                                                           |
|-----------------------------|---------------------------------------------------------------------------|
| Material                    | <b>PSILCA process</b>                                                     |
| PHA                         | Commodities - Manufacture of rubber and plastic products - NLD            |
| Rice Husk                   | Commodities - Products of agriculture, hunting and related services - ITA |
| Energy                      | <b>PSILCA process</b>                                                     |
| NTP                         | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Extruder                    | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Hopper Dryer                | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Hopper Loader               | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| MW preheating system        | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Injection moulding - caps   | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Injection moulding - Pourer | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Material                    | <b>PSILCA process</b>                                                     |
| Olive Oil closure (current) | Industries - Manufacture of rubber and plastic products - ITA             |

Table 73. LCI for the bioplastic Limoncello closure from T6.3.

## BP LIMONCELLO CLOSURE (BP LIM)

|                           |                                                                           |
|---------------------------|---------------------------------------------------------------------------|
| Material                  | <b>PSILCA process</b>                                                     |
| PHA                       | Commodities - Manufacture of rubber and plastic products - NLD            |
| Rice Husk                 | Commodities - Products of agriculture, hunting and related services - ITA |
| Energy                    | <b>PSILCA process</b>                                                     |
| NTP                       | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Extruder                  | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Hopper Dryer              | Commodities - Electrical energy, gas, steam and hot water - ITA           |
| Injection moulding - caps | Commodities - Electrical energy, gas, steam and hot water - ITA           |

|                                            |                                                                                             |
|--------------------------------------------|---------------------------------------------------------------------------------------------|
| Injection moulding<br>- Pourer<br>Material | Commodities - Electrical energy, gas, steam and<br>hot water - ITA<br><b>PSILCA process</b> |
| Olive Oil closure<br>(current)             | Industries - Manufacture of rubber and plastic<br>products - ITA                            |

Table 74. LCI for the olive oil closure benchmark from T6.3. Raw materials provided from outside Europe.

| OLIVE OIL CLOSURE CURRENT (NON EU) |                                                                    |
|------------------------------------|--------------------------------------------------------------------|
| Material                           | <b>PSILCA process</b>                                              |
| LDPE                               | Commodities - Plastics material and resin<br>manufacturing - USA   |
| Energy                             | <b>PSILCA process</b>                                              |
| NTP                                | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Extruder                           | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Hopper Dryer                       | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Hopper Loader                      | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| MW preheating<br>system            | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Injection moulding<br>- caps       | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Injection moulding<br>- Pourer     | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Material                           | <b>PSILCA process</b>                                              |
| Olive Oil closure<br>(current)     | Industries - Manufacture of rubber and<br>plastic products - ITA   |

Table 75. LCI for the olive oil closure benchmark from T6.3. Raw materials provided from Europe.

| OLIVE OIL CLOSURE CURRENT (NON EU) |                                                                    |
|------------------------------------|--------------------------------------------------------------------|
| Material                           | <b>PSILCA process</b>                                              |
| LDPE                               | Commodities - Manufacture of rubber and<br>plastic products - NLD  |
| Energy                             | <b>PSILCA process</b>                                              |
| NTP                                | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Extruder                           | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Hopper Dryer                       | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |
| Hopper Loader                      | Commodities - Electrical energy, gas, steam<br>and hot water - ITA |

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|                             |                                                                 |
|-----------------------------|-----------------------------------------------------------------|
| MW preheating system        | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Injection moulding - caps   | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Injection moulding - Pourer | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Material                    | <b>PSILCA process</b>                                           |
| Olive Oil closure (current) | Industries - Manufacture of rubber and plastic products - ITA   |

Table 76. LCI for the Limoncello closure from T6.3. Raw materials provided from outside Europe.

OLIVE OIL CLOSURE CURRENT (NON EU)

|                             |                                                                 |
|-----------------------------|-----------------------------------------------------------------|
| Material                    | <b>PSILCA process</b>                                           |
| PP                          | Commodities - Plastics material and resin manufacturing - USA   |
| Energy                      | <b>PSILCA process</b>                                           |
| NTP                         | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Extruder                    | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Hopper Dryer                | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Injection moulding - caps   | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Injection moulding - Pourer | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Material                    | <b>PSILCA process</b>                                           |
| Olive Oil closure (current) | Industries - Manufacture of rubber and plastic products - ITA   |

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Table 77. LCI for the bioplastic olive oil closure from T6.3. Raw materials provided from Europe.

OLIVE OIL CLOSURE CURRENT (NON EU)

|                           |                                                                 |
|---------------------------|-----------------------------------------------------------------|
| Material                  | <b>PSILCA process</b>                                           |
| PP                        | Commodities - Manufacture of rubber and plastic products - PRT  |
| Energy                    | <b>PSILCA process</b>                                           |
| NTP                       | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Extruder                  | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Hopper Dryer              | Commodities - Electrical energy, gas, steam and hot water - ITA |
| Injection moulding - caps | Commodities - Electrical energy, gas, steam and hot water - ITA |



*Injection moulding  
- Pourer  
Material*

*Commodities - Electrical energy, gas, steam  
and hot water - ITA*

## **PSILCA process**

*Olive Oil closure  
(current)*

*Industries - Manufacture of rubber and  
plastic products - ITA*



| Value chain     | WP  | Task | WP Leader | Consortium partners |
|-----------------|-----|------|-----------|---------------------|
| Wood composites | WP5 | T6.4 | FHF       | GUALA               |

Table 78. LCI for SBS1 (without glass fibre) from T6.4.

## SBS1

|                                 |                                                           |
|---------------------------------|-----------------------------------------------------------|
| Material                        | <b>PSILCA process</b>                                     |
| ARBOBLEND 2241x                 | Commodities - Manufacture of chemical products - DEU      |
| Natural Wood Fibre              | Commodities - Manufacture of wood and wood products - DEU |
| Energy                          | <b>PSILCA process</b>                                     |
| Eirich mixer                    | Commodities - Electricity and district heat - DEU         |
| Microwave heating system        | Commodities - Electricity and district heat - DEU         |
| Extruder                        | Commodities - Electricity and district heat - DEU         |
| Linden Kneader                  | Commodities - Electricity and district heat - DEU         |
| Warm press Machine              | Commodities - Electricity and district heat - DEU         |
| Material                        | <b>PSILCA process</b>                                     |
| Wood composite sliding bearings | Commodities - Manufacture of plastic products - DEU       |

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Table 79. LCI for SBS2 (with glass fibre) from T6.4.

## SBS2

|                          |                                                             |
|--------------------------|-------------------------------------------------------------|
| Material                 | <b>PSILCA process</b>                                       |
| ARBOBLEND 2241x          | Commodities - Manufacture of chemical products - DEU        |
| Natural Wood Fibre       | Commodities - Manufacture of wood and wood products - DEU   |
| Glass fibre              | Commodities - Manufacture of glass and glass products - DEU |
| Energy                   | <b>PSILCA process</b>                                       |
| Eirich mixer             | Commodities - Electricity and district heat - DEU           |
| Microwave heating system | Commodities - Electricity and district heat - DEU           |
| Extruder                 | Commodities - Electricity and district heat - DEU           |
| Linden Kneader           | Commodities - Electricity and district heat - DEU           |

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Warm press Machine

Commodities - Electricity and district heat - DEU

Material

**PSILCA process**

Wood composite sliding bearings

Industries - Manufacture of plastic products - DEU

Table 80. LCI for MM benchmark from T6.4. Raw materials provided from outside Europe.

## MM BENCHMARK (NON-EU)

|                          |                                                              |
|--------------------------|--------------------------------------------------------------|
| Material                 | <b>PSILCA process</b>                                        |
| Copper                   | Commodities - Basic products of nonferrous metals - CHL      |
| Cast iron                | Commodities - Alloy iron smelting - CHN                      |
| Zinc                     | Commodities - Metal Products - CHN                           |
| Aluminium                | Commodities - Nonferrous metal processing - CHN              |
| Energy                   | <b>PSILCA process</b>                                        |
| Eirich mixer             | Commodities - Electricity and district heat - DEU            |
| Microwave heating system | Commodities - Electricity and district heat - DEU            |
| Extruder                 | Commodities - Electricity and district heat - DEU            |
| Linden Kneader           | Commodities - Electricity and district heat - DEU            |
| Warm press Machine       | Commodities - Electricity and district heat - DEU            |
| Material                 | <b>PSILCA process</b>                                        |
| Metallic sliding bearing | Commodities - Manufacture of fabricated metal products - DEU |

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Table 81. LCI for MM benchmark from T6.4. Raw materials provided from Europe.

## MM BENCHMARK (EU)

|                          |                                                   |
|--------------------------|---------------------------------------------------|
| Material                 | <b>PSILCA process</b>                             |
| Copper                   | Commodities - Basic non-ferrous metals - DEU      |
| Cast iron                | Commodities - Manufacture of basic metals - ITA   |
| Zinc                     | Commodities - Manufacture of basic metals - SWE   |
| Aluminium                | Commodities - Manufacture of basic metals - NOR   |
| Energy                   | <b>PSILCA process</b>                             |
| Eirich mixer             | Commodities - Electricity and district heat - DEU |
| Microwave heating system | Commodities - Electricity and district heat - DEU |



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D2.3 "Energy, exergy, LCA, SLCA and LCC assessments"

|                          |                                                              |
|--------------------------|--------------------------------------------------------------|
| Extruder                 | Commodities - Electricity and district heat - DEU            |
| Linden Kneader           | Commodities - Electricity and district heat - DEU            |
| Warm press Machine       | Commodities - Electricity and district heat - DEU            |
| Material                 | <b>PSILCA process</b>                                        |
| Metallic sliding bearing | Commodities - Manufacture of fabricated metal products - DEU |

Table 82. LCI for PBP benchmark from T6.4. Raw materials provided from outside Europe.

PBP BENCHMARK (NON-EU)

|                          |                                                               |
|--------------------------|---------------------------------------------------------------|
| Material                 | <b>PSILCA process</b>                                         |
| PA                       | Commodities - Plastics material and resin manufacturing - USA |
| POM                      | Commodities - Manufacture of plastic products - CHN           |
| HDPE                     | Commodities - Plastics material and resin manufacturing - USA |
| Energy                   | <b>PSILCA process</b>                                         |
| Eirich mixer             | Commodities - Electricity and district heat - DEU             |
| Microwave heating system | Commodities - Electricity and district heat - DEU             |
| Extruder                 | Commodities - Electricity and district heat - DEU             |
| Linden Kneader           | Commodities - Electricity and district heat - DEU             |
| Warm press Machine       | Commodities - Electricity and district heat - DEU             |
| Material                 | <b>PSILCA process</b>                                         |
| Plastic sliding bearings | Commodities - Manufacture of plastic products - DEU           |

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Table 83. LCI for PBP benchmark from T6.4. Raw materials provided from Europe.

PBP BENCHMARK (EU)

|          |                                                                |
|----------|----------------------------------------------------------------|
| Material | <b>PSILCA process</b>                                          |
| PA       | Commodities - Manufacture of plastic products - DEU            |
| POM      | Commodities - Manufacture of plastic products - DEU            |
| HDPE     | Commodities - Manufacture of rubber and plastic products - NLD |



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|                                 |                                                            |
|---------------------------------|------------------------------------------------------------|
| <i>Energy</i>                   | <b>PSILCA process</b>                                      |
| <i>Eirich mixer</i>             | <i>Commodities - Electricity and district heat - DEU</i>   |
| <i>Microwave heating system</i> | <i>Commodities - Electricity and district heat - DEU</i>   |
| <i>Extruder</i>                 | <i>Commodities - Electricity and district heat - DEU</i>   |
| <i>Linden Kneader</i>           | <i>Commodities - Electricity and district heat - DEU</i>   |
| <i>Warm press Machine</i>       | <i>Commodities - Electricity and district heat - DEU</i>   |
| <i>Material</i>                 | <b>PSILCA process</b>                                      |
| <i>Plastic sliding bearings</i> | <i>Commodities - Manufacture of plastic products - DEU</i> |