WOOD2WOOD

**A Wood-to-Wood Cascade Upcycling Valorisation Approach**

» Deliverable 5.1

# CDW flows valorisation and digitalisation (version 1)

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# REVISION AND HISTORY CHART

| Dissemination Level | | |
|---|---|---|
| PU | Public | X |
| RE | Restricted to a group specified by the consortium | |
| CO | Confidential, only for members of the consortium (including the European Commission Services) | |

## Legal Disclaimer

# TABLE OF CONTENTS

# GLOSSARY OF ACRONYMS

| Acronym | Extended Definition |
|---|---|
| BIM | Building Information Modelling |
| CDW | Construction and Demolition Waste |
| DPMFA | Dynamic Probabilistic Material Flow Analysis |
| DPP | Digital Product Passport |
| EWC | European Waste Catalogue |
| GA | Grant Agreement |
| IoT | Internet of Things |
| MFA | Material Flow Analysis |
| NGO | Non-Governmental Organization |
| RIA | Research and Innovation Action |
| SANKE | SANKE S.A. (Greek CDW treatment operator) |
| TC | Transfer Coefficient |
| W2W | Wood2Wood |

# List of Tables



# List of Figures

# EXECUTIVE SUMMARY


This deliverable (D5.1) of the Horizon Europe project W2W – A Wood-to-Wood Cascade Upcycling Valorisation Approach– provides the first analytical application of a digital Material Flow Analysis (MFA) tool developed to support circular management of Construction and Demolition Waste (CDW), with a specific focus on wood materials.

Using real operational data from a construction site in Evia, Greece, and its associated treatment facility managed by SANKE, the deliverable models and compares two use cases. Scenario 1 reflects a baseline configuration where CDW is collected on-site and sent directly to treatment, with minimal segregation. Scenario 2 introduces an intermediate sorting phase—using mechanical or sensor-based technologies—prior to treatment, offering improved material separation and data resolution.

The MFA tool developed under Milestone 5 of the W2W project is used to quantify wood flows across both scenarios. Results indicate that the introduction of sorting enhances material purity and recovery rates, while improving visibility into system performance. Key data gaps—such as limited granularity in on-site waste tracking and incomplete treatment outcome data—are also identified, providing direction for future development.

This first version of the tool demonstrates the potential of digital MFA to support informed decision-making and resource-efficient practices in CDW management. It establishes a baseline methodology and lays the groundwork for refinement in future project phases, contributing to W2W's broader vision for high-value recovery and circular wood flows in construction.

# 1. INTRODUCTION

This deliverable introduces the first version of a digital Material Flow Analysis (MFA) tool developed within the Wood-to-Wood Cascade Upcycling Valorisation Approach (W2W) project, funded by the Horizon Europe programme (Grant Agreement No. 101138789). The tool is designed to model the flow of materials in Construction and Demolition Waste (CDW) systems, with an emphasis on wood as a strategic material for circularity and upcycling.

The deliverable applies the tool to a real-world use case from Evia, Greece, using operational data provided by SANKE, a CDW treatment operator. Two scenarios are developed for analysis: one based on the current direct flow of unsorted waste to treatment, and one that integrates an intermediate sorting stage. These scenarios allow for comparative assessment of system performance, highlighting how variations in handling and sorting affect material recovery and data visibility.

As the tool is still in early development, this version focuses on establishing the system boundaries, modelling logic, and initial outputs. The deliverable also outlines the assumptions and limitations of the approach and provides a transparent account of the data sources used. It forms the foundation for future iterations of the tool and its integration into broader decision-support frameworks within the W2W project.

## 1.1. Project intro

The Wood-to-Wood Cascade Upcycling Valorisation Approach (W2W) is a Horizon Europe project that aims to unlock the potential of wood materials within the construction and demolition sector by promoting reuse, recycling, and cascade upcycling practices. The project brings together a cross-sectoral consortium to co-develop technical, digital, and strategic tools that enable more efficient recovery and valorisation of wood waste streams.

As part of this mission, W2W is developing a digital Material Flow Analysis (MFA) tool that focuses on tracking wood within CDW flows, supporting data-informed circularity strategies. This deliverable presents the tool's first version and demonstrates its logic and applicability using a real use case. The focus at this stage is on exploring practical configurations, testing flow modelling methods, and identifying opportunities to improve wood recovery in construction through better data and system design.

## 1.2. Purpose of the deliverable

The purpose of this deliverable is to define, structure, and test the initial capabilities of the tool using real data from a construction site in Evia, Greece. The tool is designed to support more transparent, material-specific, and circular management of CDW, with a particular focus on wood waste as a priority stream.

The tool enables the systematic modelling, quantification, and visualisation of material flows, particularly those involving wood, across the various stages of CDW handling—generation, sorting, treatment, and final destination. It provides a structured digital environment for analysing real-world data, identifying inefficiencies, and comparing different system configurations (e.g. direct vs. enhanced sorting). While the tool is still in an early development phase, it offers a proof of concept for how digital MFA can support material-specific strategies in CDW valorisation.

 

This deliverable uses two practical use cases—both based on the same construction site but differentiated by their sorting configurations—to demonstrate the tool's logic, data structure, and preliminary output potential. The results serve as a foundation for refining the model, validating future versions, and eventually supporting operational decision-making, scenario planning, and circularity tracking in the CDW sector. As such, this first version is intended both as a functional prototype and as a basis for feedback and co-development within the broader W2W project.

## 1.3. Intended Audience

This deliverable is designed for a broad range of stakeholders involved in the construction, demolition, waste management, and circular economy sectors, with a particular emphasis on those working with or regulating wood-based waste streams.

At its core, the MFA tool supports construction and demolition professionals—including project managers, site engineers, demolition contractors, and sustainability officers—who are responsible for planning, executing, and managing CDW generation on-site. These users can benefit from structured insights into wood flow behaviour, on-site sorting impacts, and opportunities for improving material recovery at the source.

The tool also addresses the needs of waste management and recycling operators, such as facility managers, transport providers, and material processors, who handle downstream sorting, treatment, and valorisation. With structured modelling and visual outputs, the tool helps these stakeholders better understand flow volumes, optimise sorting strategies, and assess how system changes (e.g. enhanced sorting) affect wood recovery outcomes.

Policy makers and regulatory bodies—particularly those focused on environmental regulation, circular economy targets, and sustainable construction—represent another key audience. The MFA tool contributes to transparency by enabling traceable, structured analysis of CDW flows. It provides a data-informed foundation for evaluating interventions, setting policy goals, and monitoring compliance with material recovery benchmarks.

In addition to these operational and regulatory users, the tool also serves the interests of consultants, researchers, NGOs, and technology providers working to innovate in circular construction and digital resource management. It offers a replicable framework and real-use dataset that can be built upon for benchmarking, scenario development, or system integration. As the tool matures, it can become a component of larger circularity dashboards or national material tracking initiatives.

In summary, the MFA tool is intended to support everyone involved in the CDW value chain for wood—from on-site operators to policy makers and technology developers—by providing a clear, structured, and scalable approach to tracking, analysing, and improving the circular use of wood in construction and demolition contexts.

## 1.4. Structure of the deliverable

This deliverable presents the first version of a digital Material Flow Analysis (MFA) tool developed within the W2W project, with a focus on construction and demolition waste (CDW) and, in particular, wood as a priority stream for circularity. The document begins by outlining the methodological approach behind the tool, including how material flows are defined, modelled, and quantified. Special attention is given to the boundaries of the system, the logic of the dynamic probabilistic MFA method, and the assumptions and limitations shaping the analysis.

Building on this foundation, the deliverable introduces the practical use cases that inform the modelling. Both scenarios are based on real data from a construction site in Evia, Greece, and reflect two distinct system configurations: one that follows the current practice of direct waste flow from site to treatment, and another that integrates an intermediate sorting stage. These scenarios are not only grounded in operational reality but are designed to explore how different system setups influence material recovery, data visibility, and process efficiency.

Following the contextual description, the deliverable applies the MFA tool to both scenarios, translating their characteristics into a set of structured models. These models simulate the flow of wood waste from generation to final treatment, enabling comparison of key outputs such as recycled material stock, residual waste, and system-level variability. To extend the analysis further, an optimisation model is introduced, exploring how adjusting the capacity and routing of sorting infrastructure can enhance performance from both environmental and economic perspectives.

The final sections of the deliverable reflect on the insights gained from the simulations and modelling. They highlight the benefits of integrating sorting into CDW systems, particularly for improving the quality and quantity of recovered wood. Based on these findings, a set of practical recommendations is provided to inform future tool development, data strategies, and broader system design. The deliverable concludes by reaffirming the potential of digital MFA as a decision-support tool in the shift toward more circular and data-driven construction waste management practices.

# 2. METHODOLOGY FOR MATERIAL FLOW ANALYSIS (MFA)

## 2.1. System Definition and Boundaries

The The digital MFA tool tracks CDW flows across waste management stages, with current focus on Level 1 (construction site) analysis in Evia, Greece. While designed for three levels - (1) site, (2) regional, and (3) urban - this deliverable establishes a Level 1 baseline for wood waste flows, given available data and immediate project needs.

The framework remains scalable:

- Level 1 provides granular waste data (generation, handling, composition)
- Levels 2-3 would apply similar methodology to regional clusters/urban systems when data becomes available

Current analysis validates core functions (flow modeling, wood tracking) while identifying data gaps (traceability, mixed-stream composition) for future development.

### 2.1.1. System Definition

The system boundaries encompass the entire journey of CDW materials from generation to final treatment, with special emphasis on wood as a target stream. Both scenarios modelled in this deliverable (Scenario 1 – Direct Flow and Scenario 2 – Enhanced Flow) share the same generation context but differ in their downstream handling configurations. The system is structured to reflect these configurations and enables comparative analysis between low-sorting and enhanced-sorting pathways.

The key stages of the system are:

- **Waste Generation:** CDW is generated on-site through routine construction activities. This includes various material categories such as concrete, bricks, metals, packaging, and wood.
- **Collection and Transport:** All waste streams are collected in bulk containers and transported to the treatment facility operated by SANKE. No digital tracking or container-level classification is applied during transport.
- **Mechanical Pre-Treatment:** Upon arrival, all materials undergo initial shredding or crushing to prepare them for further processing.
- **Sorting and Material Separation:** In Scenario 1, sorting is basic and largely manual, visual, or mechanical. In Scenario 2, sorting is enhanced through sensor-based systems, improving the separation of materials like clean wood.
- **Treatment and Valorisation:** Based on material type and purity, streams are directed to secondary aggregates production, recycling facilities, energy recovery, or landfill.
- **Focus on Wood Waste:** Wood fractions—particularly those classified under EWC 17 02 and 19 12 07—are tracked through the system with added resolution. Depending on contamination levels, these may be routed to recycling, energy valorisation, or final disposal.

### 2.1.2. Scope Parameters

The system boundaries defined for this version of the MFA tool are grounded in the specific operational context of a construction site and associated treatment facility located in Evia, Greece. This geographical scope reflects real-world activities managed by SANKE, a regional CDW operator, and is considered representative of typical practices in the Greek construction sector. In terms of material scope, the system encompasses all fractions of Construction and Demolition Waste (CDW) recorded at the site. However, this deliverable places particular analytical emphasis on wood waste, aligning with the strategic objectives of the W2W project to explore cascade upcycling pathways and enable more circular use of wood-based materials. Temporally, the analysis draws on operational data collected across a defined recent period, offering a snapshot of site activity that is both current and relevant. While the MFA tool itself supports time-series modelling and comparative scenario analysis, the current application focuses on quantifying and understanding flows within this specific timeframe as a baseline for future iterations.

### 2.1.3. Functional Unit

The functional unit for analysis is one metric tonne of CDW material. For focused assessments—especially those involving wood—the functional unit is applied specifically to one metric tonne of wood waste to support targeted flow tracking and recovery assessment.

## 2.2. Data Collection Approach

The data used in this deliverable were provided by SANKE S.A., a licensed waste management operator responsible for the collection and treatment of Construction and Demolition Waste (CDW) in Greece. The dataset reflects real operational data from a construction site located in the region of Evia and serves as the primary foundation for modelling material flows within the digital MFA tool developed for the W2W project.

The main source is a structured spreadsheet detailing CDW streams classified under the European Waste Catalogue (EWC)(European Commission, 2000), handled during the 2023–2024 period. These data capture the quantities and types of waste generated on-site and subsequently transported to SANKE's treatment facility.

The dataset includes:

- EWC codes, enabling standardized standardised classification of all recorded waste streams,
- Material descriptions, corresponding to common CDW categories such as concrete, bricks, metals, and wood,
- Quantitative values, reported in kilograms and covering both separately collected and mixed fractions.

The data encompass both pure material streams (e.g., 17 01 01 – concrete; 17 04 05 – ferrous metals) and heterogeneous or mixed waste (e.g., 17 01 07 – mixture of concrete, bricks, and tiles; 17 09 04 – mixed CDW). Notably, separately collected wood waste is recorded under EWC 17 02 01, which enables more targeted tracking of wood flows in the MFA model. While the dataset does not specify treatment destinations (e.g., landfill, backfilling, recycling), the categorization and quantitative breakdown provide a robust basis for scenario modelling, particularly when estimating the effects of sorting efficiency and downstream valorisation in both use cases.

### *2.2.1. Wood-Specific Data Considerations*

In the context of this project, wood waste is treated as a key focus material, consistent with the overarching objectives of the W2W initiative. The dataset provided by SANKE contains both general and material-specific information that enables a closer analysis of wood flows, particularly in the two use cases developed.

Notably, the dataset includes entries under EWC code 17 02 01, which refers to separately collected wood waste from construction activities. This confirms that at least part of the wood generated at the site was collected and documented independently, rather than as part of a mixed material fraction. This enhances the granularity of the available data and enables more precise modelling of the wood fraction's movement through the waste management system.

Additionally, wood appears under EWC code 19 12 07, representing wood recovered after mechanical treatment of mixed waste, typically following shredding and basic or advanced sorting processes. This code applies particularly to Scenario 2, where the system includes sensor-based or mechanical sorting stages capable of isolating wood fractions post-treatment.

However, the dataset does not provide further disaggregation of mixed codes like EWC 17 02 (Wood, glass, plastic), which means that in some cases, wood quantities must be inferred based on assumed material shares. For instance, while EWC 17 02 is listed, it is unclear what percentage of the material corresponds specifically to wood in those entries. This limitation requires the use of reasoned assumptions informed by sector-specific knowledge, including expected composition ranges and typical facility practices.

To improve the reliability of wood flow tracking within the MFA tool, these assumptions were cross validated with operational input from SANKE and aligned with national and European data where appropriate. In particular, assumptions regarding wood recovery efficiency, contamination risk, and treatment pathways were informed by standard recovery practices and the technical configuration of SANKE's facility. Where gaps existed—such as missing treatment destinations or undefined material composition—conservative estimations were used and fully documented in the tool's backend logic.

Overall, the presence of explicitly reported, separately collected wood in the dataset strengthens the analytical value of the MFA for the W2W project. It allows for the development of realistic wood flow scenarios, differentiated by sorting intensity and downstream valorisation options, providing meaningful insights into the potential for circular use of wood in the construction sector.

### *2.2.2. Data Classification and Harmonization*

All data are classified according to European Waste Catalogue (EWC) codes, ensuring compatibility with European and national reporting systems. Where necessary, Greek national codes (ΕΛΟΤ) were referenced, particularly when aligning reporting obligations under local waste legislation(ΕΛΟΤ, 2018). The use of harmonised codes enables both project-level analysis and integration with broader regulatory or market monitoring frameworks.

## 2.3. MFA Model Used

### *2.3.1. Introduction to the dynamic probabilistic material flow modelling method*

The method used for the material flow modelling of wood waste between the construction site and the recycled wood endpoint is the dynamic probabilistic material flow modelling method, as developed by Bornhoft and colleagues (Bornhöft et al, 2016). The "Dynamic Probabilistic Material Flow Analysis" (DPMFA) method combines dynamic material flow modelling with probabilistic modelling and is implemented as a simulation framework in Python. This method was selected both for its advantage on modelling a dynamic system behaviour and due to existing uncertainties on the volume of the waste inflow and the rates with which the inflow divides into partial flows.

### *2.3.2. Description of the method*

The method is formulated through a set of components, called compartments, which serve as the main building blocks of the model. The compartments represent the system's spatially (or logically) separate units and constitute the static model structure. All time dependent variables, such as material releases and flows, as well as accumulated quantities refer to these compartments. After the definition of the model's compartments and transfer parameters, simulation experiments are performed to assess material stocks and flows over time.

*i. Static components*

 

The basic model components are Flow, Stock, and Sink compartments and external inflows. Compartments are distinct areas of the investigated system.

- Flow Compartments represent a system compartment with material inflows and outflows of zero residence time. Material inflow of a single time period is immediately forwarded to following compartments, without the accumulation of stocked material.
- Sinks are compartments where inflowing material is being accumulated and represent an endpoint of the process. Release of stocked material is not allowed for sink compartments.
- Stock compartments share the functionalities of both Flow Compartments and Sinks, which means they can propagate their inflow immediately, as well as on delayed time, allowing for the accumulation of stocked material within them.
- External Inflows are the source of material inflow to the system and may account for a time-dependent exogenous input. They are defined as absolute material inflow values.

ii. *Material Flows*

Material flows of a single period are considered immediate and simultaneous. In contrast to external inflows, endogenous system flows are defined via transfer coefficients (TC). The transfer coefficient $TC_{js}$ is defined as the ratio of the relative mass flow m from source compartment j to target compartment s over the sum of all inflows to source compartment j.

$$TC_{js} = \frac{m_{js}}{\sum_r m_{rj}}$$

To determine the absolute flow values of the system, a flow matrix *A* is assembled, which consists of the TCs of all flow compartments. Sinks are also present in the flow matrix with zero TCs. The absolute material inflows to the system are expressed as an input vector *I* and the endogenous system flows are expressed as a column vector *X*. Solving the equation

$$AX = I$$

for vector *X* provides us with the absolute flow values between all system compartments, calculated as a steady state of flow.

iii. *Dynamic behavior*

The dimension of time is inserted in the model as a series of time periods. For each time period the order of action is as follows:

- Initially, the external inflows and the material to be released from stock compartments are defined.
- The flows of the period are determined by solving the flow matrix equation of the system, for the corresponding time step.
- Finally, stock and sink compartments are being incremented with the calculated inflows.

iv. *Uncertainty representation*

 

The system variables for which uncertainty regarding their true value is present are represented in the model through Bayesian likelihood distributions. Thus, parametric distributions are used to model the lack of knowledge about absolute inflows and TCs. The dependent system variables are then calculated using a Monte-Carlo simulation. As the mass balance of the system needs to be preserved, during the simulation process, the dependent random values are adjusted after sampling to avoid mass balance violation. Statistical evaluations of the dependent variables over a sufficiently large sample size approximate the distributions of these variables.

## 2.4. Assumptions and Limitations

While the MFA tool and its underlying logic are grounded in operational data from an actual construction site, certain assumptions were necessary to enable system modelling, data interpretation, and scenario comparison. These assumptions concern the representativeness of the data, classification consistency, and the static nature of the modelled system. Likewise, the scope and structure of the dataset impose some limitations on the depth and granularity of the analysis. The following sections outline these assumptions and limitations to support transparency and ensure the results are interpreted within the appropriate context.

### *2.4.1. Assumptions*

While the development of the digital Material Flow Analysis (MFA) tool is grounded in real operational data from SANKE and reflects actual practices at a construction site in Evia, Greece, several assumptions are made to ensure functionality and interpretability:

- **Representativeness of the Data:** It is assumed that the construction site selected for analysis is broadly representative of typical CDW generation and handling practices in Greek vertical construction projects. This assumption allows the MFA tool to demonstrate realistic flows and system configurations, but outcomes may vary in projects with different scopes, demolition phases, or geographic characteristics.
- **Accuracy of Waste Coding and Categorisation:** All waste streams are classified using EWC codes and, where applicable, ΕΛΟΤ references. It is assumed that the data provided by SANKE are coded correctly and consistently across the reporting period, in alignment with regulatory norms and operational best practices.
- **Stable System Configuration Across Scenarios:** The core construction activity and waste generation context are assumed to remain stable between the two use cases. The difference lies in downstream processing (sorting and treatment), not in the types or quantities of materials generated. This assumption supports a controlled comparison of system efficiencies.
- **Homogeneous Wood Waste Properties:** For modelling purposes, wood waste is treated as a consistent material stream (EWC 17 02 01 and 19 12 07). Variations in treatment (e.g., painted, glued, nailed) or condition (e.g., moisture, contamination) are not fully specified in the dataset and are assumed to fall within general recovery-relevant tolerances.
- **Time-Bound Data Consistency:** Although the MFA tool is applied to a dataset spanning multiple reporting points over a defined period, it is assumed that the material flow patterns during this timeframe are sufficiently consistent to represent typical site operations. The model does not account for short-term fluctuations due to policy changes, market disruptions, or exceptional project events, and instead reflects an averaged operational state across the recorded period.

### 2.4.2. Limitations

The current application of the MFA tool and the supporting dataset are subject to several limitations that should be considered when interpreting the results and designing future project phases:

- **Single-Site Data Basis:** All data originate from one construction site managed by SANKE. While operationally accurate, this limits the generalisability of findings to broader sectoral contexts. Expansion to additional sites or time periods is recommended for stronger benchmarking and validation.
- **Limited Material Differentiation within Waste Streams:** Although wood is separately recorded under EWC 17 02 01, no further breakdown exists in terms of wood type (e.g., engineered vs. solid, treated vs. untreated). This restricts the level of detail in analysing valorisation pathways that depend on material purity or specific characteristics.
- **No Explicit Treatment Outcome Data:** The dataset does not include direct information on the final fate of each waste stream (e.g., % recycled, backfilled, incinerated). These flows are inferred based on standard practices and facility input, rather than tracked through direct mass balances or digital traceability.
- **Manually Reported and Processed Data:** The input data were collected through manual recording and internal facility documentation. While reliable, this introduces the risk of human error or inconsistencies across reporting categories, especially in mixed streams.
- **Early-Stage Tool Development:** The MFA tool remains in its early demonstrative phase. While modular and adaptable, its current implementation is not yet linked with live data sources (e.g., IoT, site sensors) or external reporting systems (e.g., national registries or EU databases). These capabilities are intended for future development.

The digital MFA tool developed in the W2W project provides a meaningful and transparent view of wood waste flows within the CDW stream, based on real data and realistic site processes. However, the assumptions and limitations outlined above must be considered when applying results, interpreting scenarios, or scaling the approach to broader use cases. Future iterations will benefit from expanded datasets, greater automation, and deeper integration with traceability systems and circularity indicators.

# 3. USE CASE CONTEXT: CONSTRUCTION SITE DESCRIPTION AND CDW GENERATION

## 3.1. Overview of Use Cases

This deliverable presents two complementary use cases that serve as foundational scenarios for analysing construction and demolition waste (CDW) flows. Both are based on real-world data collected by SANKE, a Greek waste management operator active in both CDW collection and treatment. The first scenario reflects the current standard practice, where CDW from a construction site is transported to a treatment facility and undergoes basic sorting—primarily manual inspection or mechanical separation—typically after an initial shredding or crushing phase. The second scenario introduces a more advanced flow, where enhanced sorting is integrated in the process. This enhanced configuration includes sensor-based technologies, optical systems, and automated equipment that enable more refined separation of materials before and after mechanical processing. By contrasting these two configurations, the use cases offer a comparative perspective on how sorting strategies influence material recovery, operational efficiency, and data quality in CDW management.

## 3.2. Construction Site Characteristics

The construction site used as the basis for both use cases is in the region of Evia, Greece. It reflects a typical new-built project, likely involving structural and interior construction activities. Although detailed information about the exact project type is not available, the nature of the waste streams—such as concrete, bricks, tiles, wood, and metals—suggests that the site is not associated with demolition or heavy excavation works. This interpretation is supported by the material categories recorded in the data set provided by SANKE, who also manages the treatment facility receiving the CDW. The use of the same site across both scenarios ensures consistency in the analysis and allows for a focused comparison of treatment system configurations rather than site-specific variables.

## 3.3. CDW Types, Classification, and Project-Relevant Streams

Based on the dataset provided by SANKE, the construction site in Evia generates a broad and representative range of Construction and Demolition Waste (CDW) streams, all categorised under Chapter 17 of the European Waste Catalogue (EWC). The recorded waste types include:

- Inert construction materials, such as concrete (17 01 01), bricks (17 01 02), and tiles and ceramics (17 01 03).
- Mixed inert fractions, notably 17 01 07, which combines several of the above materials.
- Recyclable materials, including separately collected wood (17 02 01) and metals (17 04 05).

Other recoverable or bulk materials, such as bituminous mixtures (17 03 02) and gypsum-based construction materials (17 08 02). Mixed construction and demolition waste, listed under 17 09 04, which represents unsorted or contaminated streams from various site operations.

Importantly, the dataset does include separate entries for wood under EWC 17 02 01 with reported quantities, confirming that at least a portion of the wood waste is collected as a distinct stream rather than as part of a mixed category. This enhances the resolution of the MFA and allows for more accurate modelling of wood flows in both Use Case 1 (direct flow) and Use Case 2 (enhanced sorting).

The CDW streams can be broadly grouped into three categories:

- Pure inert materials – such as concrete, bricks, and ceramics – which are typically suitable for secondary aggregates or direct reuse following basic treatment.
- Recoverable and recyclable materials, including wood, metals, and certain plastics, which have potential for material valorisation if properly sorted and free from contamination.
- Mixed or residual fractions, including 17 01 07 and 17 09 04, which present greater challenges for downstream treatment due to their heterogeneous composition and often lower purity.

The presence of both source-separated (e.g. 17 02 01, 17 04 05) and mixed waste streams indicates a hybrid handling model at the construction site. This is typical of many active construction environments where segregation practices are partial, opportunistic, or dependent on available logistics, rather than fully integrated into site management systems.

For the purposes of the W2W project, special emphasis is placed on the wood waste stream, due to its strategic importance for cascade upcycling and circular economy objectives. While the dataset does capture wood collected separately, it does not quantify the composition or quality of wood within mixed streams (e.g. 17 09 04), nor does it specify treatment outcomes per fraction. This highlights the need for improved data disaggregation and flow tracking in future monitoring systems, especially for materials with high circular potential like wood.

*Table 1: Overview of CDW Categories Identified at the Evia Construction Site (EWC-based Classification)*

| EWC Code | Material Description | Category |
|---|---|---|
| 17 01 01 | Concrete | Inert |
| 17 01 02 | Bricks | Inert |
| 17 01 03 | Tiles and ceramics | Inert |
| 17 01 07 | Mixture of concrete, bricks, tiles, and ceramics | Mixed inert |
| 17 02 | Wood, glass, and plastic | Recyclable fractions |
| 17 03 | Bituminous mixtures | Bulk recoverable |
| 17 04 | Metals (iron, steel, aluminum, etc.) | Recyclable |
| 17 08 | Gypsum-based construction materials | Material-specific concern |
| 17 09 | Mixed construction and demolition waste | Residual |

## 3.4. Waste Segregation and On-Site Practices

Based on the available data and the observed distribution of EWC codes, waste segregation at the Evia construction site appears to be limited and largely informal. Materials are typically collected in bulk containers with little to no source separation. While it is possible that high-value materials such as metals are manually removed when convenient, there is no evidence of a systematic sorting strategy or dedicated segregation infrastructure. The frequent presence of mixed fractions—particularly EWC codes 17 01 07 (mixtures of inert materials) and 17 09 (mixed construction and demolition waste)—indicates a handling model in which most waste is co-disposed rather than selectively managed.

There are no indications of on-site weighing systems or digital tracking technologies, and this limits the ability to quantify waste at the point of generation or trace materials through their lifecycle. As a result, the quality of CDW delivered to treatment facilities is likely variable and less suitable for high-purity recovery processes. This practice reflects broader trends in construction sites where logistical constraints, lack of training, or economic disincentives hinder the implementation of structured waste management protocols. The conditions observed at the Evia site thus serve as a realistic and representative starting point for analysing the effects of improved system design introduced in the second scenario.

## 3.5. Relevance and Complementarity of Use Cases (Relation to Abstract and Scope)

The two use cases developed in this deliverable serve distinct but complementary purposes within the W2W project. Scenario 1 reflects current practices observed on the ground: CDW is generated, loosely collected, and delivered for treatment with minimal intervention. This baseline captures the operational constraints and systemic inefficiencies that characterize much of the sector today. It provides a valuable reference point for understanding the limitations of unsorted waste flows, both in terms of recovery potential and material traceability.

Scenario 2 builds directly on this foundation, introducing sorting and pre-sorting processes—either on-site or at a transfer facility—before treatment. This enables cleaner fractions, improved recovery rates, and better visibility into material flows. By comparing the two scenarios, the project can assess how modest system interventions can significantly improve the performance of CDW management. The contrast supports the broader objectives of the W2W project by demonstrating scalable pathways to more circular and data-informed construction waste practices, aligned with EU circular economy goals.

# 4. MATERIAL FLOWS AND TREATMENT PATHWAYS IN TWO CDW USE CASES

## 4.1. Scenario 1 — Direct Flow: Construction Site → Treatment → End Use

### 4.1.1. Context and CDW Generation

Use Case 1 represents a baseline scenario grounded in actual operational data provided by SANKE, a waste management company active in the region of Evia, Greece. The scenario models the flow of Construction and Demolition Waste (CDW) from a typical construction site that produces waste primarily through standard building activities, without any major demolition phase. The site operates under standard logistical and regulatory constraints common in the sector and offers insight into how CDW is currently managed when minimal interventions are in place.

The materials generated span a range of categories—from relatively pure inert materials like concrete and bricks to more heterogeneous streams that include wood, plastics, packaging, and various composites. This diversity, linked to the different stages of building construction, requires downstream systems to be capable of handling both high-purity and mixed-material waste. These waste streams are coded according to the European Waste Catalogue (EWC), offering a formal classification that supports treatment and reporting compliance. However, the management of these streams in practice reveals significant room for improvement.

### 4.1.2. On-site Handling and Waste Management

Waste handling at the construction site follows a conventional model characterised by limited source separation. CDW is deposited directly into large bulk containers without clear material segregation. While workers may occasionally isolate recyclable or valuable items—such as metals or wood—the process is informal, inconsistent, and dependent on individual initiative rather than an established protocol. There is no dedicated equipment for on-site sorting, nor are there separate containers clearly designated for specific waste types. This results in a substantial portion of the CDW being recorded under mixed EWC codes (such as 17 01 07 and 17 09), indicating a blend of multiple material classes.

### 4.1.3. Transportation to Treatment Facility

Once collected, the waste is transported to SANKE's treatment facility, where it undergoes an initial mechanical processing step—shredding or crushing—to reduce volume and prepare the material for downstream handling. This step is essential for enabling visual inspection and any form of sorting, which typically occurs after mechanical reduction. Sorting at this stage is primarily manual or mechanical and focuses on identifying and extracting materials that can be recovered or diverted from landfill. However, the effectiveness of sorting is limited by the high degree of mixing and the lack of material purity from the outset. Visual inspection and basic mechanical screening are the main tools used, with no advanced technologies deployed.

No real-time monitoring or digital recording systems are in place at the site or during transport. This results in low traceability and makes it difficult to assess the composition, quantity, or destination of individual waste streams. As such, the scenario exemplifies a "direct flow" model where most of the burden for material differentiation and recovery is shifted downstream, and where opportunities for improving circularity at the source remain largely untapped.

### 4.1.4. Treatment Processes and Outputs

Once delivered to the treatment facility, CDW undergoes an initial volume reduction process, typically through shredding or crushing. This step prepares the material for further handling, including manual sorting and mechanical screening. Based on the types of EWC codes present in the dataset and standard facility practices, inert materials such as concrete and bricks are separated and processed into secondary aggregates. Metals are manually or magnetically extracted where feasible, while residual materials are sorted as mixed fractions or sent for disposal.

The dataset suggests a classification of treatment destinations (e.g., landfill, recycling, backfilling), but it lacks complete mass balance or recovery efficiency data per material stream. Therefore, it is assumed that material recovery rates are estimated retrospectively based on sorted outputs rather than continuously measured. The level of sorting achieved is influenced by the mixed nature of incoming waste and the basic infrastructure used (visual/manual inspection, standard screening). Advanced separation technologies do not appear to be used at this stage. While the treatment pathway follows common practices, the lack of high-resolution output data constrains the ability to evaluate system performance or optimise recovery operations.

As wood waste is a priority stream within the W2W project, particular attention will be given to its treatment pathway in the analysis that follows. This deliverable will examine how different system configurations influence the visibility, handling, and potential valorisation of wood waste specifically.

Given that wood waste is a key priority stream within the W2W project, this deliverable pays particular attention to its treatment route, exploring how different system configurations impact the visibility, traceability, and valorisation potential of wood. Looking forward, additional processes identified in the W2W cascade valorisation framework will be progressively integrated and examined, including: (i) cascading reuse strategies (e.g., recovery of wood elements for direct reuse), (ii) remanufacturing into engineered wood products (e.g., particleboard, CLT), (iii) bio-based transformation processes (e.g., pyrolysis, biobinders), and (iv) final energy recovery where necessary. Although these downstream options are not fully modelled in this version of the MFA tool, they define the strategic direction for upcoming deliverables. Their integration will allow for a more comprehensive representation of the wood-to-wood value chain and enable more targeted assessments of how sorting, treatment, and digital tracking affect the circular potential of each process.

### 4.1.5. Material Flow Mapping and Key Data Gaps

The conceptual material flow begins at the construction site, moves through collection and transport, and ends at the treatment facility where materials are shredded, sorted, recovered, or disposed. Although SANKE has provided structured data on CDW types and treatment outcomes, it is understood that these records are compiled at the facility level—after waste delivery—rather than through real-time tracking or source-level logging. Materials are typically classified based on visual inspection and sorting results following mechanical processing, such as shredding. As a result, key data gaps remain there is a lack of precise input-output data, no digital records directly linking waste generation at the site to downstream treatment, and limited insight into contamination levels or rejection rates. These limitations hinder the development of robust material flow models and complicate future integration with digital traceability systems. Addressing them will be critical in the next phase of the W2W project.

## 4.2. Scenario 2 — Enhanced Flow: Construction Site → Sorting → Treatment → End Use

### 4.2.1. CDW Generation at Construction Site

Scenario 2 builds upon the same construction site as Scenario 1, with no changes to the nature, composition, or generation patterns of Construction and Demolition Waste (CDW). The site continues to produce a typical spectrum of materials associated with vertical construction, including inert substances, metals, wood, and mixed residuals. The classification of waste under European Waste Catalogue (EWC) codes remains consistent, reflecting routine activities across different phases of the construction process.

The point of departure between the two scenarios lies not in waste generation, but in the system design that follows. Scenario 2 introduces a more advanced configuration at the treatment facility, where CDW—after initial shredding—is directed through enhanced sorting infrastructure. This includes automated or sensor-assisted technologies designed to improve material separation, reduce contamination, and support higher recovery yields. The generation phase thus serves as a common input to two alternative downstream flows, allowing for comparative insights into how process upgrades influence material outcomes and data quality.

### 4.2.2. Integration of Sorting Processes

The defining feature of Scenario 2 is the integration of a more sophisticated sorting phase following the initial shredding of Construction and Demolition Waste (CDW) at the treatment facility. Unlike Scenario 1, where post-shredding sorting is limited to manual or basic mechanical inspection, the enhanced flow introduces additional equipment and technologies to improve the separation and classification of materials.

This sorting phase is designed to be complementary—not a substitute for shredding—and takes place either within the main treatment facility or at a dedicated intermediate sorting station managed by the operator. The system combines mechanical processes (e.g. conveyor-based screening, density separation) with advanced sensor technologies, such as near-infrared (NIR) sorting, camera-assisted identification, and possibly even optical recognition tools. These are used to differentiate between material types based on composition, colour, or density—especially in complex or contaminated fractions.

The enhanced configuration allows for the extraction of higher-purity material streams from the mixed CDW input. High-value or reusable fractions such as metals, clean wood, and unpolluted concrete are more effectively identified and separated. Inert materials are screened and crushed with improved granularity, while lighter fractions like plastics, packaging, and gypsum-based components can be channelled into specialised recovery routes. This multi-stage process increases the share of CDW that can be prepared for recycling or reuse, reduces contamination in residual streams, and facilitates more accurate reporting. (Bonifazi & Serranti, 2016)

By improving the precision of sorting after shredding, this scenario establishes a more efficient bridge between raw waste inputs and downstream valorisation. It represents a step-change from conventional practice, enabling material-specific routing that supports higher circularity potential and a more robust data trail for analytical modelling. (Cossu & Lai, 2015)

### 4.2.3. Benefits of Enhanced Sorting

The introduction of enhanced sorting technologies after shredding significantly improves the efficiency and environmental performance of CDW management (Demetriou & Mavromatidis, 2024). By enabling more accurate separation of waste fractions, sorting reduces the volume of contaminated or mixed materials sent for disposal and increases the quantity of materials suitable for recycling or reuse. This leads to improved recovery rates, more targeted routing of materials, and better use of available treatment infrastructure. Furthermore, separating materials into more homogeneous streams contributes to operational stability in downstream processes and opens access to higher-value secondary raw material markets. (Sustainability Journal, 2025), (Rousta & Ekström, 2020)

### 4.2.4. Modified Treatment Pathways

Once sorting is complete, the differentiated waste streams follow dedicated treatment routes aligned with their physical and material properties. Clean inert fractions, such as concrete and bricks, are crushed into secondary aggregates. (Demetriou & Mavromatidis, 2024) Recovered metals are processed through existing recycling channels, and wood—when identified with sufficient purity—can be directed toward specialised recovery or energy valorisation. Plastics, packaging, and other lightweight fractions may be separated further or transferred for external treatment. Compared to the more generalised pathway in Scenario 1, these tailored flows reduce unnecessary processing, increase resource efficiency, and support alignment with circular economy objectives.

Wood—depending on its level of contamination and composition—can be diverted to different recovery routes, including material recycling, energy valorisation, or exclusion from reuse if degraded.

### 4.2.5. Improved Material Characterisation and Recovery

Enhanced sorting contributes directly to more accurate material characterization by producing output streams with well-defined composition profiles. This enables more reliable input-output assessments, supports process calibration at treatment facilities, and lays the foundation for improved recovery strategies. For the W2W project, wood waste is of particular interest as a priority stream. In Scenario 2, the use of mechanical and sensor-based sorting allows for more effective identification of wood, especially where it is intermixed with other materials such as glass, nails, plastics, or insulation residues.

By separating wood at an earlier stage—after shredding but before cross-contamination deepens, Scenario 2 improves the chances of recovering wood fractions of adequate quality for recycling or secondary use. Depending on the type and extent of contamination detected during sorting, the wood can be directed toward recycling processes, energy recovery, or excluded from reuse pathways if degraded. This enhanced capability to isolate and assess wood waste is critical for developing circular strategies that target high-value recovery streams. The system design proposed here supports such differentiation in future iterations.

## 4.3. Comparative Insights between Scenarios

Compared to the direct flow model presented in Scenario 1, the enhanced flow configuration in Scenario 2 demonstrates clear advantages in material purity, recovery efficiency, and operational precision. While both scenarios begin with identical construction site conditions and waste generation patterns, the introduction of an advanced sorting stage after shredding significantly improves downstream outcomes. Cleaner fractions are produced, contamination is reduced earlier in the process, and more materials—particularly wood—can be routed appropriately based on quality and composition.

Moreover, Scenario 2 supports more granular data capture and reporting, enabling improved alignment with regulatory demands and future circularity monitoring frameworks. These gains, however, come with trade-offs: they require capital investment in sorting technologies, skilled operators, and more controlled process flows. As such, the comparison illustrates a broader systemic tension between complexity and performance, highlighting the need for strategic decision-making in designing CDW treatment systems that are both efficient and scalable.

# 5. MATERIAL FLOW MAPPING AND QUANTIFICATION

## 5.1. IMPLEMENTED MODELS

To translate the conceptual scenarios into quantifiable outputs, two distinct models were implemented using the digital Material Flow Analysis (MFA) tool developed within the W2W project. These models reflect the two CDW handling scenarios introduced in Chapter 4 and aim to simulate material flows with particular emphasis on wood waste.

Each model builds on real operational data from a construction site and treatment system operated by SANKE in Evia, Greece. Scenario 1 ("Basic Model") reflects the current operational status with limited upstream sorting, while Scenario 2 ("Sorter Model") integrates an additional sorting stage designed to improve wood waste separation and valorisation.

### *5.1.1. Basic Model*

The Basic Model corresponds to the "direct flow" scenario described in Chapter 4.1. It represents the prevailing CDW management system applied at the construction site and SANKE's treatment facility. In this configuration, wood waste is collected as part of broader CDW streams, with minimal sorting occurring on-site. Materials are transported to the treatment facility, where initial shredding and visual inspection support the downstream sorting of recoverable fractions.

This model includes the following compartments:

- **External Inflow (Flow):** Represents the entry of wood contained in CDW from the construction site. It is modeled as a continuous flow with a Gaussian distribution, averaging 23 tons per period (based on 2023–2024 site data), with a standard deviation of 2 tons.
- **Pre-Treatment Center (Stock):** Performs shredding and preliminary separation of materials. To reflect processing delays, this compartment is modeled as a stock that holds material temporarily before transferring it to the next phase.
- **Recycling Unit (Stock):** Processes the sorted wood fraction. Due to the batching and throughput limitations typical in such operations, this is also modeled as a stock compartment.
- **Sink Nodes:** Represent final destinations of materials, including:
  - Recycled Wood
  - Residual Wood Waste
  - Non-Wood Fractions

**Transfer Coefficients (TCs):**

- Pre-treatment to recycling: Normally distributed ($\mu = 85\%$, $\sigma = 5\%$)
- Recycling to Recycled Wood Sink: Normally distributed ($\mu = 67.5\%$, $\sigma = 5\%$)
- Residual and non-wood fractions: Fixed values derived from remaining flows

**Delay Settings:**

- Pre-treatment: 50% processed in current period, 50% in the next
- Recycling: 20% processed immediately, remaining spread over the next three periods (50%, 10%, 20%)

Figure 1 illustrates the flowchart of the Basic Model, and Figure 2 presents the histogram of transfer coefficient distributions applied during simulations.

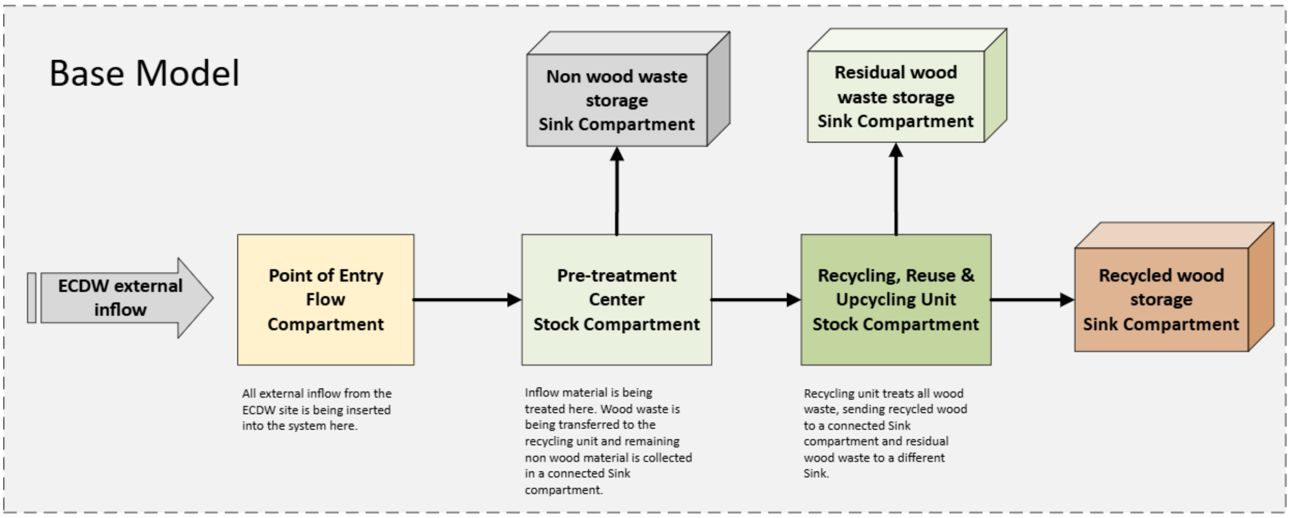


*Figure 1: Basic Model flow chart*

 

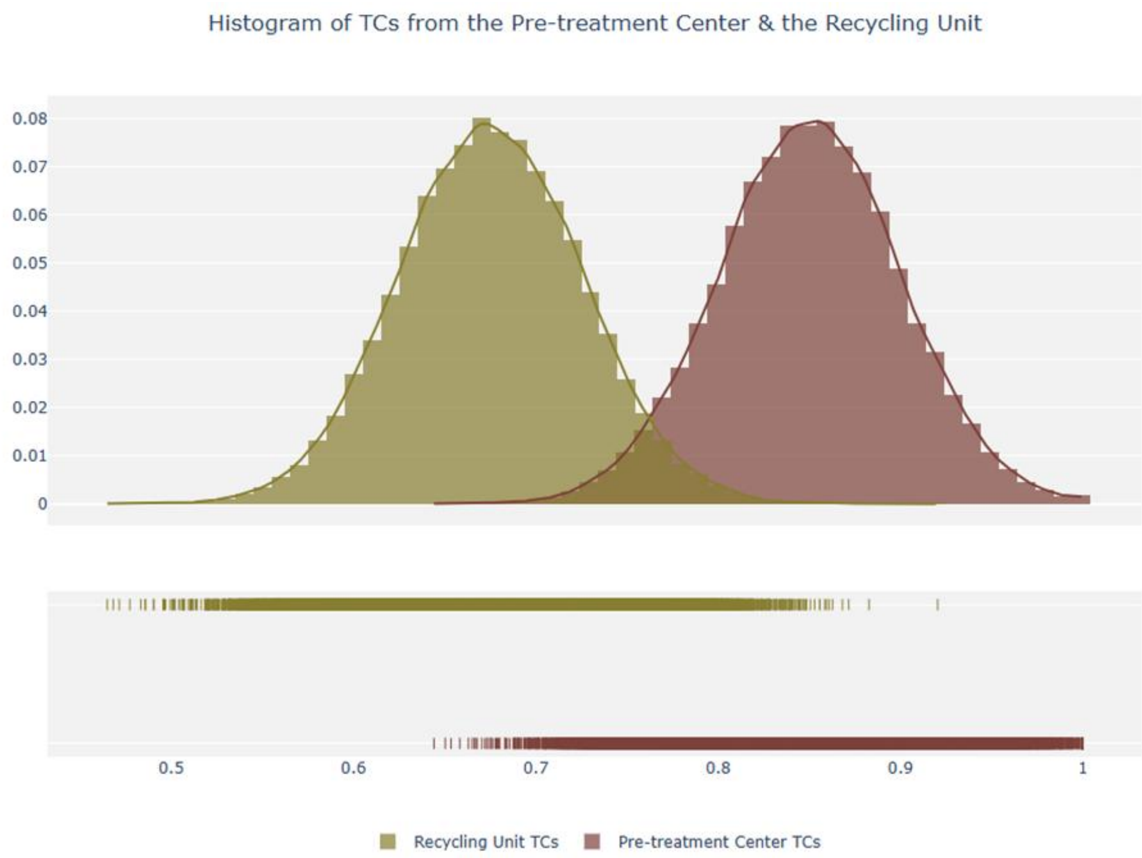


*Figure 2: Histogram of TCs*

The delays of the material outflow in the pre-treatment and recycling facilities were defined as a fixed proportion per time period, corresponding to the percentage of the material inflow of a single period that is released in the same and following periods. In this way, the pre-treatment centre was designed to process 50% of the current inflow on the same time step and 50% on the next time step. Likewise, the recycling unit was modelled to process 80% of the current inflow on the same time period and 20% in the following time period.

### 5.1.2. Sorter Model

The Sorter Model simulates the enhanced flow scenario detailed in Chapter 4.2, where a dedicated sorting stage is added before pre-treatment. This model explores the effects of improved upstream separation on downstream processing performance—especially with respect to wood.

Key differences from the Basic Model include:

- **Sorting Unit (Flow):** Added immediately after the initial inflow. This unit separates CDW into wood and non-wood fractions. Only the wood stream continues to the pre-treatment centre.
- **Modified Pre-Treatment Centre:** Now functions solely as a volume reduction step (e.g. shredding) for already separated wood waste. No longer performs sorting.
- **Adjusted Transfer Coefficients:**
  - Sorting to Pre-treatment: Normally distributed (μ = 95%, σ = 5%) (Dodampegama, 2024)

- Recycling to Recycled Wood Sink: Normally distributed (μ = 75%, σ = 5%)

- **Processing Delays:**
    - Sorting: 80% in current period, 20% in the next
    - Pre-treatment delays were eliminated
    - Recycling unit retains same delay dynamics as in the Basic Model

This model is designed to reflect a more efficient and higher-resolution configuration, improving the quality of input streams to the recycling phase and reducing contamination. It also supports higher material recovery rates, as confirmed in the MFA-based scenario comparisons in later chapters.

Figure 3 provides a visual schematic of the Sorter Model and the sequence of compartments.

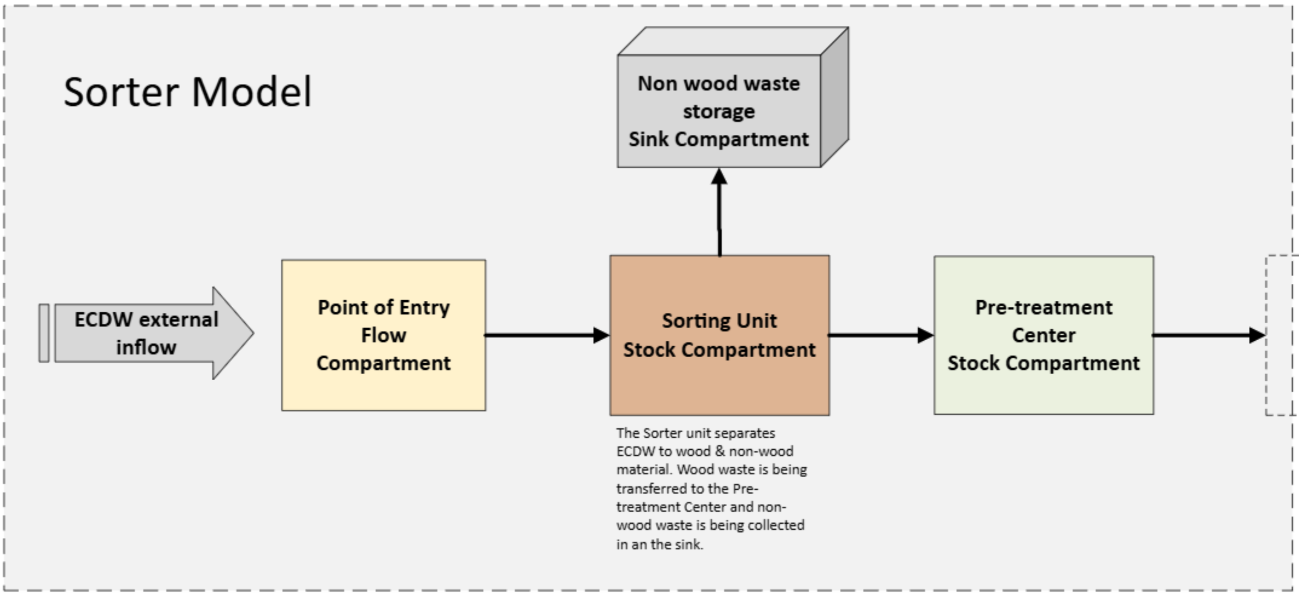


*Figure 3: Sorter Model flow chart*

## 5.2. Simulation Results and Comparative Insights

To evaluate the dynamics of material flows and storage within the system, both the Basic and Sorter models were simulated over a time horizon from 2024 to 2028. These simulations focused specifically on wood waste and its potential recovery, following the structure and flow logic established in Section 5.1. Each model was executed 50,000 times to ensure statistical robustness and account for uncertainty propagation across time steps.

The simulation framework was implemented using the dpmfa-simulator package, a Python-based discrete process simulator publicly available via the Python Package Index (PyPI) at: https://pypi.python.org/pypi/dpmfa-simulator. Simulations were run on a mid-range laptop (AMD Ryzen 7 7435HS, 16 GB RAM), with each complete model execution requiring approximately 30 seconds.

### *5.2.1. Recycled Wood Stock Development*

Figures 4 and 5 display the projected accumulation of recycled wood at the Sink endpoint for both the Basic and Sorter models, respectively.

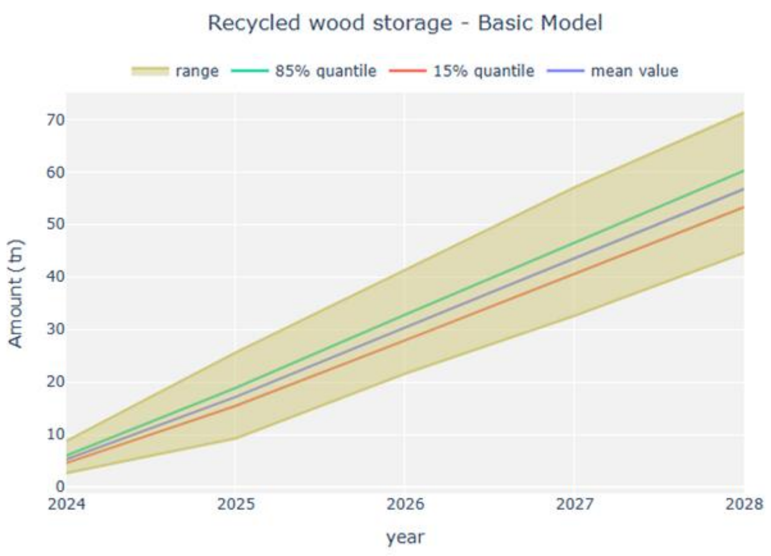


*Figure 4: Recycled wood Stock for Basic model*


*Figure 5: Recycled wood Stock for Sorter model*

The plotted values include the average trend, interquartile ranges, and full range bands derived from all 50,000 runs.

- In the **Basic model**, the final accumulated stock of recycled wood by 2028 is projected to reach approximately 56 tons.
- In the **Sorter model**, which incorporates a dedicated sorting stage prior to treatment, the projected recycled wood stock increases significantly to 75 tons by 2028.

This increase in recovered material is attributed to two main factors:

1. The enhanced efficiency of the sorting unit in separating wood from mixed CDW fractions.

2. The higher recovery rate in the recycling stage under the Sorter scenario, reflecting improved feedstock purity.

### 5.2.2. Comparative Performance in Residual Waste Reduction

Figure 6 presents a comparative bar chart of key output streams for the two scenarios. In the Basic model, the residual wood waste—i.e., unrecovered material after recycling—reaches 27 tonnes by 2028. In contrast, the Sorter model reduces this to 25 tonnes, marking a substantial gain in recovery performance and a more efficient overall material management approach.

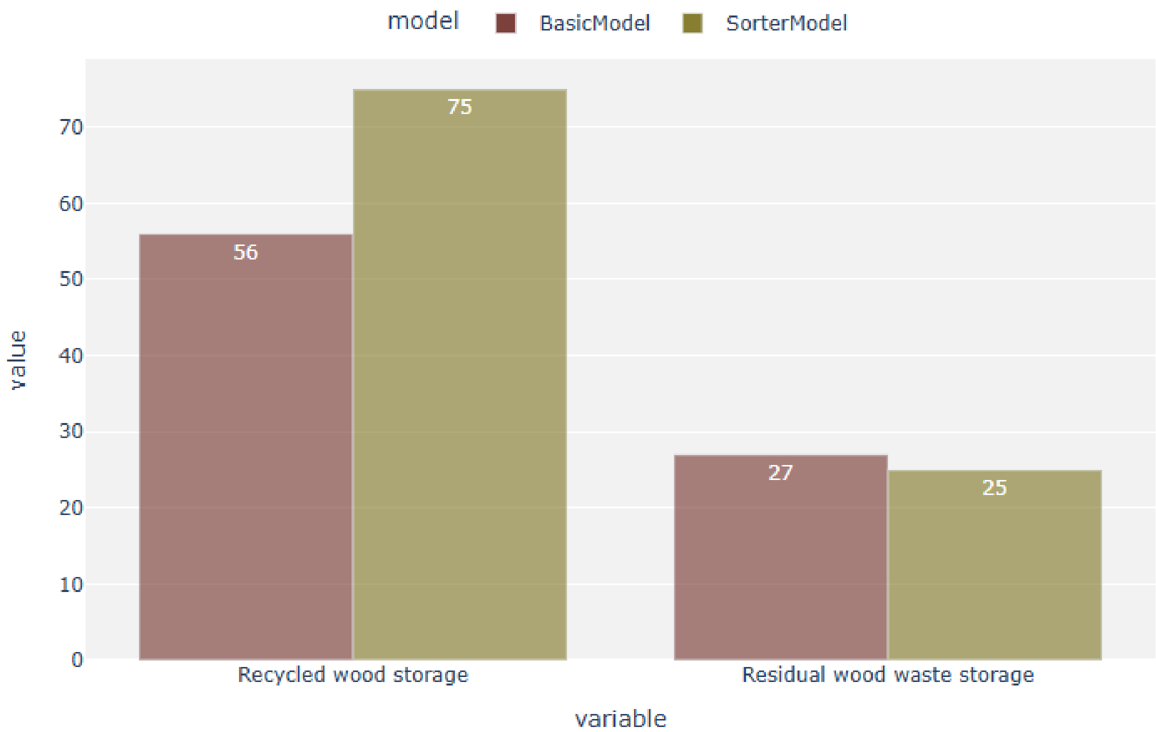


*Figure 6: Mean values of output materials for the two models*

### 5.2.3. Variability and Uncertainty Analysis

Figure 7 illustrates the probability distributions of recycled wood stocks in the Basic model for the years 2024 and 2028. These visualisations reveal increasing variability over time, reflecting the compounding effect of input uncertainty and stochastic process dynamics. In 2028, the inter-quantile range (IQR) for recycled wood stock spans 7 tonnes in the Basic model and expands further to 7.2 tonnes in the Sorter mode.

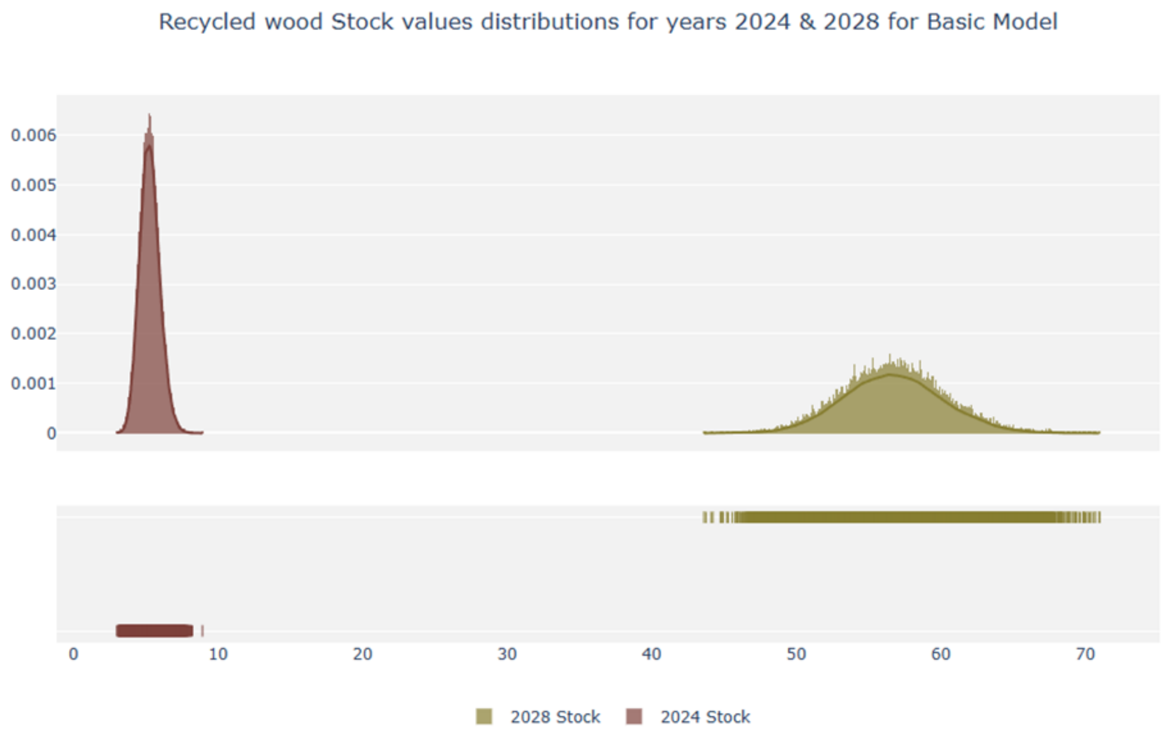


*Figure 7: Distributions of Recycled wood Stock*

### *5.2.4. System-Level Flow Mapping*

To synthesise system performance over the full simulation period, a Sankey diagram (Figure 8) visualises cumulative flows between compartments for the Sorter model. Over the total time frame of the simulation, 2024 through 2028, the external inflow of CDW reaching the Off-site sorter accounts for 115 tonnes, of which 5 tonnes are being transferred to the attached sink and 104 tonnes are being forwarded to the Pre-treatment Center. The remaining 6 tonnes of the inserted CDW had not yet been processed by the Sorter by the end of 2028, due to the modelled Sorter delay. This breakdown shows that ~90% of input waste is successfully routed to pretreatment, while ~5% is diverted (sink) and ~5% remains pending due to delays.

Subsequently, the Pre-treatment Center channels all 104 tonnes of wood waste to the Recycling unit, and the resulting Recycled wood manages to reach 75 tonnes, whereas Residual wood waste reaches 25 tonnes and 4 tonnes are yet to be processed by the Recycling unit in the future. Here, the recycling efficiency is ~72% (75/104 tonnes), with ~24% residuals and ~4% still in progress—highlighting both recovery potential and processing bottlenecks.

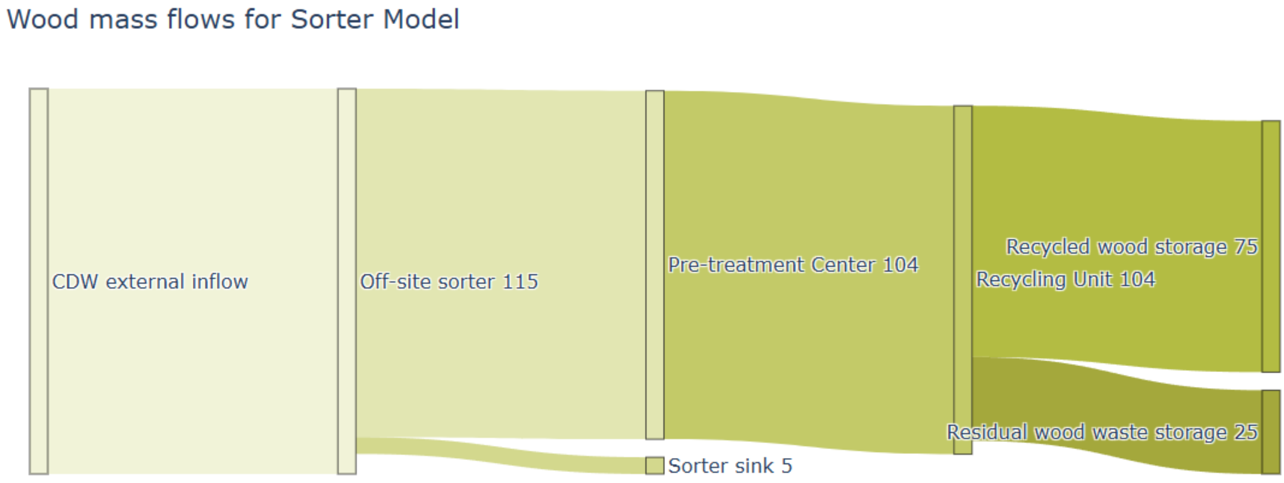


*Figure 8: Sankey Diagram of system flows for Sorter model*

## 5.3. Optimisation Model

Building on the two use cases presented in Sections 4 and 5.1, and the simulation results in Section 5.2, an optimisation model was developed to explore how sorting infrastructure could be best deployed to enhance system-wide performance. The previous analysis confirmed that introducing a sorting step (Scenario 2) significantly increases the amount of wood recovered as a recyclable fraction and reduces the amount of residual wood waste sent to landfill or low-value applications.

To extend these findings and provide decision support for future infrastructure investment, this section introduces an optimisation model that allows for flexible routing of incoming CDW flows between a pre-treatment centre and a sorting unit. The goal is to determine the most economically beneficial configuration of system capacities and flow allocation, using realistic cost, performance, and material flow parameters informed by the data and assumptions used in the MFA tool.

### *5.3.1. Model Description*

The optimisation model reflects a hybridised version of the Basic and Sorter scenarios, with both treatment options available. Following the point of material entry, CDW flows can be routed either to a pre-treatment facility (as in Scenario 1) or to a dedicated sorting unit (as in Scenario 2). Separated wood fractions from both paths are then directed to the recycling unit. The objective is to determine the optimal sorting capacity and allocation of material flows that maximise economic performance over the period 2024–2028.

Figure 9 presents the optimisation model flowchart.

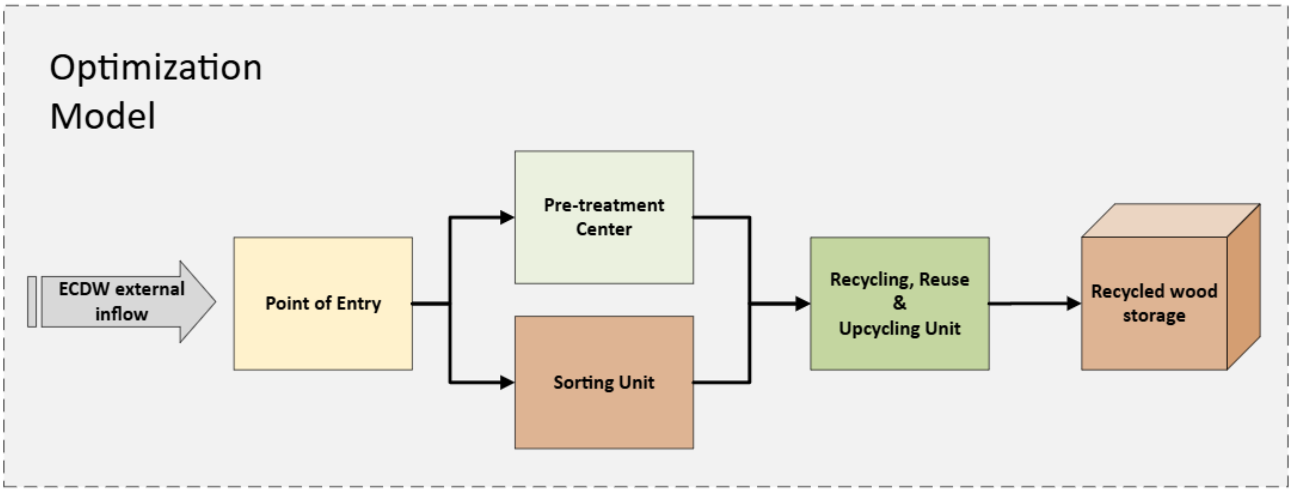


*Figure 9: Optimisation model flow chart*

### 5.3.2. Model Assumptions and Inputs

The model formulation is structured as a constraint-based optimization problem with the following features:

- **Objective**: Maximise profit from wood recycling, considering revenue from recycled wood and the costs of treatment, energy consumption, and sorter installation.
- **Decision Variables**: Installed capacity of the sorter (in tons/hour), and annual allocation of incoming CDW between the sorting unit and the pre-treatment center.
- **Time Horizon**: 2024 to 2028.
- **Key Assumptions**:
    - Annual CDW inflow: 100,000 tonnes.
    - Wood fraction of CDW: 10%.
    - Sorting and recycling efficiencies based on parameters derived from the MFA tool (Section 5.1).
    - Economic parameters sourced from national reports (Ministry of the Environment and Energy, 2020) and market research (Table 2).

*Table 2: Recycled Wood Treatment System Parameters*

| Economic Parameter | Value |
|---|---|
| **Pre-treatment Unit Treatment Capacity** | 1 tn/h |
| **Storage Capacity** | 30000 tn |
| **Recycled wood Selling price** | 1700 €/tn |
| **Energy consumption of Sorter** | 5 kWh/tn |
| **Energy price** | 0.119 €/kWh |
| **Treatment cost for non-separated waste** | 10.5 €/tn |

| | |
|---|---|
| **Treatment cost for separated waste** | 4.5 €/Tn |
| **Sorter Installation cost** | 10000 €/Tn |

Performance parameters such as sorting accuracy and recycling efficiency were derived from the implemented MFA models:

- Sorter accuracy: 95%
- Pre-treatment accuracy: 85%
- Recycling efficiency (Sorter flow): 75%
- Recycling efficiency (Pre-treatment flow): 67.5%

### 5.3.3. Constraints

- **Mass Balance:** All inflow must be routed to either the sorter or the pre-treatment center.

$$WoodwWasteflow_t = PreTreatmentInflow_t + SorterInflow_t$$

- **Stocking Dynamics:** Each unit's stock is calculated based on current inflow, previous stock, and processing capacity.

$$Stock_t = \max(0, Stock_{t-1} + Inflow_t - SortingCapacity$$

- **Storage Limit**: Total stock must not exceed system capacity (30,000 tons).
- **Objective Function**: Maximise total profit across the time horizon, incorporating all income and costs from material flows, as detailed in the full equation above.

### 5.3.4. Optimisation Results

*Table 3: Optimisation Outcomes (2024–2028)*

| Year | CDW Inflow | Pre-treatment Flow | Sorter Flow |
|---|---|---|---|
| 2024 | 100,000 tn | 0 | 100,000 tn |
| 2025 | 100,000 tn | 0 | 100,000 tn |
| 2026 | 100,000 tn | 0 | 100,000 tn |
| 2027 | 100,000 tn | 0 | 100,000 tn |
| 2028 | 100,000 tn | 0 | 100,000 tn |

- **Optimal sorting capacity**: 48 tn/h
- **Total profit (2024–2028)**: €59,583,125

The results clearly indicate that routing the entire CDW inflow through the sorter yields the highest financial return, due to both higher material recovery and reduced treatment costs. The optimal sorter capacity was sized to accommodate 100% of the inflow within each time period, avoiding delays and stock accumulation.

Smaller sorter capacities were less profitable, as storage and delayed recovery reduce revenue potential within the model's five-year timeframe. For example, a sorting capacity of 24 tn/h would yield a profit of €31,120,098, almost half of the total profit of the optimal sorting capacity.

# 6. DISCUSSION AND RECOMMENDATIONS

This chapter reflects on the insights gained through the implementation of the digital MFA tool and the scenario-based modelling applied to Construction and Demolition Waste (CDW) management, with an emphasis on wood waste. Drawing from the outputs of the Basic and Sorter models, as well as the optimisation analysis, the discussion evaluates system performance, recovery efficiency, and economic potential, while proposing practical recommendations for further development and application.

## 6.1. Comparative Insights from the Use Cases

The two use cases developed for this deliverable—Scenario 1 (Basic model) and Scenario 2 (Sorter model)—represent different operational approaches to CDW handling:

- **Scenario 1** reflects the current practice observed at the Evia construction site, where CDW is transported directly to treatment without prior sorting.
- **Scenario 2** introduces a dedicated sorting stage prior to treatment, simulating an enhanced system configuration.

The comparative analysis shows that Scenario 2 outperforms Scenario 1 across all key indicators:

- Recycled wood output increased from 56 tons to 74 tons over the analysis period.
- Residual wood waste decreased from 27 tons to 24 tons.
- Data quality and traceability improved, as sorting enables finer resolution and categorization of flows—particularly for materials like wood that are prone to contamination.

These results highlight the value of sorting as a pre-treatment step—not only in boosting recycling rates but also in improving the transparency and reliability of flow data. For wood, early isolation from mixed CDW streams (e.g. 17 02 or 17 09) enables higher recovery quality and reduces downstream processing complexity.

## 6.2. Insights from the Optimisation Model

Building on the performance gap between the two scenarios, an optimization model was developed to explore how system design choices influence economic outcomes. The model considered a combined flow architecture, allowing CDW inflows to be split between a sorter and a pre-treatment center. Key findings include:

- The optimal configuration directs 100% of the flow to the sorter, with a recommended capacity of 48 tons/hour.
- Economic performance improves when higher sorting accuracy (95%) and recycling efficiency (75%) are leveraged.
- Costs related to treatment, energy, and installation were critical variables in determining profitability.

This confirms that increasing sorting capacity compared with operational efficiency—can generate both environmental and economic returns. The model further demonstrates the value of digital MFA tools for scenario planning and investment decision-making in real CDW systems.

## 6.3. Implications for Wood Waste Valorisation

The wood waste stream—central to this analysis—illustrates broader trends in CDW circularity:

- Contamination risk is high when wood remains mixed with glass, metals, or plastics, as is common in EWC 17 02 or 19 12 12 fractions.
- Clean wood flows (e.g., 19 12 07) are more suitable for mechanical recycling, reuse, or upcycling, particularly when isolated early in the process.
- The potential for cascade valorization increases with material purity, allowing for applications beyond biomass or energy recovery—such as engineered wood panels, furniture, or secondary raw materials.

Scenario 2 and the optimization model highlight how improved sorting not only increases volumes of recovered wood but also improves the quality of this resource, making higher-value reuse possible.

## 6.4. Recommendations

The analysis of wood flows across the two use cases, supported by simulation and optimisation models, highlights key areas for improvement in CDW management. The following recommendations are proposed for the next phases of the W2W project and broader sectoral application:

- **Integrate Sorting Infrastructure Early in the Chain**: Prioritise on-site or transfer-level sorting to separate wood waste before treatment. This reduces contamination, increases recovery efficiency, and supports higher-value valorisation.
- **Enhance Data Granularity**: Improve classification of wood waste beyond EWC codes by distinguishing types (e.g. treated, untreated, composite). More detailed data will support better modelling and recovery planning.
  - **Recommendation**: **Connect Digital Product Passports (DPPs) with MFA systems** to enable the traceability of wood components from construction through to end-of-life. This linkage allows for more accurate material identification, enhances circular tracking, and supports better sorting and reuse decisions.
- **Expand and Refine the MFA Tool**: Incorporate lifecycle metrics, link to Digital Product Passports (DPPs), and explore integration with BIM systems to broaden the tool's utility and support design-for-reuse strategies.
- **Inform Policy with Data-Driven Evidence**: Leverage MFA outputs to support more effective regulations on waste separation and circularity. Evidence from the tool can guide national and EU targets, especially for wood reuse and upcycling.
- **Scale Simulation and Optimisation**: Apply the models to multiple sites and test advanced scenarios—such as regional sorter placement or dynamic flow routing—to identify cost-effective pathways for systemic improvement

## 6.5. Next Steps and Strategic Outlook

As the W2W project moves forward, the MFA tool is set to expand beyond the construction-site scale to inform decision-making at regional and national levels. This progression will allow for the evaluation of sorting strategies not only in terms of technical performance but also in terms of system-wide impact and magnitude. In particular, the optimisation of sorting—both in terms of infrastructure placement and efficiency—has proven to be a critical enabler of improved recovery, reduced residuals, and higher circular value for wood waste, as demonstrated by our simulation and optimisation results.

A key priority in the next phase is the integration of Digital Product Passports (DPPs) to enable material traceability and more intelligent end-of-life decision-making. The ability to track wood components throughout their lifecycle will allow for better source separation, cleaner recovery streams, and ultimately more effective reuse or upcycling. Coupling the MFA with complementary tools—such as LCA for environmental performance and supply chain optimisation models—will further enhance system-level planning and promote cross-sector alignment.

Importantly, this trajectory directly supports the overarching cascade valorisation framework of the W2W project, which aims to maximise the retention of value across successive life cycles of wood. By modelling real-world flows, identifying critical interventions, and enabling evidence-based decisions, this deliverable contributes not only to the digitalisation of CDW management but also to the long-term transformation of wood recovery into a strategic, value-driven process. In this way, the MFA tool acts as a foundation for systemic change—advancing the shift toward higher-value circularity, better resource use, and the full realisation of the W2W cascade upcycling vision.

# 7. CONCLUSION

The development and application of the digital Material Flow Analysis (MFA) tool within the framework of the W2W – Wood-to-Wood Cascade Upcycling Valorisation Approach project marks a significant step forward in the data-driven management of Construction and Demolition Waste (CDW), with a particular emphasis on wood waste. By modelling real-world operations at a construction site and affiliated treatment facility in Evia, Greece, this deliverable has demonstrated how targeted interventions—most notably, the addition of a sorting phase—can meaningfully improve recovery outcomes, economic performance, and data transparency.

The comparative simulation between the Basic (As-Is) and Sorter (Enhanced) models revealed substantial gains in the quantity and quality of recycled wood when pre-treatment sorting was introduced. These operational improvements were validated through 50,000 simulation runs, and further reinforced by an economic optimization model, which showed that channeling the entire CDW stream through a well-sized sorting unit maximized financial returns under realistic constraints.

Wood waste emerged as a particularly sensitive and strategic material stream. The analysis showed that early separation significantly improves its potential for reuse, mechanical recycling, and cascade upcycling—contributing to the broader goals of the circular economy and sustainable construction. However, the study also revealed limitations in existing data granularity, the lack of detailed categorization of wood fractions in typical EWC-coded datasets, and the need for better integration between digital tools and operational practices.

This first version of the MFA tool provides a solid foundation for supporting the implementation of more circular CDW systems. It enables stakeholders to visualise flows, test interventions, and quantify trade-offs between operational simplicity and recovery performance. While this version remains a demonstration prototype applied to a single site, its modular structure, adaptability, and use of open-source simulation components position it for future scaling, integration, and refinement.

In conclusion, this deliverable affirms that even incremental shifts—such as introducing targeted sorting—can lead to meaningful improvements in both environmental and economic performance. As construction practices evolve, digital tools like the MFA to be developed in W2W will become increasingly essential in designing, monitoring, and optimizing systems that are not only more efficient, but also more aligned with Europe's circularity goals and resource conservation targets. The work presented here lays the groundwork for future phases of the W2W project, including more detailed data integration, multi-site applications, and enhanced support for policy development and industry best practices.

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