WOOD2WOOD

A Wood-to-Wood Cascade Upcycling Valorisation Approach

» Deliverable 4.5

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RE	Restricted to a group specified by the consortium	
CO	Confidential, only for members of the consortium (including the European Commission Services)	

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GLOSSARY OF ACRONYMS

Acronym	Extended Definition
W2W	Wood2Wood
EU	European Union
GA	Grant Agreement
CNF	Cellulose NanoFibers
KPI	Key Performance Indicator
FBG	Fluidized Bed Gasification
HTC	Hydrothermal carbonisation
CDW	Construction Demolition Wastes
C&D	Construction and Demolition
THL	Technology Harmfulness Level
TRL	Technology Readiness Level
MDF	Medium Density Fiberboard
MW	MicroWave
WP	Work Package
RP	Reporting Period
MWS	Management of Waste Streams
MR	Material Recycling
UC	Use Case

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EXECUTIVE SUMMARY

Wood2Wood (W2W) is a European Union (EU) funded project aiming at revolutionizing how wood is used and reused in Europe, addressing the critical need for sustainable practices that can keep pace with the demands of our planet.

The present deliverable i.e. Deliverable 4.5 “Definition of impact assessment methodologies and KPIs” has been conducted in the context of Work Package (WP) 4 “Transformation Framework for Sustainable-by-design Construction Demolition Wastes Biorefining”, specifically referring to Task 4.5. The primary objective of the task was to establish Key Performance Indicators (KPIs) for all use cases (UCs) and the developed digital tools, in order to evaluate the results obtained by implementing the W2W framework to the project use cases. In this context, analysis of all three Use Cases and of the Management of Waste Streams (MWS) system took place, in order to understand them thoroughly, based on information provided by each pilot leader in given questionnaires. Then, a four-step methodology was followed. The main target of the methodology was to establish KPIs that are both measurable and achievable, directly representing the project's use cases and digital tools.

Primarily, document analysis took place, meaning a detailed review and analysis of the Grand Agreement (GA) to ensure that the proposed KPIs are aligned with the four main innovation pillars of the W2W project, addressing the specific needs and objectives outlined in these focus areas. The second step consisted of creating questionnaires grounded in ISO 22400 standards, which were then used by DRAXIS to preselect indicators for each use case. The next step involved the validation of the KPIs within a structured process and then, all partners were asked to fill in the questionnaires with necessary data and information for the definition of each KPI. Moreover, when KPI questionnaires were filled and after careful examination and thorough discussions with the respective partners, the final list of KPIs was created, as some of the suggested KPIs were not selected, while new KPIs, to enhance the existing set, were also introduced by partners. Eventually, all indicators were grouped into the three categories of Technological, Environmental and Socio-Economic, aiming to enhance the understanding of the W2W framework's impact through a sustainability lens.

In addition, a strategy for evaluating and monitoring KPIs was developed to facilitate the collection of calculated KPIs and to report progress toward the targets established in the W2W project. Bringing up-to-date the KPIs is organised and divided into three chronic stages associated with the three technical reporting periods (RP) of W2W project.

Overall, 29 Technical, 13 Environmental and 7 Socio-economic KPIs were imported in the final list, referring to the three use cases, the sorting process and three digital tools, and are to be monitored throughout the project, assessing the results of the technological solutions of all three use cases and proving their efficiency in all presented aspects: technologically, environmentally, as well as socio-economically.

1. INTRODUCTION

1.1. PROJECT INTRO

The W2W project aims to establish and validate a comprehensive framework for multi-dimensional cascade valorisation of wood waste derived from construction, demolition and furniture sectors. With Europe facing a potential wood shortage by 2030 due to rising demand, the project addresses significant challenges in wood waste management, by minimizing waste sent to landfills or incineration and fostering a transition towards circular economy.

The core of the W2W framework are four essential pillars:

i. development of cutting-edge technologies for advanced separation and sorting,
ii. implementation of innovative upcycling processes,
iii. creation of digital tools that enhance circular flows of secondary materials,
iv. establishment of supportive frameworks in policy, market dynamics and skills development.

The W2W project aspires to achieve a Technology Readiness Level (TRL) of 6 by its conclusion, showcasing efficient and sustainable value chains through three practical use cases that will generate: pollutant-free wood, bio-composite materials for construction, biopolymers, polyols, cleaning agents and nutrient recovery solutions.

1.2. PURPOSE OF THE DELIVERABLE

This deliverable presents the work undertaken in Task 4.5 “Definition of impact assessment methodologies and KPIs”, in the context of Work Package (WP) 4 “Transformation Framework for Sustainable-by-design Construction Demolition Wastes Biorefining”. It seeks to establish the most appropriate KPIs necessary for guiding the performance of the W2W use cases and the development of the digital tools. Specifically, these KPIs will help in quantitively evaluating the results of W2W, by analysing in detail the current systems and collaborating with the related partners to identify the composing elements of the experiments of the W2W use cases.

Indicators are very valuable as they give important information, which can support the decision-making process. Indicators can be categorised either as **descriptive**, which explain a situation or trend with more information, or as **performance**, which evaluate progress and outcomes towards a timeline and a target. The latter is commonly named as **Key Performance Indicators (KPIs)** (Amaro, et al., 2024). By providing a clear and measurable method of assessment, KPIs guarantee that progress is monitored in a manner that aligns with both the project's specific objectives and its wider strategic goals.

Finally, the deliverable provides a comprehensive roadmap for tracking and evaluating the progress of W2W across various stages of its deployment. It outlines not only the KPIs, but also the methodology for their periodic updating and assessment, examining the agreement of the project with its expected results.

1.3. INTENDED AUDIENCE

The dissemination level of D4.5 is public (PU). The deliverable will be highly beneficial for project partners, offering a structured framework for evaluating the effect of the W2W framework in the use cases. By outlining the methodologies and KPIs, partners can monitor progress, assess outcomes and make data-driven decisions throughout the implementation. It guarantees that all stakeholders are aligned on performance benchmarks and offers a clear path for adjusting strategies based on the insights generated, thus optimizing the overall project outcomes.

Additionally, industry professionals looking to implement similar frameworks can use the deliverable as a guide for understanding best practices KPIs definition, supporting wider adoption and scalability of the W2W framework.

1.4. STRUCTURE OF THE DELIVERABLE

This document is organised into the following chapters:

i. **Chapter 1** introduces the document, outlining its scope, the purpose of KPIs definition, and the key contents of the deliverable.
ii. **Chapter 2** offers an overview of the current systems developed within the W2W project, including the sorting system and the three use cases, explaining all the composing elements of the experiments based on the contribution from relevant partners.
iii. **Chapter 3** details the methodology for KPIs definition, which is structured as a four-step process encompassing document analysis, a template-based selection of KPIs, validation and the finalisation of the KPIs list along with the development of the evaluation methodology for their measurement and monitoring.
iv. **Chapter 4** presents the categorized KPIs grouped into technical, environmental or socio-economic categories, with each KPI linked to its respective owner responsible for the related use case or tool.
v. **Chapter 5** recommends a structured process for KPIs monitoring and evaluation, ensuring continuous assessment throughout the project.
vi. **Chapter 6** outlines important outcomes of the deliverable while discussing the next steps for implementing the evaluation framework.

2. W2W USE CASES

In order to identify appropriate KPIs, W2W Use Cases (UC) were carefully reviewed. To this end, the three UCs are described based on information provided by each pilot leader in given questionnaires regarding: 1) the background, 2) the objectives, 3) specific challenges, 4) the technologies to be tested, 5) the requirements, 6) the inputs (materials or data), 7) the end products/outputs and 8) the targeted validation plan (examining if the developed technologies of the UCs meet all expectations). Furthermore, the adaptive separation and sorting system, developed by ICCS, which forms the first pillar of the UCs is described in this section, following the same template.

2.1. MANAGEMENT OF WASTE STREAMS

The pilot leader of management of waste streams (MWS), referring to the developed Construction Demolition Waste (CDW) separation and sorting technology, is ICCS (contributing partner is IRIS), which provided the following information.

Background

The abundance of wood in Construction and Demolition (C&D) and furniture waste offers a low-cost resource that is primarily used for landfilling and energy recovery. Wood cascade valorisation relies on the sequential use of wood, in multiple stages or processes, with each stage aiming to extract the highest possible value before moving on to the next. However, the variability in material composition and contamination, especially in post-consumer waste, complicates the identification of suitable applications at each stage. Furthermore, state-of-the-art sorting and separating processes for wood can be complex and resource-intensive processes. MWS focuses on sorting wood particles in an efficient manner based on their quality and potential uses for maximum valorisation.

Objectives

i. to develop the overall methodology for the CDW separation and sorting systems,
ii. to put in place the most adequate optical and spectroscopic characterisation techniques for the most efficient particle size of wood and glass coming from CDW to further process these materials,
iii. to deploy an adaptive system for sorting glass waste,
iv. to develop an adaptive cyber-physical system for sorting wood waste extracted from CDW,
v. to create a station where a collaborative robot will cooperate with the workforce to jointly process the wood stream with existing assembled elements separated,
vi. to develop a Material Recycling (MR) system detecting the material and state of the recycled products.

Challenges

i. creation of adaptive classification thresholds,
ii. high classification accuracy of pure and contaminated wood waste,
iii. efficient robotic gripping of varying wood objects,
iv. high classification accuracy of glass waste,
v. well-defined human-robot collaboration for efficient wood processing.

W2W technologies to be tested

i. optical and spectroscopic characterization for wood and glass,
ii. glass separation based on thresholds,
iii. robotic waste sorting for CDW,
iv. human-Robot Collaboration for waste processing and disassembly,
v. mixed-Reality for human-robot collaboration.

Requirements

i. batches of CDW wood of different classes, i.e. of different composition and contamination,
ii. characterization of CDW wood,
iii. collaborative and industrial robots,
iv. high precision optical and spectroscopic sensors.

Material or data inputs

i. construction Demolition Wastes and furniture waste.

End products or outputs

i. wood streams of Classes A, B and C with high purity,
ii. glass streams of different grades based on quality and valorisation potential.

Validation plan

It consists of:

i. real-time classification and sorting of general-mixed streams,
ii. adaptive sorting based on valorisation value,
iii. development of industrial sorting line at Technology Readiness Level (TRL) 5.

Additionally, a diagram of the activities which will take place in MWS is presented in Figure 1, as provided by POLIMI in the context of Task 16.2. At this stage of the W2W project, the figure below is at its draft version and has yet to be finalised.

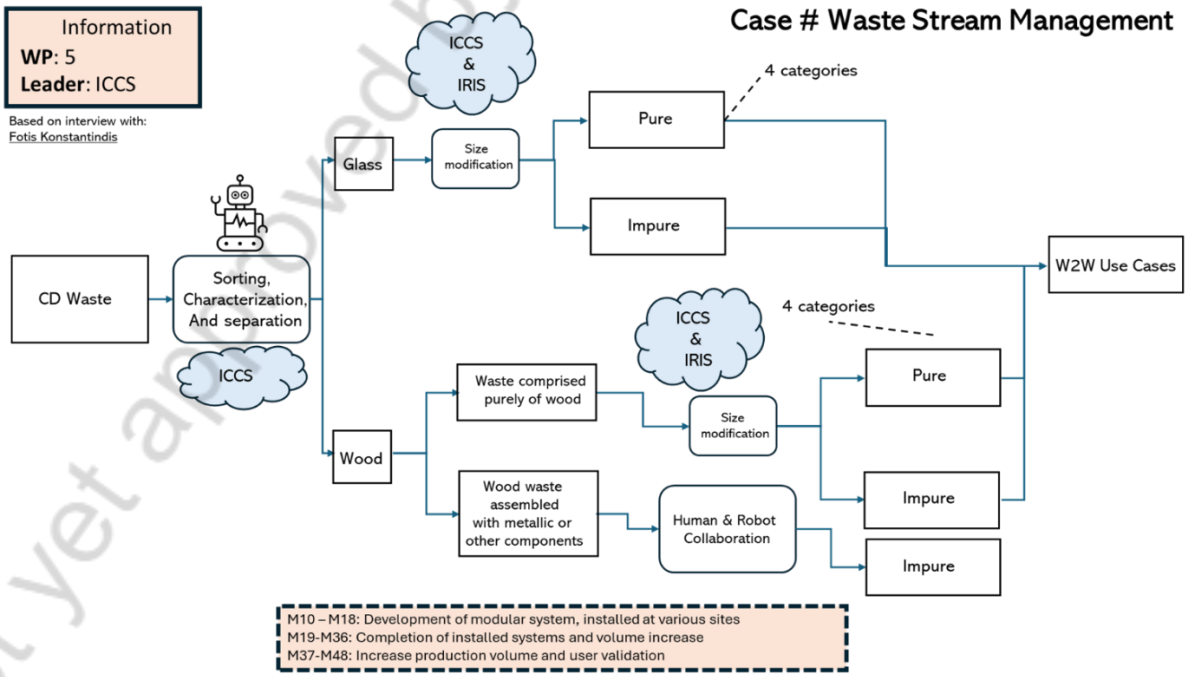

Figure 1: Management of waste streams activity diagram

2.2. USE CASE 1 - CASCADE REFINEMENT TECHNOLOGIES FOR WOOD WASTE UPCYCLING

The pilot leader for use case #1 is NTUA (contributing partners are: UHE, BLOOM-LEVERY, ICCS), which provided the following information.

Background

The fractionation of mixed wood into its main components, which could be subsequently re-used for different applications, has yet to be fully evaluated and addressed. Additionally, the reuse of residual mixed wood from CDW can provide a viable solution for the preservation of the ecosystems and the improvement of the environmental footprint of the involved industrial sectors. However, several gaps and concerns have to be efficiently addressed in the wood waste upcycling for fiber production. The two main concerns are the following:

i. The lengths of fibers obtained from waste wood are often shorter than those obtained from native wood.
ii. Fibers produced retain debris, such as plastics or decorative elements (e.g., melamine coating). As they also still contain some of the additives originally contained in the waste wood (glues, paints, fungicides, etc.), achieving efficient and effective use of wood resources requires considering multidimensional valorisation of wood, including time, value and function.

Objectives

i. to develop and optimise the extraction of cellulose nanofibers (CNFs) from waste wood,
ii. to improve the compatibility of the CNFs via functionalisation with organic compounds, as well as the compatibility of the lignin via functionalisation with fatty acids,
iii. to deliver composite compounds that will serve as sustainable recycled materials,
iv. to validate the final products through the integration of the composite components into a developed prefabricated façade system.

Challenges

i. extraction of CNFs has to be optimized in order not to hinder the achievement of the targeted performance of end products,
ii. defining the most suitable end-users for the developed product,
iii. ensuring that the quality aspects and characteristics of the end product are similar to the conventional ones.

Technologies to be tested

i. organosolv pulping for wood waste fractionation,
ii. mechanical treatment for the production of CNFs,
iii. functionalization/modification of CNFs,
iv. lignin isolation and purification,
v. composite compounds production via a combination of the recovered lignocellulose-based materials with thermoplastic matrices,
vi. integration of the composite compounds into a developed prefabricated façade system.

Requirements

i. appropriate equipment for the recovery and functionalization of CNFs,
ii. a pilot scale extruder for the composite compounds production,
iii. thermoforming equipment to allow transforming the composites compounds into building blocks.

Inputs (materials or data)

Data regarding:

i. flows and composition of the received waste,
ii. the properties that the end product has to possess in order to optimize the involved processes.

End products/outputs

i. composite compounds based on the recovered lignocellulose materials,
ii. building blocks that will contain the developed composite compounds.

Validation plan

It consists of the following:

i. development of the composite compounds,
ii. incorporation of the composite compounds into building blocks,
iii. introduction of the composite materials and/or building blocks into the façade industry and evaluation of their compliance with regulatory and market requirements.

In addition, a diagram of the activities which take place in use case #1 is shown in Figure 2, as provided by POLIMI in the context of task 16.2. At this stage of the W2W project, the Figure below is at its draft version and has yet to be finalised, considering also the replacement of FOCCHI by BLOOM-LEVERY cooperation, as contributing partners.

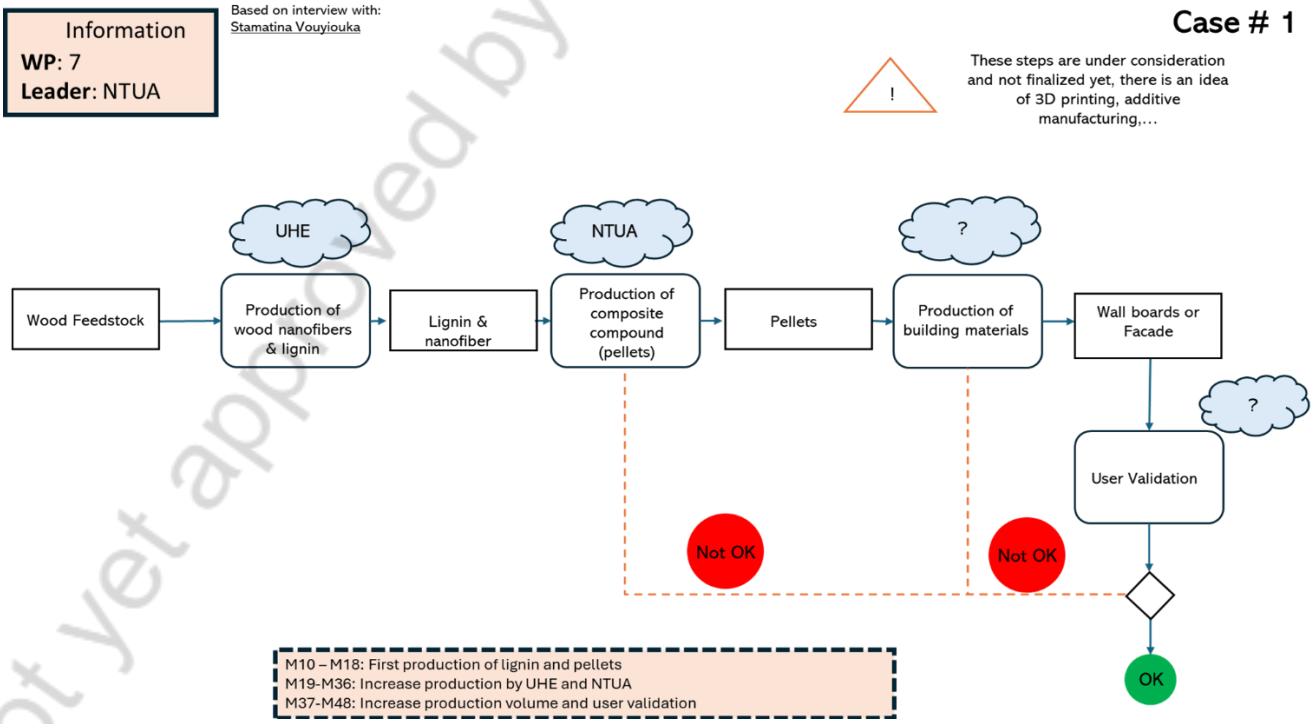

Figure 2: Use case 1 activity diagram

2.3. USE CASE 2 - CHEMICAL AND BIOREMEDIATION TECHNOLOGIES FOR WOOD WASTE UPCYCLING

The pilot leader for use case #2 is LERMAB (contributing partners are: UHE, ECOM, ICCS), which provided the following information.

Background

Recycling waste wood may require the removal of pollutants such as glues and chemical additives. It has been demonstrated at LERMAB that the environmental-friendly steam explosion process can effectively eliminate a large proportion of urea formaldehyde glues, the most widely used glue in the panel industry. For its part, UHE has been interested, for several years, in the production of green glue from wood using a liquefaction process. The final aim of case study #2 is to use these skills to produce, at Technology Harmfulness Level (THL) 5, 100% recycled wood panels by combining purified wood particles and glue derived from the liquefaction of waste wood.

Objectives

i. optimization of the Steam Explosion process for cleaning waste wood at TRL 4,
ii. optimization of the Steam Explosion process for cleaning waste wood at TRL 5,
iii. bioremediation of the waste wood and of the water effluents of the process using fungi,
iv. liquefaction of waste wood,
v. production of adhesive resin from liquefied wood,
vi. production of green panels meeting current specifications.

Challenges

i. scale-up of the steam explosion process,
ii. production of mycocomposites,
iii. liquefaction of waste wood,
iv. production of resin without isocyanate,
v. production of panels from 100% recycled wood with properties comparable to industrial panels.

Technologies to be tested

i. steam explosion process TRL5,
ii. use of filamentous fungi to decontaminate formaldehyde-rich liquid effluents,
iii. production of waste-wood based mycocomposites.

Requirements

i. batches of sorted wood,
ii. steam explosion pilot TRL 4 & 5,
iii. hot press,
iv. reactors (bioreactors and high-pressure reactors),
v. chemical analysis equipment (LC-MS, HPTLC),
vi. mechanical analysis equipment (strength and flexural modulus of the panels).

Inputs (materials or data)

i. batches of sorted wood with different characteristics (furniture, demolition, heavily polluted with heavy metals, Medium Density Fiberboard (MDF) etc.),
ii. data regarding the flows and the composition of the received waste.

End products/outputs

i. green particle board panels meeting current specifications.

Validation plan

It consists of the following:

i. elaboration of wood waste-based panels meeting current specifications,
ii. TRL5 development of a pre-industrial model.

Moreover, a diagram of the activities which take place in use case #2 is presented in Figure 3, as provided by POLIMI in the context of task 16.2. At this stage of the W2W project, the figure below is at its draft version and has yet to be finalized.

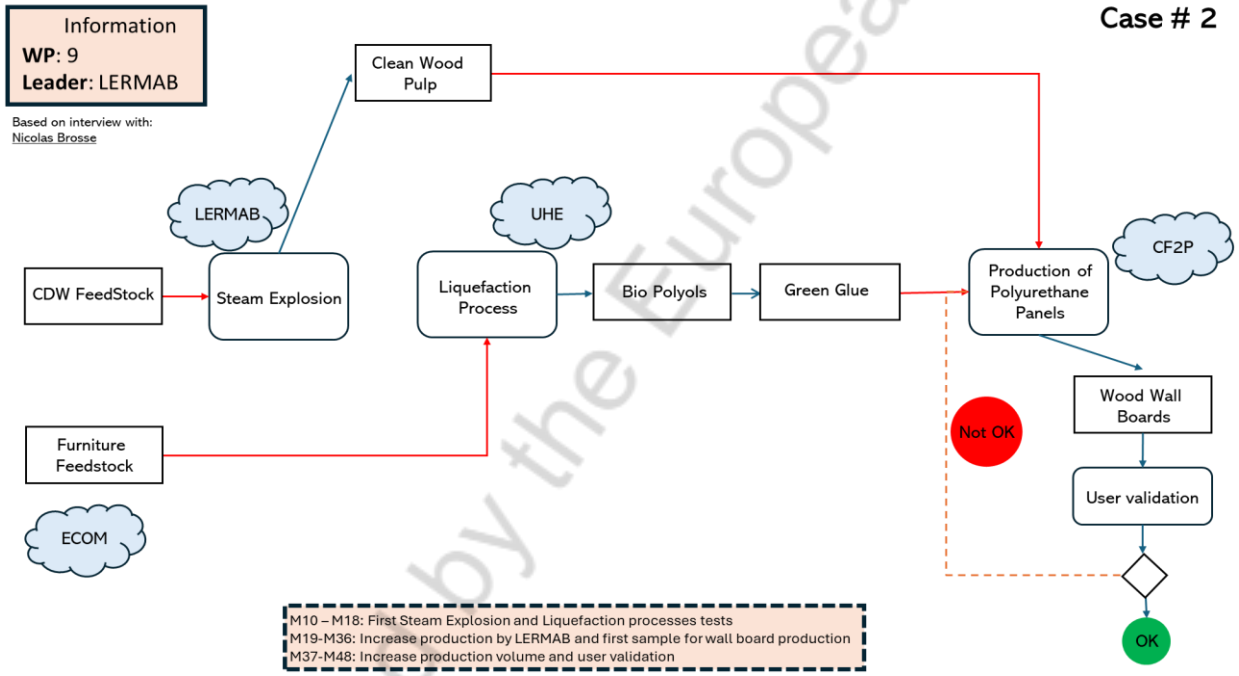

Figure 3: Use case 2 activity diagram

2.4. USE CASE 3 - ENERGY, GAS AND ASHES VALORISATION

The partner responsible for use case #3 is CIRCE (contributing partners are: KIVERDI, P&G, ICCS), which provided the following information.

Background

There is an increasing amount of residual wood contained in C&D wood and furniture residues in the European Union each year. Recycling them can provide an abundant and cost-effective raw material source, not only for the wood, but also fossil-fuel based carbon included as coatings, paints, plastics or preservatives. Thermochemical processes can allow the recuperation of these fuels. However, the most common process, combustion, is not able to handle adequately these exogenous materials from the wood, as energy will be recovered, but fossil fuel derived materials and other contaminants are not recuperated but thrown to the atmosphere. The strategy proposed

here, aims to produce not only energy derived from a combustion process, but also a high-added value output, a chemical surfactant that can be upgraded to a commercial detergent.

Objectives

i. to produce a suitable hydrochar via hydrothermal carbonisation (HTC) process and demonstrate the technology for this feedstock,
ii. to compare the micro-wave (MW) and the standard heating technologies in HTC,
iii. to demonstrate the viability of hydrochar gasification,
iv. to compare the direct CDW gasification with hydrochar gasification,
v. to produce and optimize the dodecanol process,
vi. to demonstrate and validate the surfactants produced via dodecanol.

Challenges

i. to optimize the feedstock for HTC process,
ii. to produce a clean syngas,
iii. to obtain enough hydrochar for gasification,
iv. to obtain CDW incineration ashes,
v. to eliminate the contaminants from the ashes,
vi. to couple the processes.

Technologies to be tested

i. HTC process of the CDW. It will enable to assess the evolution of the exogenous wood materials and to produce a high C material: hydrochar,
ii. HTC of ashes,
iii. two application ways for HTC technology: 1) MW assisted HTC and 2) conventional HTC,
iv. fluidized bed gasification (FBG) of hydrochar or the C&D, as a substitution of combustion/incineration, to produce valuable syngas (mainly H_2 and CO_2) instead of just energy,
v. fermentation for fatty acids biosynthesis and fatty acid beta-oxidation, using as an input the syngas produced in the FBG stage. This procedure will allow to obtain a stream of fatty acids that will be further validated in the final task of the work package (WP12),
vi. validation from the exhausted cells and fatty acids towards formulation of low impact detergents leveraging a micro falling film pilot reactor.

Requirements

i. liner for HTC reactor,
ii. adaptation of the gas cleaning system of the FBG,
iii. characterization of ashes and valorised products,
iv. gas bottles for fermentation input,
v. transportation of fatty acids from KIV's to P&G's facilities.

Inputs (materials or data)

i. CDW, hydrochar, ashes and syngas,
ii. fatty acids and exhausted cells.

End products/outputs

i. Chemical detergents for different application sectors,
ii. nutrients recovery from HTC i.e., recovery of ammonia from process water.

Validation plan

It consists of the following:

i. preliminary assessment of compatibility of fatty acids and exhausted cells from fermentation with surfactants formulation by performing stress tests (stability, colour, odour etc.),
ii. leveraging a micro falling film pilot reactor converting fatty alcohols and aminoacids into ionic surfactants,
iii. small scale consumer exposure tests for final validation.

Also, a diagram of the activities which take place in use case #3 is shown below, as provided by POLIMI in the context of task 16.2. At this stage of the W2W project, the figure below is in its draft version and has yet to be finalised.

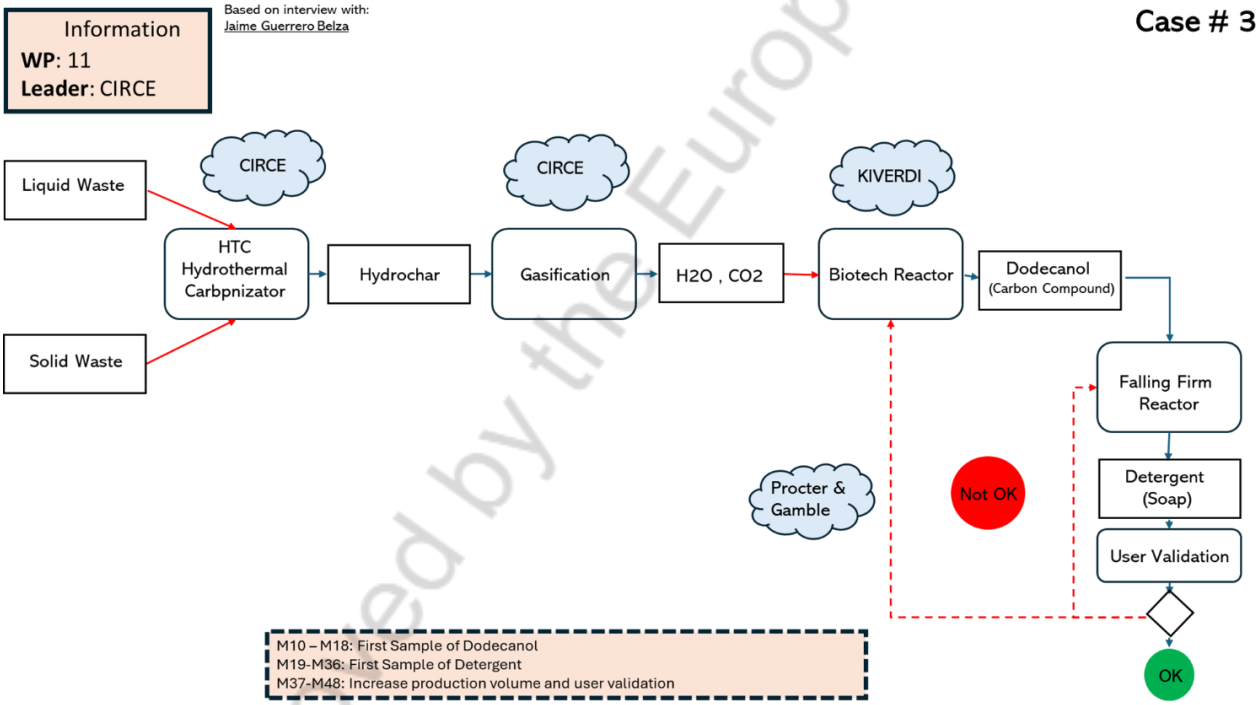

Figure 4: Use case 3 diagram

3. METHODOLOGY

3.1. OVERALL APPROACH

Key performance indicators (KPIs) are critical quantifiable metrics used to evaluate performance or effectiveness (Setiawan and Purba, 2020). According to Task 4.5 of the W2W project, the KPIs are to be defined with the goal of evaluating the results obtained by implementing the W2W framework to the project use cases. The GA categorizes the KPIs into three distinct groups:

i. **Product KPIs:** This category encompasses metrics that are directly related to the performance and impact of the final outputs generated within the project's use cases. They are designed to evaluate the effectiveness of the W2W framework in enhancing the quality, sustainability and economic value of the end products across all three use cases.
ii. **Expected Outcomes KPIs:** This category is centred on evaluating the broader impact of the W2W project, specifically its contribution to achieving the desired long-term outcomes. They assess the project's success in driving systemic improvements, such as advancing resource efficiency, reducing environmental footprints and enhancing industry competitiveness by validating the practical application and benefits of the W2W technologies across the value chain.
iii. **Objectives KPIs:** These KPIs focus on evaluating the successful development, implementation and validation of the project's core frameworks, technologies and processes. By tracking progress against clearly defined objectives, they ensure that the project stays aligned with its aims.

Moreover, as some KPIs were added by the partners involved in the use cases, not mentioned in the GA, those are referred to as '**New KPIs**'.

In the frame of the W2W project and Task 4.5, all KPIs were grouped into the following categories, with the aim to establish a better understanding of the impact of the W2W framework in all sustainability levels, meaning the aspects of environment, economy etc. (Purvis, et al., 2019):

i. **Technical KPIs:** evaluating the W2W framework's operational effectiveness and efficiency,
ii. **Environmental KPIs:** assessing the W2W framework's impact on the environment,
iii. **Socio-economic KPIs:** estimating the W2W framework's financial performance and social impact.

As seen in chapter 4, most of the socio-economic KPIs are mainly economic rather than social, due to the scope of the project which complicates the feasibility of including more social indicators. That is the main reason for including both aspects into a single KPI category. Moreover, some indicators (UC1_TEC_1, UC1_TEC_3, UC1_TEC_7 and UC2_TEC_1, in specific) could be included in both the technical and environmental categories, addressing both operational and environmental issues. In this context, they were chosen to be included in the technical category, targeting to represent the technological effectiveness and efficiency of the respective UCs.

To ensure the accuracy and effectiveness of the KPIs, we employed a four-step methodology, previously developed and applied by DRAXIS in the CAPTUS EU Horizon project (Deliverable 2.3: Evaluation Methodology) [URL1]. The goal of this methodology is to develop KPIs that are measurable and achievable, while also ensuring their relevance to the project's use cases and the tools being developed.

The four distinct methodological steps for KPIs development are:

i. document analysis,
ii. template-based pre-selection of KPIs per use case or tool, developed by DRAXIS,
iii. validation of KPIs with the related partners,
iv. finalization of KPIs, as well as of the guidelines for their proper measurement.

The steps are further explained in the following sub-sections.

3.2. STEP 1: DOCUMENT ANALYSIS

Step 1 involves the review and analysis of the GA, focusing mainly on:

i. the specific requirements and characteristics of each use case, as well as all the elements composing the experiments,
ii. the section of the GA: W2W Objectives and Success Criteria, where objectives KPIs are defined,
iii. the section of the GA: Overview of the Sustainable Value Chains of Secondary Materials, where the use cases are described in detail and the product KPIs are defined,
iv. the section of the GA: Contribution of W2W towards Achieving the Expected Outcomes of the Target Topic, where expected outcomes KPIs are defined,
v. the work foreseen regarding the toolkit development under the technical WPs: WP13 & WP14.

This detailed review ensures that the KPIs developed are aligned with the four main innovation pillars of the W2W project (Figure 5), by addressing the specific needs and objectives outlined in these focus areas.

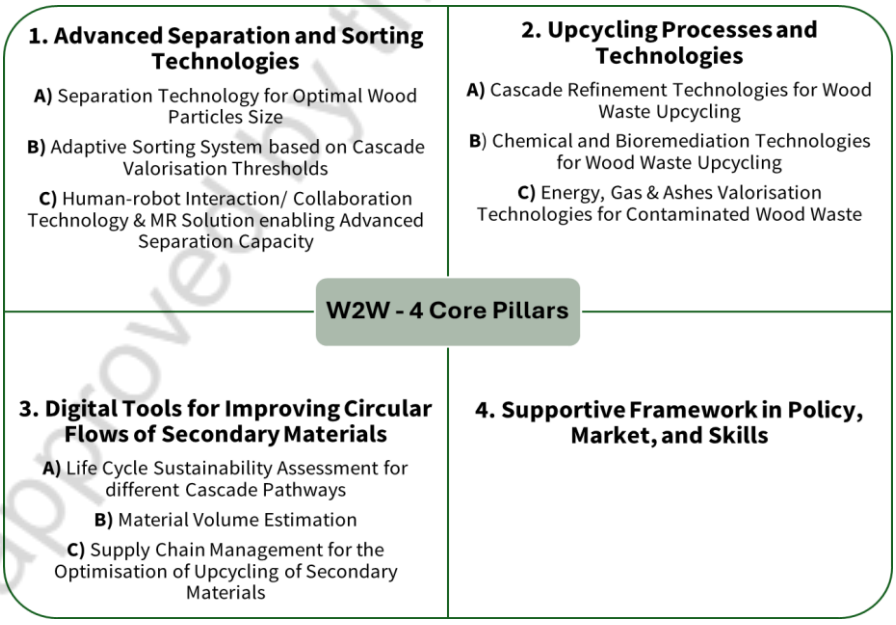

Figure 5: W2W core pillars

3.3. STEP 2: TEMPLATE-BASED SELECTION OF KPIS

Step 2 involves the development of a template that the partners were asked to fill in with necessary data and information for the definition of each KPI. The template was based on the ISO 22400

standard of "Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management" [URL2], which was deemed suitable for effectively capturing the required information. According to this standard, the description of a KPI definition should contain the following elements:

i. Content:
    i) name,
    ii) description,
    iii) scope,
    iv) formula,
    v) unit of measure,
    vi) range,
    vii) trend.
ii. Context:
    i) timing,
    ii) audience,
    iii) production methodology,
    iv) effect model diagram,
    v) notes.

After appropriate adjustments according to the project's needs, KPIs have been defined using the following template:

Table 1: KPIs definition template

Content	
KPI name	Name of the KPI
Owner	The KPI owner
Description	A brief description of the KPI
Scope	Identification of the element that the KPI is relevant for, which can be a work unit, work centre or production order, product or personnel
Resources required	The source/s from which the use case is going to obtain the data needed to calculate this KPI, such as a machine, manual inspection, sensor, information system etc.
Baseline	The baseline value of this KPI at Month 10
Formula	The mathematical formula of the KPI specified in terms of elements
Unit of Measure	The basic unit or dimension in which the KPI is expressed
Range	Specifies the upper and lower logical limits of the KPI or a specific goal

Trend	Is the information about the improvement direction, higher is better or lower is better?
Context	
Timing	A KPI can be calculated either in: i. real-time: after each new data acquisition event, ii. on demand: after a specific data selection request, iii. periodically: done at a certain interval, e.g., once per day.
Notes	Can contain additional information related to the KPI. Typical examples are: i. constraints, ii. usage, iii. other information. **If this definition refers to a KPI from the grant agreement, please add 'Addresses GA KPI xx'**

Then, a preselection process of the proposed indicators for each use case was followed by DRAXIS. When a KPI did not refer to a specific use case, it was listed as "General". General KPIs also include the ones related with the digital tools to be developed in the W2W project, in the context of the third pillar.

3.4. STEP 3: VALIDATION OF KPIS

The next step involves the validation of the KPIs within a structured process. Communication activities were conducted with all related to the use cases (pillar 2) and waste stream management (pillar 1) partners, as well as the ones related to the digital tools (pillar 3), in order to acquaint each partner regarding the aim of Task 4.5 and their expected contribution, creating a mutual understanding of each indicator. The relevant partners are:

i. Use case partners: NTUA (Use Case 1), LERMAB (Use Case 2) and CIRCE (Use Case 3)
ii. Partner responsible for the separation and sorting process: ICCS
iii. Digital tools partners:
    i) life cycle sustainability assessment tool – DRAXIS,
    ii) material volume estimation tool – ICCS,
    iii) supply chain optimisation tool – UPV,
    iv) digital product passport – CERTH,
    v) circular wood upcycling platform – eBOS.

Then, a document was handed out containing all KPIs preselected by DRAXIS (in step 2). The instructions to all related partners were the following:

i. Use case partners should at least fill all 5 product KPIs and any other KPI covering a specific target for their use case.
ii. There is no maximum limit for KPI selection and each KPI can be selected by multiple use case partner; there can be only 1 KPI owner per use case or tool.

3.5. STEP 4: FINALISATION OF KPIS AND OF THE EVALUATION METHODOLOGY

After a series of discussions and communications with the partners, the final list of KPIs was created. In these frameworks, some of the suggested KPIs were not selected as they do not directly pertain to the use cases. This decision was made after careful examination and thorough discussions with the respective partners, ensuring that only relevant and applicable KPIs were chosen. At the same time, partners introduced new KPIs to enhance the existing set (see Table 50 in Annex). Specifically, five of these KPIs are relevant to use case 2 (adding a thorough evaluation of the production process specifications) and three KPIs pertain to use case 3 (associated with the validation process of purified syngas).

Eventually, the comprehensive list of final KPIs was grouped based on their characteristics, which they would either be technical, environmental or socio-economic. The completed tables are presented in the results section (4.2 - 4.8). All KPIs were given an identification code (ID), based on the category included. The IDs produced are based on a specific formula which is: **UCx_y_z** or **Gx_y_z**, where:

i. **UC** stands for the use case which the KPI refers to and **G** to generic (non-use case and digital tool related KPIs), while **x** presents the numbering (1, 2,…n),
ii. **y** stands for the category which each KPI belongs to, so **y** is stated as: TEC (for technical), ENV (for environmental) and SEC (for socio-economic),
iii. **z** presents the numbering of each KPI in each of the three categories and respective use case or digital tool, thus **z** equals to 1, 2,…n.

Finally, the methodology concludes with the definition of the KPI evaluation (KPI monitoring), which outlines the approach to coordinate the collection of calculated KPIs and report the progress toward the targets set in the W2W project.

4. RESULTS: W2W KPIS

4.1. FINAL LIST OF KPIS

The following subsections present the final lists of KPIs per category (Technical, Environmental and Socio-economic) that will be further analysed in the frame of section 4 and evaluated throughout the project (see KPIs monitoring and evaluation).

The goal of this chapter is to present the final list of KPIs, following the implementation of the methodology outlined in Section 3, and to clearly identify the responsible partner 'owner' for each KPI. Therefore, these KPIs will be further analysed and organised by the owner.

It is noted, that the KPI ID line is derived from the identifier details provided in the template, outlined in Section 3.3.

4.2. NTUA – USE CASE 1

Number of KPIs per category in use case 1:

i. technical: 8,
ii. environmental: 4,
iii. socio-economic: 2.

4.2.1. Technical KPIs

Table 2: Definition of UC1_TEC_1

Content	
KPI name	Increase of secondary raw materials use
Identifier	UC1_TEC_1
Owner	NTUA
Description	Validate/Monitor the use of secondary raw materials in the composite materials produced within Use Case 1
Scope	Relevant to product
Resources required	Internal Use Case databases
Baseline	0%
Formula	100 * ((amount of wood filler in the PLA before – amount of wood filler in the PLA after)/ amount of wood filler in the PLA before)
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	

Timing	On demand
Notes	Addresses GA KPI “Increase of secondary raw materials use”

Table 3: Definition of UC1_TEC_2

Content	
KPI name	Up-cycling, reuse and upgrade secondary raw materials technologies implemented
Identifier	UC1_TEC_2
Owner	NTUA
Description	Implement new technologies
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0
Formula	Number of new technologies implemented
Unit of Measure	Number
Range	3
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Up-cycling, reuse and upgrade secondary raw materials technologies implemented”

Table 4: Definition of UC1_TEC_3

Content	
KPI name	Increase in the amount of Class B and Class C wood waste recovered and used to produce composite building materials and panels
Identifier	UC1_TEC_3
Owner	NTUA
Description	Increase in the number of Class B and C recovered wood waste
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0%

Formula	100% * ((amount of wood waste used in the end product after W2W - amount of wood waste used in the end product before W2W)/ amount of wood waste used in the end product before W2W)
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI 1.4: "Increase in amount of Class B and Class C wood waste recovered and used to produce composite building materials and panels"

Table 5: Definition of UC1_TEC_4

Content	
KPI name	Increase in the suitability of wood fibres derived from wood waste for use in end products
Identifier	UC1_TEC_4
Owner	NTUA
Description	Increase in the suitability of wood fibers through the recycling of wood waste
Scope	Relevant to the product
Resources required	Use Case database
Baseline	0%
Formula	100% * ((amount of suitable wood fibres in the end product after W2W - amount of suitable wood fibres before W2W)/ amount of suitable wood fibres before W2W)
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand

Notes	Addresses GA KPI 1.6: “Increase in the suitability of wood fibres derived from wood waste for use in end products”

Table 6: Definition of UC1_TEC_5

Content	
KPI name	Number of end product types produced through the use of secondary resources with identical properties and performance as those produced using primary resources
Identifier	UC1_TEC_5
Owner	NTUA
Description	Measure the new end products derived from the utilization of secondary resources
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0
Formula	Number of new end-products
Unit of Measure	Number
Range	5
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Number of end product types produced through the use of secondary resources with identical properties and performance as those produced using primary resources”

Table 7: Definition of UC1_TEC_6

Content	
KPI name	% increase in lignin and cellulose fibres recovered from waste wood
Identifier	UC1_TEC_6
Owner	NTUA
Description	Evaluate the increase of recovered lignin and cellulose from wood waste

Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((Lignin and cellulose fibers recovered after W2W - Lignin and cellulose fibers recovered before W2W)/ Lignin and cellulose fibers recovered before W2W) *100%
Unit of Measure	%
Range	50%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI 2.2: "% increase in lignin and cellulose fibers recovered from waste wood"

Table 8: Definition of UC1_TEC_7

Content	
KPI name	Increase in the use of recovered wood
Identifier	UC1_TEC_7
Owner	NTUA
Description	Evaluate the increase in the use of recovered wood
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((Recovered wood used after W2W - Recovered wood used before W2W)/ Recovered wood used before W2W) *100%
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI "Increase in the use of recovered wood"

Table 9: Definition of UC1_TEC_8

Content	
KPI name	Number of end product quality properties validated in Use Case 1
Identifier	UC1_TEC_8
Owner	NTUA
Description	Assess the number of new end-products from UC1
Scope	Relevant to the production processes
Resources required	Internal Use Case data
Baseline	0
Formula	Number of new end-products
Unit of Measure	Number
Range	4
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Number of end product quality properties validated in Use Case 1”

4.2.2. Environmental KPIs

Table 10: Definition of UC1_ENV_1

Content	
KPI name	Waste reduction
Identifier	UC1_ENV_1
Owner	NTUA
Description	Validate/Monitor the reduction of wood waste
Scope	Relevant to the production department
Resources required	Life Cycle Sustainability Assessment Tool for Cascade Pathways and Internal Use Case databases
Baseline	0%
Formula	((Quantity of wastes recycled and reused - Quantity of baseline wastes)/Quantity of baseline wastes) *100%
Unit of Measure	%

Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Waste reduction”

Table 11: Definition of UC1_ENV_2

Content	
KPI name	GHG emissions reduction
Identifier	UC1_ENV_2
Owner	NTUA
Description	Evaluate the decrease in GHG emissions
Scope	Relevant to the production processes, final products and wastes
Resources required	Life Cycle Assessment and Internal Use Case databases
Baseline	0%
Formula	((Quantity of GHG emissions before W2W - Quantity of GHG emissions after W2W)/Quantity of GHG emissions before W2W) *100%
Unit of Measure	%
Range	20%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “GHG emissions reduction”

Table 12: Definition of UC1_ENV_3

Content	
KPI name	Reduction of wood-containing waste sent to landfill or incineration
Identifier	UC1_ENV_3
Owner	NTUA
Description	Evaluate the decrease in incinerating or disposing of landfill wood waste

Scope	Relevant to end-users, products and production processes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((Wood waste sent to landfill or incineration before W2W - Wood waste sent to landfill or incineration after W2W)/ Wood waste sent to landfill or incineration before W2W) *100%
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI 2.1: "Reduction of wood-containing waste sent to landfill or incineration"

Table 13: Definition of UC1_ENV_4

Content	
KPI name	Reduction in CO_2 emissions resulting from the diversion of wood waste from landfills or incineration
Identifier	UC1_ENV_4
Owner	NTUA
Description	Evaluate the decrease in CO_2 emissions after W2W
Scope	Relevant to production processes and end of life of products
Resources required	Life Cycle Assessment and Internal Use Case data
Baseline	0%
Formula	((CO_2 emissions before W2W – CO_2 emissions after W2W)/CO_2 emissions before W2W))*100%
Unit of Measure	%
Range	20%

Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI "Reduction in CO_2 emissions resulting from diversion of wood waste from landfills or incineration"

4.2.3. Socio-economic KPIs

Table 14: Definition of UC1_SEC_1

Content	
KPI name	By-products value increase
Identifier	UC1_SEC_1
Owner	NTUA
Description	Increase in the number of by-products generated by the implementation of W2W
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((Revenue of by-products generated after W2W – by-products generated before W2W)/By-products generated before W2W)*100%
Unit of Measure	%
Range	>50%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI "By-products value increase"

Table 15: Definition of UC1_SEC_2

Content	
KPI name	Proportion of the process industry that adopts the use of secondary resources in their production processes

Identifier	UC1_SEC_2
Owner	NTUA
Description	The percentage of industries that utilize secondary raw materials
Scope	Relevant to the production processes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((industries adopting secondary resources after W2W – industries adopting secondary resources before W2W)/industries adopting secondary resources before W2W)*100%
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI "Proportion of the process industry that adopts the use of secondary resources in their production processes"

4.3. LERMAB – USE CASE 2

Number of KPIs per category in use case 2:

i. technical: 8,
ii. environmental: 4,
iii. socio-economic: 1.

4.3.1 Technical KPIs

Table 16: Definition of UC2_TEC_1

Content	
KPI name	Increase of secondary raw materials use
Identifier	UC2_TEC_1
Owner	LERMAB
Description	Validate/Monitor the use of secondary raw materials in the particle boards produced within Use Case 2
Scope	Relevant to product
Resources required	Internal Use Case databases

Baseline	0%
Formula	((amount of wood – amount of w2w wood)/ amount of wood) x 100
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Increase of secondary raw materials use”

Table 17: Definition of UC2_TEC_2

Content	
KPI name	Upcycling technologies
Identifier	UC2_TEC_2
Owner	LERMAB
Description	Technologies implemented for the up cycling of waste wood
Scope	Relevant for project management
Resources required	Internal Use Case databases
Baseline	0
Formula	Number of new technologies implemented
Unit of Measure	Number
Range	3
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Up-cycling, reuse and upgrade secondary raw materials technologies implemented”

Table 18: Definition of UC2_TEC_3

Content	
KPI name	Urea-formaldehyde (UF) removal from waste wood

Identifier	UC2_TEC_3
Owner	LERMAB
Description	Efficiency of the removal of urea-formaldehyde (UF) from waste wood
Scope	Relevant to the production processes, final products and wastes
Resources required	Internal Use Case databases
Baseline	0%
Formula	((%N in waste wood - %N in treated wood)/ %N in waste wood) x100
Unit of Measure	%
Range	50%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI 1.7: “Increase in the efficiency of the removal of urea-formaldehyde (UF) from waste wood”

Table 19: Definition of UC2_TEC_4

Content	
KPI name	End product quality properties validated in Use Case 2
Identifier	UC2_TEC_4
Owner	LERMAB
Description	The end products generated in case study 2 (wood panels and mycocomposites) will be characterized in order to anticipate their future industrial uses
Scope	Relevant for the production department
Resources required	Internal Use Case data: Wood panels & mycocomposites produced with upcycled wood
Baseline	0
Formula	-
Unit of Measure	Number of properties

Range	5
Trend	The higher the better
Context	
Timing	On demand
Notes	Addresses GA KPI “Number of end product quality properties validated in Use Case 2”

Table 20: Definition of UC2_TEC_5

Content	
KPI name	Removal of >70% of urea formaldehyde glue by steam explosion
Identifier	UC2_TEC_5
Owner	LERMAB
Description	UF glue is the main resin present in waste wood. To facilitate and improve cascade recycling, it is advisable to eliminate as much resin as possible.
Scope	Relevant for the production department
Resources required	Internal Use Case data: Waste wood before and after treatment Nitrogen quantification
Baseline	0%
Formula	(1- (%N after treatment / %N before treatment)) x 100
Unit of Measure	%
Range	>70%
Trend	Higher is better
Context	
Timing	On demand
Notes	New KPI

Table 21: Definition of UC2_TEC_6

Content	
KPI name	Production of wood panels meeting current specifications (mechanical strength)
Identifier	UC2_TEC_6
Owner	LERMAB

Description	Certification of panels made from recycled wood
Scope	Relevant to the production department
Resources required	Internal Use Case data: standardized methods will be used, mechanical strength by the EN 319 standard
Baseline	0
Formula	-
Unit of Measure	Mechanical strength: MPa
Range	Mechanical strength Internal Bond Strength > 0.35 MPa
Trend	Mechanical strength: Higher is better
Context	
Timing	On demand
Notes	New KPI

Table 22: Definition of UC2_TEC_7

Content	
KPI name	Production of wood panels meeting current specifications (swelling)
Identifier	UC2_TEC_7
Owner	LERMAB
Description	Certification of panels made from recycled wood
Scope	Relevant to the production department
Resources required	Internal Use Case data: standardized methods will be used, swelling according to EN 317
Baseline	0%
Formula	-
Unit of Measure	Swelling: %
Range	-
Trend	Swelling: lower is better
Context	
Timing	On demand

Notes	New KPI

Table 23: Definition of UC2_TEC_8

Content	
KPI name	Removal of formaldehyde from steam explosion effluent by bioremediation
Identifier	UC2_TEC_8
Owner	LERMAB
Description	Aqueous effluent from the purification process contains highly toxic formaldehyde. It will be removed by bioremediation
Scope	Relevant for production department
Resources required	Internal Use Case data: Aqueous effluent from steam explosion treatment of wood waste
Baseline	0%
Formula	(1 - (formaldehyde conc in treated solution in mg/L / formaldehyde conc in initial solution in mg/L)) x 100
Unit of Measure	%
Range	90
Trend	The higher the better
Context	
Timing	On demand
Notes	New KPI

4.3.2 Environmental KPIs

Table 24: Definition of UC2_ENV_1

Content	
KPI name	Waste reduction
Identifier	UC2_ENV_1
Owner	LERMAB
Description	Waste reduction
Scope	Validate/Monitor the reduction of wood waste
Resources required	Life Cycle Sustainability Assessment Tool and Internal Use Case databases

Baseline	0%
Formula	((Quantity of baseline wastes - Quantity of wastes recycled and reused)/Quantity of baseline wastes) *100%
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Waste reduction”

Table 25: Definition of UC2_ENV_2

Content	
KPI name	GHG emissions reduction
Identifier	UC2_ENV_2
Owner	LERMAB
Description	Evaluate the decrease in GHG emissions
Scope	Relevant to the production processes, final products and wastes
Resources required	Life Cycle Sustainability Assessment Tool and Internal Use Case databases
Baseline	0%
Formula	(Quantity of GHG emissions before W2W - Quantity of GHG emissions after W2W)/Quantity of GHG emissions before W2W) *100%
Unit of Measure	%
Range	20%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “GHG emissions reduction”

Table 26: Definition of UC2_ENV_3

Content	
KPI name	Reduction in CO_2 emissions
Identifier	UC2_ENV_3
Owner	LERMAB
Description	Reduction in CO2 emissions resulting from diversion of wood waste from landfills or incineration
Scope	Relevant for project management
Resources required	Life Cycle Sustainability Assessment Tool and Internal Use Case databases
Baseline	0%
Formula	(Quantity of CO2 emissions before W2W - Quantity of CO2 emissions after W2W)/Quantity of CO2 emissions before W2W) *100%
Unit of Measure	%
Range	70%
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI “Reduction in CO2 emissions resulting from diversion of wood waste from landfills or incineration”

Table 27: Definition of UC2_ENV_4

Content	
KPI name	Production of wood panels meeting current specifications (formaldehyde emission)
Identifier	UC2_ENV_4
Owner	LERMAB
Description	Certification of panels made from recycled wood
Scope	Relevant to the production department

Resources required	Internal Use Case data: standardized methods will be used, formaldehyde emission by EN 120
Baseline	0
Formula	-
Unit of Measure	Formaldehyde: emission mg of formaldehyde / 100 g of panel
Range	Formaldehyde emission < 3.2 mg/100 g
Trend	Formaldehyde emission: lower is better
Context	
Timing	On demand
Notes	New KPI

4.3.4. Socio-economic KPIs

Table 28: Definition of UC2_SEC_1

Content	
KPI name	By-products value increase
Identifier	UC2_SEC_1
Owner	LERMAB
Description	The main aim of W2W technologies is to add value to waste that is poorly or not at all recycled. The aim of this KPI is to assess value creation.
Scope	Relevant for project management
Resources required	Internal Use Case databases
Baseline	0%
Formula	(Wood waste price after treatment - Wood waste price before treatment) / Wood waste price before treatment) x 100
Unit of Measure	%
Range	>50%
Trend	The higher the better
Context	
Timing	On demand

Notes	Addresses GA KPI “By-products value increase”

4.4. CIRCE – USE CASE 3

Number of KPIs per category in use case 3:

i. technical: 5,
ii. environmental: 3,
iii. socio-economic: 2.

4.4.1 Technical KPIs

Table 29: Definition of UC3_TEC_1

Content	
KPI name	Increase of secondary raw materials used
Identifier	UC3_TEC_1
Owner	CIRCE
Description	Use case #3 will use recycled wood and other by-products, such as sewage sludge and ashes, for the final production of surfactants. In this regard, the use of these secondary raw materials will reach up to 50 kg, at least, for the production of a gas/fuel suitable for fermentation in the next steps of the use case (for long chain hydrocarbon production).
Scope	Relevant to the product. The gasification and HTC processes will be fed with at least 50 kg of recycled wood.
Resources required	Internal Use Case databases. Gasification reactor, HTC reactor
Baseline	The % of wood coming from used sources (boards, pallets, furniture) is zero. This amount will reach up to 50 kg.
Formula	Amount of material fed into gasification or HTC processes
Unit of Measure	kg
Range	50
Trend	Higher is better
Context	
Timing	End of WP12. On demand.

Notes	Addresses GA KPI “Increase of secondary raw materials use”

Table 30: Definition of UC3_TEC_2

Content	
KPI name	Number of technologies implemented (Up-cycling, reuse and upgrade secondary raw materials technologies implemented)
Identifier	UC3_TEC_2
Owner	CIRCE
Description	The overall concept and approach of this project considers different cascade paths: i. sequential reuse of materials after their separation (reuse of materials in their original form for similar or alternative applications), NTUA, ii. cleaning (when materials can no longer be reused, it is promoted repurposing by removing additives and delivering wood of better quality), iii. upcycling (transformation into higher-value products). Energy recovery (of materials that can no longer be repurposed or upcycled In use case 3, relevant to this KPI, the third path is implemented. For the upcycling, four technologies have been proposed: i. HTC processing of wet streams and ashes, ii. gasification of waste wood, iii. syngas fermentation for long chain hydrocarbons production, iv. production of surfactants from long chain hydrocarbons. At the end of the project, at least three of them will be demonstrated feasible for the proposed path.

Scope	Relevant to the production processes. CIRCE, KIVERDI, P&G will be involved.
Resources required	Internal Use Case databases. All the necessary equipment and inputs for demonstrating each stage.
Baseline	For the demonstration of the technologies, the following baselines will be overcome: i. HTC: Carbon recovery: 40%, ii. gasification: Cold gas efficiency: 60%, iii. gas fermentation to hydrocarbon yield: 50%, iv. surfactants production yield: 50%.
Formula	%: Final product production – Initial feedstock input / Initial feedstock input * 100 This formula will be implemented and adapted to each one of the processes involved
Unit of Measure	Number
Range	3
Trend	Higher is better
Context	
Timing	End of WP12
Notes	Addresses GA KPI “Up-cycling, reuse and upgrade secondary raw materials technologies implemented”

Table 31: Definition of UC3_TEC_3

Content	
KPI name	Detergents production
Identifier	UC3_TEC_3
Owner	CIRCE
Description	Use case #3 relies on the conversion of liquid and solid waste from different industries (construction, paper, urban, etc.) into building blocks (CO2 and H2) for further production of valuable compounds (detergents) that can be

	used in other industry sectors. The liquid waste will be pre-treated through (HTC-MW). During the HTC-MW treatment, the carbon contented into the waste is densified producing hydrochar that has a higher heating capacity. Furthermore, the hydrochar contains high dewaterability properties reducing the high energy demand steps to remove water from the liquid wastes. Hydrochar and dry solid waste will be used as feedstock for gasification to produce H_2 and CO_2. CO_2 and H_2 will feed the Biotech reactor to produce long chain carbon compounds that will be upgraded to surfactants (detergents) that are valuable in different industry sectors. A set of at least 2 detergents will be produced and tested
Scope	Relevant to the production processes. P&G, with CIRCE and KIVERDI support.
Resources required	Syngas, long chain hydrocarbons from H_2 and CO_2 fermentation
Baseline	0 Current detergents formulations
Formula	N/A
Unit of Measure	Number of detergents tested
Range	>2 detergents
Trend	The higher the better
Context	
Timing	End of WP12
Notes	Addresses GA KPI 1.5: “Validation of purified syngas-derived dodecanol and aminoacids”

Table 32: Definition of UC3_TEC_4

Content	
KPI name	Number of end product quality properties validated in Use Case 3
Identifier	UC3_TEC_4
Owner	CIRCE
Description	Validation of the desired properties for the commercialization of the surfactant
Scope	Surfactant production (P&G)
Resources required	Needed properties for the commercialization
Baseline	0 Comparison with commercial surfactants tests
Formula	-
Unit of Measure	Number
Range	4
Trend	The higher the better
Context	
Timing	End of WP12
Notes	Addresses GA KPI “Number of end product quality properties validated in Use Case 3”

Table 33: Definition of UC3_TEC_5

Content	
KPI name	Validation of purified syngas derived long chain carbon compounds into detergents
Identifier	UC3_TEC_5
Owner	CIRCE
Description	Validation of purified syngas (CO_2/H_2) derived fatty acids/long chain carbon molecules from exhausted biomass into at least 2 detergents formulations proving: The fulfilment of technical and safety requirements (properties identical to those obtained from standard fatty acids)

Scope	Using syngas simulating detailed composition provided by CIRCE, Kiverdi will perform tests for conversion of CO2/H2 into fatty acids via gas fermentation first at a small scale (20L bioreactor) and then at a larger scale (100L). Samples will be validated by P&G for preliminary feedback and characterisation and then into formulation of low impact detergents
Resources required	Small scale (10L bioreactor) and Large Scale (100L bioreactor) facilities for CO2/H2 conversion and Down Stream Processing. Micro falling film pilot reactor
Baseline	0
Formula	Properties identical to those obtained from standard fatty acids
Unit of Measure	%
Range	-
Trend	The higher, the better
Context	
Timing	End of WP12
Notes	New KPI

4.4.2. Environmental KPIs

Table 34: Definition of UC3_ENV_1

Content	
KPI name	Ashes valorisation (Waste reduction)
Identifier	UC3_ENV_1
Owner	CIRCE
Description	Valorisation of ashes coming from biomass combustion/incineration with HTC or HTC-MW technologies
Scope	Flying ashes are produced during biomass combustion or incineration, which have difficult valorisation. A new technology is proposed to provide a solution to this by-

	product through HTC or HTC-MW technologies
Resources required	Internal Use Case databases. Ashes coming from waste valorisation.
Baseline	0% The ash valorisation will be calculated over the baseline of ash generation during the combustion or incineration of biomass. The ashes will be considered valorised when the toxic components are eliminated, other structures (ash aluminosilicates) are produced or when an alternative use is provided
Formula	Ash valorisation = Ash mass generated during combustion – ash valorised / ash mass generated during combustion * 100
Unit of Measure	%
Range	30%
Trend	Higher is better
Context	
Timing	End of WP12. On demand.
Notes	Addresses GA KPI “Waste reduction”

Table 35: Definition of UC3_ENV_2

Content	
KPI name	GHG gas reduction
Identifier	UC3_ENV_2
Owner	CIRCE
Description	This KPI measures the percentage reduction in CO2 emissions over a specified period, reflecting the success in implementing emission reduction strategies
Scope	Affects mainly the gasification process

Resources required	Life Cycle Sustainability Assessment Tool for Cascade Pathways and Internal Use Case databases CO_2 emissions during biomass waste incineration or combustion processes and Emission Factors for different energy sources and activities
Baseline	0% CO_2 emissions from biomass incineration and combustion
Formula	% Reduction in GHG emissions = (incineration/combustion CO2 emissions – gasification CO2 emissions) / (incineration/combustion CO2 emissions) *100
Unit of Measure	%
Range	70%
Trend	Higher is better
Context	
Timing	On demand/end of each period
Notes	Addresses GA KPI “GHG emissions reduction” Addresses GA KPI “Reduction in CO2 emissions resulting from diversion of wood waste from landfills or incineration”

Table 36: Definition of UC3_ENV_3

Content	
KPI name	Validation of purified syngas derived long chain carbon compounds into detergents
Identifier	UC3_ENV_3
Owner	CIRCE
Description	Validation of purified syngas (CO2/H2) derived fatty acids/long chain carbon molecules from exhausted biomass into at least 2 detergents formulations proving:

	The environmental sustainability (GHG savings): 50% compared to fossil based fatty acids and 70% compared to fatty acids obtained from palm/coconut oils from outside the EU equivalent to 1.5 ton of CO2eq saved/ton of fatty acids
Scope	Using syngas simulating detailed composition provided by CIRCE, Kiverdi will perform tests for conversion of CO2/H2 into fatty acids via gas fermentation first at a small scale (20L bioreactor) and then at a larger scale (100L). Samples will be validated by P&G for preliminary feedback and characterisation and then into formulation of low impact detergents
Resources required	Small scale (10L bioreactor) and Large Scale (100L bioreactor) facilities for CO2/H2 conversion and Down Stream Processing. Micro falling film pilot reactor
Baseline	0
Formula	Properties identical to those obtained from standard fatty acids, GHG savings: 50%-70% compared to fossil-based compounds
Unit of Measure	%
Range	50%-70%
Trend	The higher, the better
Context	
Timing	End of WP12
Notes	New KPI

4.4.3 Socio-economic KPIs

Table 37: Definition of UC3_SEC_1

Content	
KPI name	% Increase in By-products value (By-products value increase)
Identifier	UC3_SEC_1

Owner	CIRCE
Description	Variation of the value of the upcycled feedstock compared to that of the final product.
Scope	Relevant for project management. Affects the whole upcycling pathway, starting from waste wood and compared to the final surfactant produced.
Resources required	Internal Use Case databases. Range of prices of the upcycled products and the finalized products.
Baseline	0% Price of waste wood
Formula	% Increase of value: Final product price – initial waste wood price / initial waste wood price * 100
Unit of Measure	%
Range	>50%
Trend	The higher the better
Context	
Timing	End of WP12
Notes	Addresses GA KPI “By-products value increase”

Table 38: Definition of UC3_SEC_2

Content	
KPI name	Validation of purified syngas derived long chain carbon compounds into detergents
Identifier	UC3_SEC_2
Owner	CIRCE
Description	Validation of purified syngas (CO_2/H_2) derived fatty acids/long chain carbon molecules from exhausted biomass into at least 2 detergents formulations proving:

	The cost-competitiveness (price not higher than current price of standard fatty acids in the market).
Scope	Using syngas simulating detailed composition provided by CIRCE, Kiverdi will perform tests for conversion of CO_2/H_2 into fatty acids via gas fermentation first at a small scale (20L bioreactor) and then at a larger scale (100L). Samples will be validated by P&G for preliminary feedback and characterisation and then into formulation of low impact detergents
Resources required	Small scale (10L bioreactor) and Large Scale (100L bioreactor) facilities for CO_2/H_2 conversion and Down Stream Processing. Micro falling film pilot reactor
Baseline	0
Formula	Properties identical to those obtained from standard fatty acids
Unit of Measure	%
Range	-
Trend	The higher, the better
Context	
Timing	End of WP12
Notes	New KPI

4.5. ICCS – SEPARATION & SORTING

Number of KPIs per category in waste stream management process:

i. technical: 6,
ii. environmental: 0,
iii. socio-economic: 0.

4.5.1 Technical KPIs

Table 39: Definition of G1_TEC_1

Content	
KPI name	Increase in efficiency of successful wood material classification

Identifier	G1_TEC_1
Owner	ICCS
Description	Tasks T5.2 & T6.2, T5.3 & T6.3 and, T5.4 & T5.4 outline all levels of the sorting procedure that will be utilized to increase the efficiency of effective wood waste classification.
Scope	The scope is to improve the sorting process to prioritize the cascading value of input materials.
Resources required	A multi-robot composite sorting system will be used to separate wood and glass from mixed CDW with over 95% accuracy. Sensor equipment will be selected based on the optimal particle size, and classification thresholds will be dynamically updated based on defined flows. The classification levels will be dynamically created based on sustainability assessment standards and input from digital tools for production planning and supply-vs-demand.
Baseline	75%
Formula	N/A
Unit of Measure	%
Range	90%
Trend	Higher is better
Context	
Timing	On demand.
Notes	Addresses: GA KPI 1.1 “Increase in efficiency of successful wood material classification” GA KPI 1.3 “Improvement in overall efficiency and productivity of the separation process”

Table 40: Definition of G1_TEC_2

Content	
KPI name	Improvement in latency of the human-robot collaboration execution
Identifier	G1_TEC_2
Owner	ICCS
Description	Mixed reality technology will be utilised for human-robot collaboration (HRC) along the conveyor picking line to improve the accuracy and speed of the separation and sorting process. In this context, 'latency' is the high-level combined effect of those two components. The indicator will be measured during trials where the duration of correctly sorting a specific waste stream with and without HRC will be timed.
Scope	Task T5.6 and T6.6 'MR system for better separation and quality control'
Resources required	Trials with/without XR technology on the collaborative sorting line
Baseline	0%
Formula	100% x (duration of collaborative sorting) / (duration of automated sorting at the same level of accuracy)
Unit of Measure	Percentage of duration shortening
Range	80%
Trend	Lower is better
Context	
Timing	On demand
Notes	Addresses GA KPI O2.3: "To allow collaboration between Robots and humans with non-latency constraints" and GA KPI 1.2 "Improvement in latency of the human-robot collaboration execution"

Table 41: Definition of G1_TEC_3

Content	
KPI name	Increase in the availability of Grade A wood feedstock in the process industry compared to the baseline prior to the project
Identifier	G1_TEC_3
Owner	ICCS
Description	W2W novel technologies (W2W Pillar 1 & 2) can convert recovered wood (Grade B & C) to Grade A wood, meeting the demand for feedstock in the process industry. The Digital Product Passport and Supply Chain Management Tool will improve traceability and transparency of recovered wood in the value chain, aligning supply and demand for feedstock.
Scope	The project's primary goals are to reduce the need for virgin materials, reduce waste that is dumped in landfills or burned, and aid in the transition to a circular economy, resulting in increased availability of Grade A wood feedstock in the process industry compared to the baseline before the project.
Resources required	The project use cases provide a complete assessment of quality restrictions and potential supplementary resources, facilitating decision-making for both suppliers and the processing industry in general
Baseline	0%
Formula	N/A
Unit of Measure	%
Range	20%
Trend	N/A
Context	
Timing	

Notes	Addresses GA KPI “Increase in the availability of Grade A wood feedstock in the process industry compared to the baseline prior to the project”

Table 42: Definition of G1_TEC_4

Content	
KPI name	Increase in the efficiency and traceability of material streams within the value chain
Identifier	G1_TEC_4
Owner	ICCS
Description	The W2W project incorporates Life Cycle Assessment (LCA), Life Cycle Cost Assessment (LCCA), and Social Life Cycle Assessment (S-LCA) to create a comprehensive Life Cycle Sustainability Assessment (LCSA), which includes environmental, economic, and social dimensions to inform policy and industry decision-making. Machine Learning improves accuracy by anticipating missing data and influence parameters.
Scope	Using complex algorithms, W2W digital platform aims to model scenarios to optimize the flow of secondary materials, making recycling operations more efficient and cost effective, and increasing in the efficiency and traceability of material streams within the value chain
Resources required	W2W uses computer vision approaches to estimate material volume, creating exact 3D models from multisource data and employing semantic segmentation to accurately identify waste. W2W also addresses the challenges of cascade usage by creating a supply chain optimizing digital tool.
Baseline	0%
Formula	N/A
Unit of Measure	%

Range	85%
Trend	N/A
Context	
Timing	On demand
Notes	Addresses GA KPI “Increase in the efficiency and traceability of material streams within the value chain”

Table 43: Definition of G1_TEC_5

Content	
KPI name	To achieve a 95% accuracy of wood separation from mixed CDW sources
Identifier	G1_TEC_5
Owner	ICCS
Description	This KPI tracks the success of the classification and sorting process for the wood stream processed to the sorting system developed for T5.4 and T6.4. If more than 95% of the objects result to the intended output stream, then more than 95% accuracy is attained.
Scope	Relevant to products and production processes
Resources required	AI model (classifier) and manual inspection at the end of the process
Baseline	80%
Formula	(# of objects correctly separated / # of objects processed by the wood sorting system) *100%
Unit of Measure	N/A
Range	95%
Trend	The higher the better
Context	
Timing	Periodically e.g. calculated once per hour, once per day

Notes	Addresses GA KPI O2.1 “To achieve a 95% accuracy of wood separation from mixed CDW sources”

Table 44: Definition of G1_TEC_6

Content	
KPI name	To adoptively sort wood based on dynamically updated classification criteria with 90% accuracy
Identifier	G1_TEC_6
Owner	ICCS
Description	This KPI tracks the way that sorting system continuously updates the thresholds of the classification accuracy based on the stakeholders’ needs or the quality of the feedstock, resulting to separate them in the required quantities and desired quality.
Scope	Relevant to products and production processes
Resources required	AI models to separate the woods, Mechanism to change the classification accuracy
Baseline	-
Formula	(# of objects correctly separated / # of objects processed by the wood sorting system) *100%
Unit of Measure	%
Range	90%
Trend	The higher the better
Context	
Timing	Periodically with certain batches
Notes	Addresses GA KPI O2.2: “To adoptively sort wood based on dynamically updated classification criteria with 90% accuracy”

4.6. DRAXIS – DIGITAL TOOL

Number of KPIs per category in DRAXIS’s digital tool:

i. technical: 0,
ii. environmental: 2,

iii. socio-economic: 0.

4.6.1 Environmental KPIs

Table 45: Definition of G2_ENV_1

Content	
KPI name	LCA-based cascade process sustainability assessment tool validated in the 3 proposed value chains
Identifier	G2_ENV_1
Owner	DRAXIS
Description	This KPI addresses the validation of the LCA-based cascade process in the project value chains.
Scope	Relevant to project management and production department
Resources required	Life Cycle Assessment and Internal Use Case data
Baseline	0
Formula	Number of value chains addressed
Unit of Measure	Number
Range	0-3 value chains
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI O4.1 “LCA-based cascade process sustainability assessment tool validated in the 3 proposed value chains”.

Table 46: Definition of G2_ENV_2

Content	
KPI name	% reduction in environmental impact of products
Identifier	G2_ENV_2
Owner	DRAXIS
Description	This KPI measures the overall environmental impact of products considered in W2W use case processes. For the calculation of this KPI,

	data from LCA analyses will be required and specifically the CO_2 equivalent emitted throughout the lifecycle of the W2W final products, which can be compared to that of traditional, linear products.
Scope	Relevant to the production department
Resources required	Life Cycle Sustainability Assessment Tool for Cascade Pathways and Internal Use Case databases (if available)
Baseline	0%
Formula	100 * ((Kg CO_2 eq before – Kg CO_2 eq after)/ Kg CO_2 eq before)
Unit of Measure	%
Range	A reduction of the environmental impact of 70% is desired
Trend	Higher is better
Context	
Timing	On demand
Notes	i. Constraints: The % reduction goal shall be secured by the individual use cases, while DRAXIS will be in charge of measuring it. ii. Addresses GA KPI 7.2 "% reduction in environmental impact of products compared to their linear counterparts" and "Reduction in the environmental impact of products over their life cycle, as measured by the project's Life Cycle Sustainability Assessment Tool for Cascade Pathways".

4.7. UPV – DIGITAL TOOL

Number of KPIs per category in UPV's digital tool:

i. technical: 1,
ii. environmental: 0,
iii. socio-economic: 1.

4.7.1. Technical KPIs

Table 47: Definition of G3_TEC_1

Content	
KPI name	Validation of the Supply Chain Optimisation tool in the value chain of the 3 use cases
Identifier	G3_TEC_1
Owner	UPV
Description	This KPI indicates whether the Supply Chain Optimisation tool has been validated or not for use in the value chain of the 3 specified use cases. It is a binary measure, with the tool being either validated (yes) or not validated (no).
Scope	Relevant to the Logistics and Supply Chain Management
Resources required	Supply Chain Optimisation Tool and Internal use case databases (if available)
Baseline	0
Formula	The use of formulas is not required
Unit of Measure	Value chain validated
Range	The goal is to validate the value chains of the 3 use cases
Trend	Higher is better
Context	
Timing	On demand
Notes	i. Constraint: The validation will be carried out by the UPV with the involvement of the 3 use cases regarding the data provided. ii. Addresses GA KPI O4.2 “Supply chain optimisation tool validated in the 3 proposed value chains”.

4.7.2. Socio-economic KPIs

Table 48: Definition of G3_SEC_1

Content	
KPI name	Reduction of transport costs
Identifier	G3_SEC_1
Owner	UPV
Description	This KPI measures the decrease in transportation expenses associated with moving secondary materials in the supply chain processes of the W2W use cases. It evaluates the effectiveness of cost-saving transport improvements, such as optimising delivery routes and enhancing logistics operations. For the calculation of this KPI, data on transportation expenses before and after implementing the W2W solutions will be required.
Scope	In the first instance, relevant to the Operations department. Indirectly, also to departments such as Finance, Purchasing or Marketing.
Resources required	Supply Chain Optimisation Tool and Internal use case databases (if available)
Baseline	0%
Formula	100 × ((Transport Costs Before - Transport Costs After) / Transport Costs Before)
Unit of Measure	%
Range	Transport costs are expected to be reduced by 20%.
Trend	Higher is better
Context	
Timing	On demand
Notes	i. Constraint: The % reduction goal will be secured by the individual use cases, while the UPV will be responsible for calculating and monitoring it. ii. Addresses GA KPI 4.2 “Reduction of transport costs”.

4.8. EBOS – DIGITAL TOOL

Number of KPIs per category in eBOS's digital tool:

i. technical: 1,
ii. environmental: 0,
iii. socio-economic: 0.

4.8.1. Technical KPIs

Table 49: Definition of G4_TEC_1

Content	
KPI name	Multi-digital interface platform integrating several digital tools/services (i.e. dynamic LCA, dynamic DPP) developed by Month 48 with at least 200 active users.
Identifier	G4_TEC_1
Owner	eBOS
Description	This KPI addresses the validation of the multi-digital interface platform in the project's scope.
Scope	Digital Transformation
Resources required	Multi-digital Interface platform, Development of the subsequent digital tools and Internal use case databases (if available).
Baseline	0%
Formula	N/A
Unit of Measure	Platform validation
Range	3 use cases
Trend	Higher is better
Context	
Timing	On demand
Notes	Addresses GA KPI O5.1: "To demonstrate the application of all the developed technologies at TRL 6 in 3 use cases"

5. KPIS MONITORING AND EVALUATION

Within the context of the W2W project, considering that there is no separate task for keeping track of the KPIs progress, i.e. filling baseline values and the final results, each KPI owner is responsible for measuring and providing its corresponding indicators (see Figure 6).

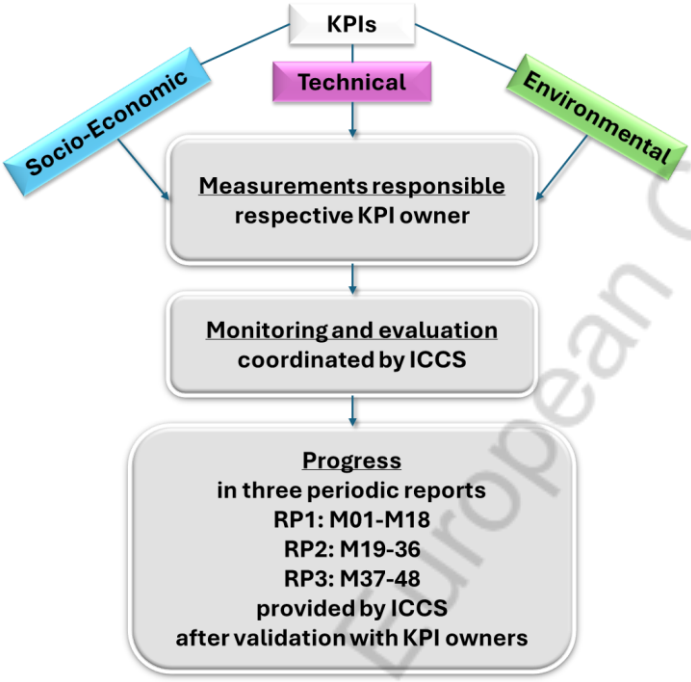

Figure 6: Monitoring and evaluation of KPIs plan

All KPIs associated with the W2W project will be systematically monitored and evaluated to ensure comprehensive assessment and accountability. As presented in Figure 6, ICCS is to be responsible for the coordination of the KPIs monitoring and evaluation actions, always in cooperation with the respective KPI owners.

The status of each KPI, including whether it has been achieved and to what extent, will be thoroughly documented. This evaluation will form an integral part of the Technical Report submitted at the conclusion of each reporting period, which are RP1 (M01-M18), RP2 (M19-36) and RP3 (M37-48), as seen on pg. 11 of the GA, thereby providing stakeholders with a clear and detailed overview of project performance and progress. All KPIs are to be provided by ICCS, after being evaluated with the respective KPI owners. This systematic approach not only facilitates successful project's progress, but also enhances the capacity for informed decision-making throughout the project lifecycle.

6. CONCLUSIONS

The deliverable aims to set the most suitable KPIs required to guide the implementation of the W2W use cases and the development of the digital tools. More specifically, these KPIs help in quantitively evaluating the results of W2W based on a structured framework, while they comprehensive roadmap for tracking and evaluating the progress of W2W across various stages of its deployment. Through KPIs measurement and evaluation, partners can monitor progress, assess outcomes and make data-driven decisions throughout the implementation.

Overall, 29 Technical, 13 Environmental and 7 Socio-economic KPIs were imported in the final list, referring to the three use cases, the sorting process and three digital tools, and are to be monitored throughout the project, assessing the results of the technological solutions of all three use cases and proving their efficiency in all presented aspects: technologically, environmentally, as well as socio-economically. Monitoring, evaluating and updating of the KPIs is organised and planned to take place parallelly to the three technical reporting periods of the W2W project.

Lastly, as W2W cascade valorisation scheme consists of several different components and in order to adequately assess the sustainability of W2W innovative solutions and approaches, various aspects have been taken into account: environmental, economic, as well as logistics. As task 4.5 defines the impact assessment methodologies and KPIs to be used and monitored, T4.3 “CDW recycled wood cascade valorisation framework for pure and mixed treatment” describes the first iteration of the framework. The results of the work performed in the current deliverable will be incorporated into the developed framework of T4.3 (described in D4.3) to evaluate the sustainability of W2W project. The aforementioned activities will be further exploited in WP15 “Material Flows and Pilot Activities” and in T15.3 “Final validation and sustainability assessment of the overall cascade valorisation scheme”. Finally, the framework (T4.3) and the monitored KPIs (T4.5) will provide the foundation for verifying the sustainability of the proposed CDW valorisation schemes.

7. ANNEX

Table 50: New KPIs

KPI ID	KPI Name	KPI Target
UC2_TEC_5	Removal of >70% of Urea formaldehyde glue by steam explosion	>70%
UC2_TEC_6	Production of wood panels meeting current specifications (mechanical strength)	> 0.35 MPa
UC2_TEC_7	Production of wood panels meeting current specifications (swelling)	-
UC2_ENV_4	Production of wood panels meeting current specifications (formaldehyde emission)	< 3.2 mg/100g
UC2_TEC_8	Removal of formaldehyde from steam explosion effluent by bioremediation	>90%
UC3_TEC_5	Validation of purified syngas derived long chain carbon compounds into detergents	-
UC3_ENV_3	Validation of purified syngas derived long chain carbon compounds into detergents	50-70%
UC3_SEC_2	Validation of purified syngas derived long chain carbon compounds into detergents	-

8. REFERENCES

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URL2: https://www.iso.org/standard/54497.html

WOOD2WOOD