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D2.1 Report on the waste management supply chain

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LIST OF ABBREVIATIONS

ACRONYM	DESCRIPTION
AUA	Agricultural University of Athens
AD	Anaerobic Digestion
CA	Consortium Agreement
DoA	Description of Action
EC	European Commission
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FCC MA	FCC Medio Ambiente
GA	Grant Agreement
Monti	Montinutra OY
MSW	Municipal Solid Waste
OECD	Organisation for Economic Co-operation and Development
OFMSW	Organic Fraction of Municipal Solid Waste
SA	Succinic Acid
UN	United Nations
VTP	Valdemingomez Technological Park
WP	Work package

Publishable summary

This report aims at understanding the supply chain limitations of using sawdust and OFMSW as feedstocks in the LUCRA process. Although both are residual and biodegradable, the challenges of using one or the other waste stream are quite different.

On one hand, evidence suggests that sawdust production is steady, and, in spite of its natural origin, it is available at any time of the year. On the other hand, OFMSW is ruled by seasonality. This has been concluded from a literature review and four OFMSW characterisations carried out (1 per season) at the Biomethanisation Plant Las Dehesas (Madrid). Differences between seasons have been found, with winter often accounting for lower OFMSW volumes and autumn for higher ones.

While weather and local characteristics influence the production of the two, there are unique aspects determining the available quantities of each feedstock, like sawmill size and milling output for sawdust or festivities and consumption trends for OFMSW.

In the same way, with regard to the management supply chain of each waste type, despite the fact that some elements are identical (like the benefits of implementing cutting-edge collection technologies or the presence of fire hazards,…), others are contrary, for example: sawdust is usually stored and OFMSW is not; there is a high market demand for sawmill residues which is non-existent for OFMSW.

The biggest challenge affecting sawdust availability is that its price is closely related to fluctuations in renewable energy markets and wood trade dynamics. The moment this increases too much, LUCRA process may be unprofitable.

The other two most important aspects to consider about sawdust are that its production is restricted to certain regions of the world and it has around 50% water content. Therefore, it is advisable to locate sawdust valorisation facilities close to production areas and avoid high transportation costs.

In contrast to sawdust, OFMSW is guaranteed anywhere close to human settlements, however for the material to be suitable as a feedstock, current contamination levels in the stream need to be highly reduced. This cannot be achieved without strongly engaging with OFMSW producers, i.e. households and businesses. Awareness activities as well as incentives for them to separate biowaste correctly are essential.

The feasibility of using sawmill residues and OFMSW as feedstocks in the LUCRA process has been partly confirmed in this Deliverable. While it has been proven that the logistics of these waste streams can be integrated in the LUCRA project, their suitability for microorganisms' growth still needs to be tested in the remaining activities of this project.

1. Introduction

The challenge

The LUCRA project aims at maximising the value of two residual streams: wood by-products and the organic fraction of municipal solid waste (OFMSW). As of now, the main application of these streams is burning them to convert and use them for energy purposes (heat or electricity). However, these residual streams are a great source of sugars and nutrients, which can be used as feedstock in fermentation processes to produce e.g. biobased chemicals as platform building blocks, with higher market value than energy production.

The goal of the project is to yield a significant industrial end user interest molecule, succinic acid. This is achieved through an innovative and integrated process of fermentation and electrochemical extraction that is more sustainable than the conventional methods.

Deliverable purpose and target group

In order to ensure the success of scaling-up the LUCRA process, it is necessary to firstly analyse the availability and composition of sawdust and OFMSW all over the year, as well as providing insight into the elements involved in its generation and supply as feedstocks. Having understood the weaknesses of these resources, proposals for improving their reliability can be made.

This report is addressed to forest industry residues and OFMSW producers, companies willing to invest in the scale-up of LUCRA technologies and also anyone interested in organic waste, second generation feedstocks, circular/biobased economy, biomass processing, etc.

Introduction to the objectives of the Work Package:

This deliverable is part of Work Package 2 (WP2) “Biomass availability and pre-treatment to enhance usable sugars and nutrient content”, whose main objective is the optimisation of biomass collection, storage and supply to the main processing sites and pre-treatments in realistic environments.

In particular, Deliverable 2.1 is a compilation of the results of the first Task of WP2, “Analysis of biomass resources availability based on the seasonality and composition study”, which has been carried out to ensure optimised and reliable logistics that provide a continuous supply of feedstock at minimum cost and energy consumption.

Links with other workpackages

The task mentioned above is followed up by Task “Feedstock characterisation” and its corresponding deliverable (D2.2), because even when the feedstock is at hand, it is necessary that its composition is suitable for the processes downstream. Therefore, the interest in analysing real samples of sawdust from MONTI (brand name: Boreal Bioproducts) in Finland and the bio-waste received at Las Dehesas AD plant (FCC MA) in Madrid for each of the seasons. Lab analysis will provide data of their compositional fractions (cellulose, hemicellulose, pectin, lignin, protein, etc.), enabling the prediction of the potential SA yield that can be obtained from these feedstocks.

The outcomes of Deliverable 2.1 will be helpful for the work packages that following the project, including:

- **WP3 (Bioprocess optimisation for succinic acid production using an electrochemical membrane bioreactor)**: The seasonality of OFMSW will have to be taken into account upon the optimisation of conversion processes for SA production. Ensuring that biomass is always available is essential to maximize yield and efficiency, including the integrated system.
- **WP4 (LUCRA Biorefinery demonstration)**: At this stage of the project that includes the shipment of important volumes of sawdust and OFMSW from Finland and Spain, respectively, to Belgium, the logistics aspects described in this deliverable (such as handling, storage, firefighting measures, transport information, etc.) will have to be considered. Also, at BBEPP facilities (Belgium), where pilot trials are going to take place.
- **WP6 (Safety, sustainability and economic assessment)**: Health & safety requirements, market prices, as well as the cost and environmental impacts of transporting feedstocks will play a major role in the calculations made in this WP.
- **WP8 (Communication, dissemination, exploitation and stakeholder engagement)**: Seasonal characterisations of OFMSW is key in order to convey the importance of disposing biowaste in a separate bin all year long.

2. Objectives and expected items

Objectives

This Deliverable is dedicated to summarising the work about the location, handling, disposal, utilisation, quantities, and seasonality of the sawdust and OFMSW, respectively. It addresses the elimination of hurdles and bottlenecks regarding the logistics, transport modes and associated infrastructure in the targeted biomass feedstock supply, which include collection systems, intermediate storage, and safety aspects.

The ultimate goal is to provide a strategy to handle any variation in the feedstock in terms of composition and quantity.

Expected impact

The results of this report will guide the decision making of stakeholders willing to implement LUCRA developments or any other process using the waste streams under study in this project.

3. Methodology

Section 4 and 5 follow a similar structure. From Generation to Utilisation, Forest Industry Residues and OFMSW are described using mostly secondary sources of the likes of UN, OECD and EU. After conducting a literature review, it has been concluded that data on the production of these residues is not easily available in many countries, nor is it consistently gathered. Therefore, this report has referred principally to data from EU Member States (MS), where sawdust and OFMSW have been monitored recently using comparable units of measurement.

The information contained in this report is to a certain extent based on direct knowledge from the industrial partner within LUCRA, since both, MONTI and FCC MA have been working for years with these residues.

The Case Study on Section 5 (about OFMSW) includes the findings of a field investigation on the different organic flows received at the Anaerobic Digestion (AD) Plant, operated by FCC Medio Ambiente in Madrid. Municipal biowaste samples were collected and characterised in different periods of the year (fall, winter, spring, and summer).

4. Forest industry residues

The Global Forest industry generates millions of tons of wood residues every year as a by-product of harvesting and sawmilling operations. Harvest residues consist of stumps, bark, crown material and tree heads and butts. They are typically left in forests to maintain forest and soil health for subsequent plantings. Sawmill residues are either used onsite or sold to downstream processors or markets (Lock P. & Whittle L., 2018).

The efficient use of harvest and sawmill residues can reduce disposal costs and create additional revenue streams, contributing to competitiveness and sustainability of the forest and wood processing industry (Lock P. & Whittle L., 2018).

Harvest residues production depends on forest type (hardwood native, hardwood plantation and softwood) and grade (high and low quality). The production and use of sawmill residues depend on broad species (hardwood/softwood), residue type (solid offcuts, sawdust, shavings and bark) and mill size. End uses include conventional wood products (such as export grade woodchips, wood pulp and wood-based panels) and alternative uses such as wood-based fuels (wood pellets, bioethanol and briquettes) and burning for heat or electricity (Lock P. & Whittle L., 2018).

4.1. Sawmill residues

Sawmill residues, including chips, sawdust and bark, are valuable byproducts of the sawmilling, plywood manufacturing and wood processing industry. The characteristics, utilization, and availability of these residues can vary by region and depend on the specific operations of the sawmill.

The aim of sawmilling operations is to maximize production value yield and volume yield, the latter reported in m3. When calculating the volume yield, the volume of the wood obtained from the logs is compared to the total volume of the original log.

Yield means the ratio of the amount of raw wood used to the amount of lumber produced. As a rule of thumb, the Nordic sawmill industry uses a ratio of 2. This means that 2 m3 of logs are needed for 1 m3 of lumber. When sawing is optimized based on production value yield, the value produced by by-products such as wood chips and sawdust can be taken into account.

A Nordic softwood log typically produces (Thiffault et al, 2018):

- 45-50% sawn wood
- 28-32% chips
- 10-15% sawdust
- 10-12% bark

4.2. Forest industry by-products and wood residues

4.2.1. Globally

Sawmill residues, including sawdust, are produced in regions with active wood processing industries (**Figure 1** and **Figure 2**). These are often located in forested areas, where timber harvesting and processing are prevalent.

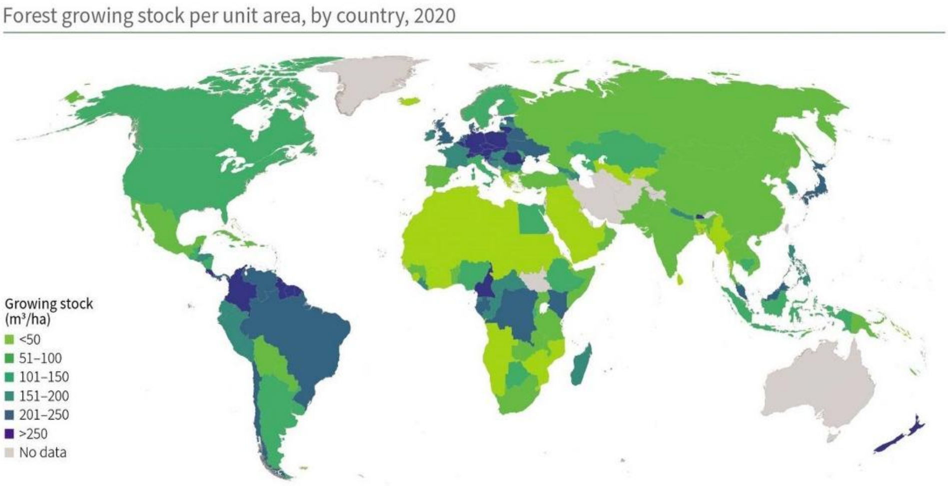

Figure 1. Forest growing stock per unit area, by country 2020. Adapted from UN World map. Source: Global Forest Resources Assessment 2020.

Sawnwood is a product derived from the simple process of sawing lengthways and the associated processes of hewing and profile chipping. Wood chips and particles include intermediate products that may be manufactured from a number of sources and have a great variety of uses. Wood residues consist of wood that has passed through some form of processing, but which also constitutes the raw material of a further processing.

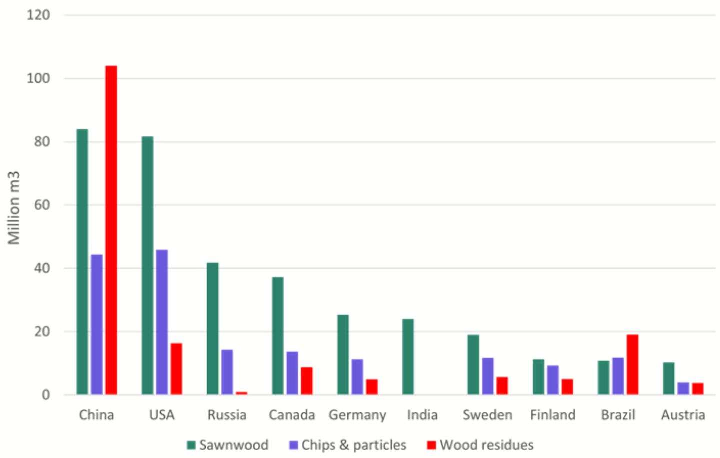

Figure 2. Top10 producers Globally 2022. Source: FAOSTAT (2025)

4.2.2. Europe

In 2022, the Nordic countries produced 33.0 million m3 of softwood sawnwood (**Figure 3**). This can be compared with an average of 31.7 million m3 annually for the past ten years. The production in Sweden reached 18.9 million m3, accounting for 57% of the total volume in the region, followed by Finland (34%), Norway (8%), and Denmark (1%). The shares have been practically unchanged over the past decade (Hannerz & Ekström, 2023)

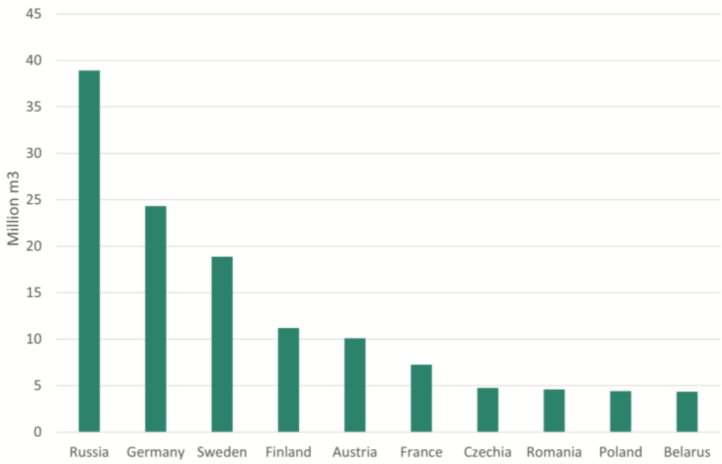

Figure 3. Top10 Sawnwood producers in European continent 2022, Total 155 million m3, Source: FAOSTAT (2025)

In 2022, sawmills in Finland produced 4.6 million dry-matter tons of sawn goods of which 2.6 million tons of pine sawn wood and 1.9 million tons of spruce sawn wood. In total, the Finish sawmilling industry produced approx. 6 million dry-matter tons of by-products and wood residues.

4.3. Residues handling

Sawmill residues are typically collected and stored on-site at sawmills. As shown in **Figure 4**, their handling involves the collection of sawdust, wood chips, and other byproducts from the sawing and milling processes. This material may be stored in bins, silos, or piles until it can be transported or processed further.

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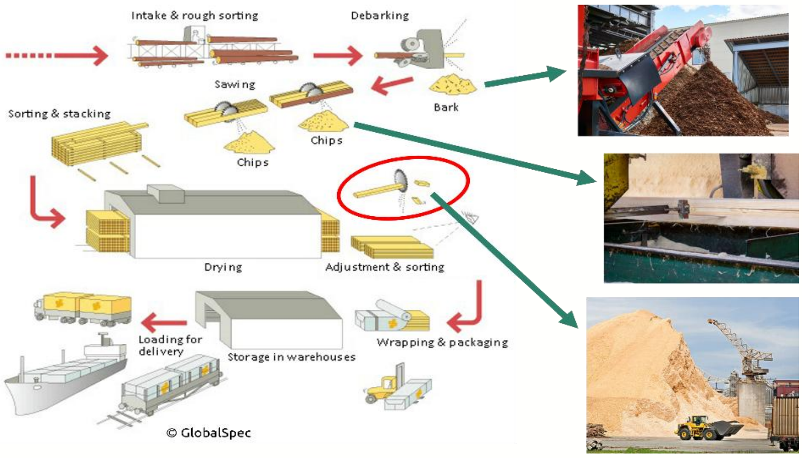


Figure 4. Residues flow at the sawmill. Source: Adapted from Swedish Wood (2020)

4.4. Residues utilisation

Sawmill residues are rarely disposed of as waste. Instead, they are usually utilized in various ways (**Figure 5**). In some cases, excess residues may be sold or given away to other industries, such as paper mills or wood pellet manufacturers, rather than being disposed of in a landfill. This can be observed in **Annex 1. Sankey Diagram of Woody Biomass Flows in the EU**, that visualizes how by-products from the Sawmill industry are destined for Energy and, to a lesser extent, for Panel and Paper Industries.

As represented in **Annex 1**, the majority of sawmill residues are commonly used in the production of wood pellets for heating and energy generation. These residues can also serve to make composite wood products like particleboard and fibreboard. Besides, sawdust and other small wood particles are utilized in landscaping and agriculture as mulch, and in livestock and poultry farming as bedding material. Furthermore, sawdust can be composted to create organic matter for gardening and agriculture.

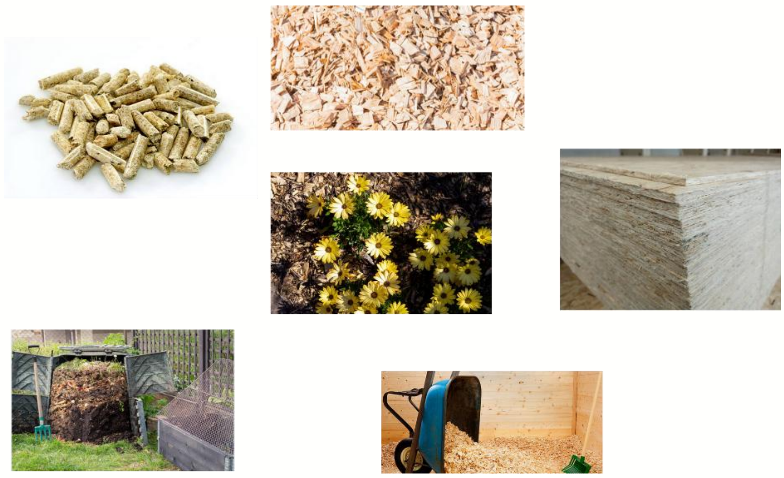


Figure 5. Most common applications of sawmill residues. Source: Author's own work using copyright free pictures.

In addition to the above mentioned, there are various emerging technologies such as bio-oils, chemicals, agri-char and food flavouring.

4.5. Quantities and seasonality

The quantities of sawmill residues can vary depending on the size and output of the sawmill, the species of wood being processed, and regional factors.
Seasonality may also be influenced by factors like the availability of raw wood materials, which can be affected by weather conditions. As it appears in **Figure 6**, during the period 2015-2024, sawn softwood production in Finland was typically stable across the seasons, driven mainly by the demand (housing and construction).

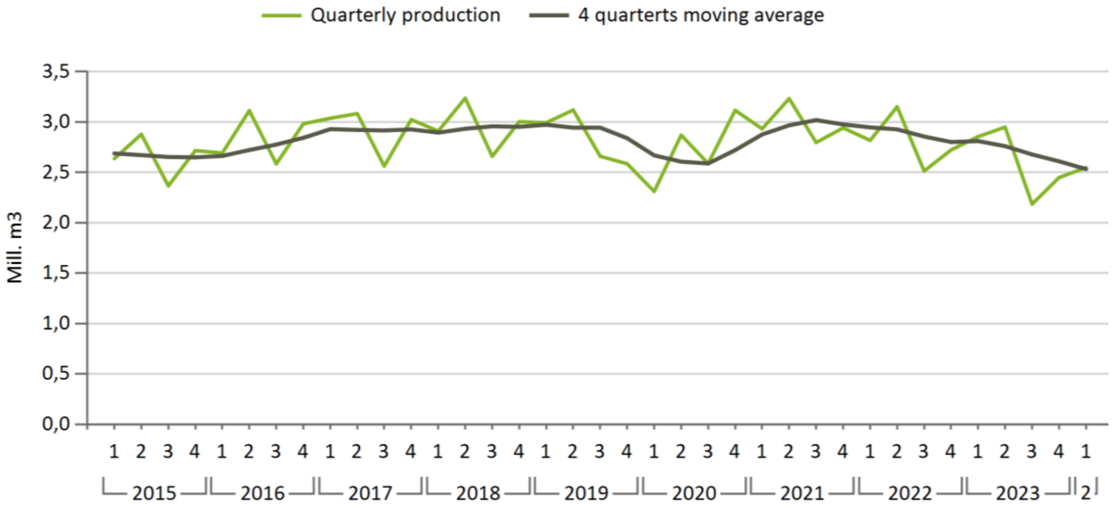


Figure 6.Sawn softwood production quarterly, Finland 2015-2024. Source: Finnish Forest Industries (2023)

4.6. Managing sawmill residues efficiently

Capturing and efficiently managing sawmill residues as biomass feedstock can present various hurdles and bottlenecks related to logistics, transport modes, and associated infrastructure. Solutions addressing these challenges are crucial for maximizing the utilization of these valuable resources. MONTI, as an important player in the valorisation of sawdust, have provided their insight in this respect in **Table 1**.

Eliminating these hurdles and bottlenecks requires a combination of investments, infrastructure improvement, technology adoption, and adherence to safety and environmental regulations. Collaboration among sawmills, transportation companies, and end-users is essential to create efficient and sustainable supply chains for sawmill residues as biomass feedstock. Additionally, continuous monitoring and adaptation to changing conditions and technologies are essential for long-term success.

Table 1. Hurdles and solutions of managing sawmill residues

	Hurdles	Solutions
Collection systems	• Inefficient or inadequate collection systems can result in the loss of valuable residues. • Collection might be inconsistent, and there could be challenges in handling fine materials like sawdust.	• Implement well-designed collection systems that incorporate efficient dust extraction equipment to capture sawdust and other fine particles. • Train personnel on proper collection techniques. • Regular maintenance and calibration of collection equipment to ensure optimal performance.
Intermediate storage	• Insufficient storage capacity can lead to bottlenecks, especially if there are fluctuations in the demand for residues. • Storage facilities must also protect the material from weather and fire hazards.	• Invest in additional storage facilities or expand existing ones to accommodate varying quantities of residues. • Utilize weather-resistant covers or enclosed storage systems to protect the material. • Implement fire prevention and safety measures such as fire-resistant materials, firebreaks, and fire extinguishing systems.
Transport modes	• Choosing the right transport mode (trucks, rail, or bulk carriers) can be challenging. • Different modes have various capacity and cost considerations.	• Optimize the choice of transport mode based on the quantity of residues, distance to the end-users, and cost considerations. • Develop efficient loading and unloading procedures to minimize transportation time and costs.
Associated infrastructures	• Inadequate infrastructure, such as loading and unloading facilities, can cause delays and additional costs.	• Upgrade infrastructure at sawmills and end-user facilities to ensure efficient loading and unloading. • Ensure that infrastructure is designed to handle the specific characteristics of sawmill residues, including dust control measures.
Safety aspects	• Safety concerns related to handling sawmill residues include dust explosions, fire hazards, and potential health risks for workers	• Implement strict safety protocols and procedures for handling, storing, and transporting sawmill residues. • Provide appropriate personal protective equipment for workers. • Install dust control and fire prevention systems in key areas.

	Hurdles	Solutions
Regulatory and compliance issues	• Regulations related to the transportation and handling of biomass feedstock, particularly if it is considered hazardous material, can add complexity and compliance costs.	• Stay informed about relevant regulations and ensure compliance with safety, environmental, and transportation requirements. • Work closely with regulatory authorities to address compliance challenges.
Market and demand fluctuations	• Market demand for sawmill residues as biomass feedstock can fluctuate, leading to supply chain challenges.	• Diversify the use of sawmill residues to reduce reliance on a single market. • Establish long-term contracts with reliable end-users to stabilize demand.

4.7. Renewable energy

Biofuels and waste consist of harvesting residues, residuals from forest industry (sawdust), pellets and fuelwood. Black liquor is a waste stream from pulp mills, mostly used by the forest industry itself. **Figure 7** shows how, in recent years, the role of bioenergy has increased at the expense of oil and coal. Wood fuels are Finland's most significant single energy source with a 28 per cent share of total energy consumption (Luke, 2023)

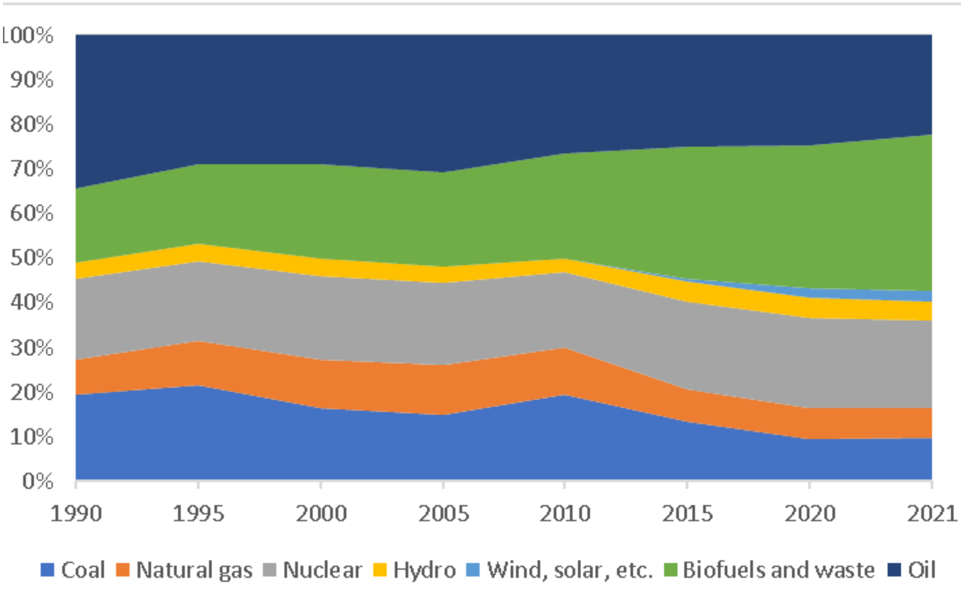


Figure 7. Total energy supply (TES) by source, Finland 1990-2021. Source: IEA (2022)

Renewable energy consumption is higher than the consumption of fossil fuels and peat combined in Finland. The country's target for the share of renewable energy was 38% of final energy consumption in 2020, and this share was reached for the first time as early as 2014. The Finnish Government has set an ambitious goal for 2030: the share of renewable energy in the final consumption should be increased to 50% (Invest in Finland, 2019). This phenomenon has impact on forest industry residuals prices.

4.8. Prices

Renewable energy targets and demand for fuel feedstock have impacted on forest industry residuals prices.

The war in Ukraine significantly changed wood trade in the Baltic Sea region and the flows of foreign wood into Finland. Previously, Russia was the most important source of foreign wood for Finland, but imports from Russia ended in spring 2022 (Simola, 2024). As a consequence, sawdust prices were impacted and began to rise. This is obvious in the chart of **Figure 8** below:

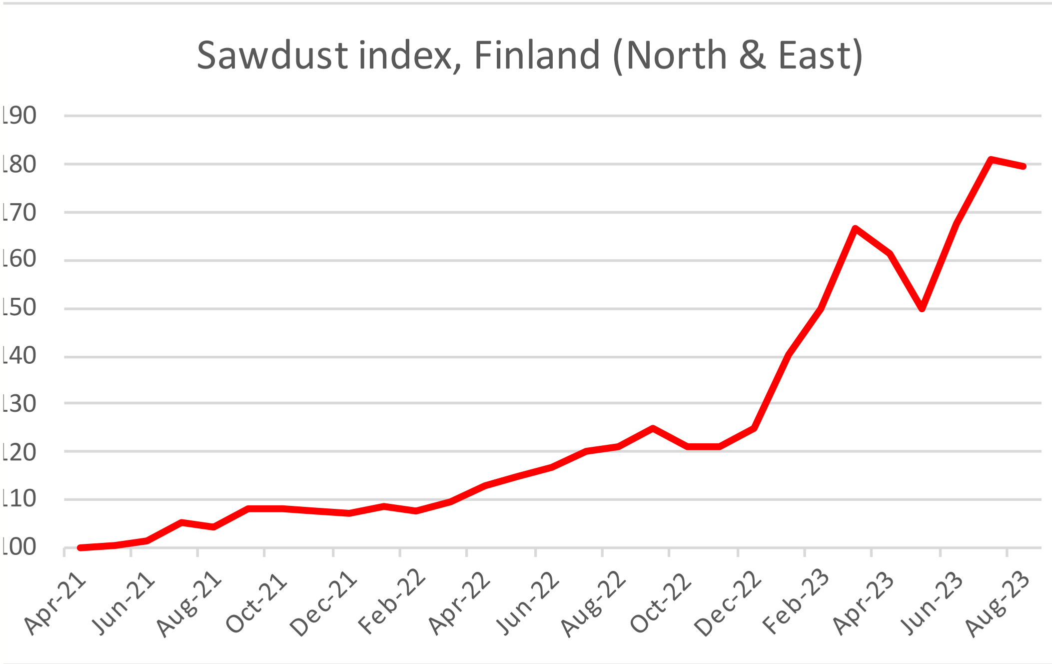


Figure 8. Sawdust price index, Finland N&E, April 2021- August 2023 April 2021=100, Source: PIX Forest Biomass Index (2023)

In Austria, sawmill waste prices have usually been dropping between the first and the second quarter. Recently, however, similar to Finland, Austria saw strong price increases (**Figure 9**) for both sawdust and wood chips at the beginning of 2022 (Ebner, 2023). There are no signs that sawdust demand will decrease. Pellet boiler sales have been on record levels in Germany and Austria lately. As a result, pellets production will be boosted even more.

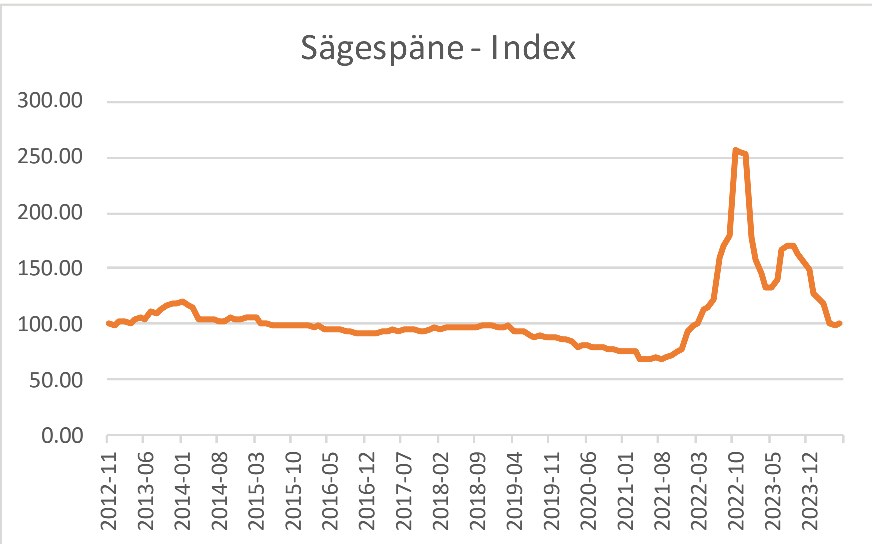


Figure 9. Sägespäne Index, Austria 2012-2023, 2012=0. Source: Fachverband der Holzindustri (2023)

5. Organic fraction of Municipal Solid Waste (MSW)

5.1. Municipal Solid Waste

Many types of wastes are generated by the sectors of industry: agricultural, industrial, construction, healthcare, for example. The focus of this section is municipal waste, from households, commercial businesses and public services. Although this is a small part of the environmental problem, compared to the number of waste tonnes that are produced annually by non-municipal sources (only 10% of total waste generated according to Waste Statistics Regulation - Eurostat 2024), MSW is a hot topic because of its scattered production, complexity and continuous growth linked to consumption patterns.

Unlike forest residues which are found only in specific areas of the world, MSW is ubiquitous, and it appears wherever there is a human settlement. **Figure 10** shows that North America region holds the record in MSW generation per capita, while East and Southeast Asia is the region with highest total MSW generation.

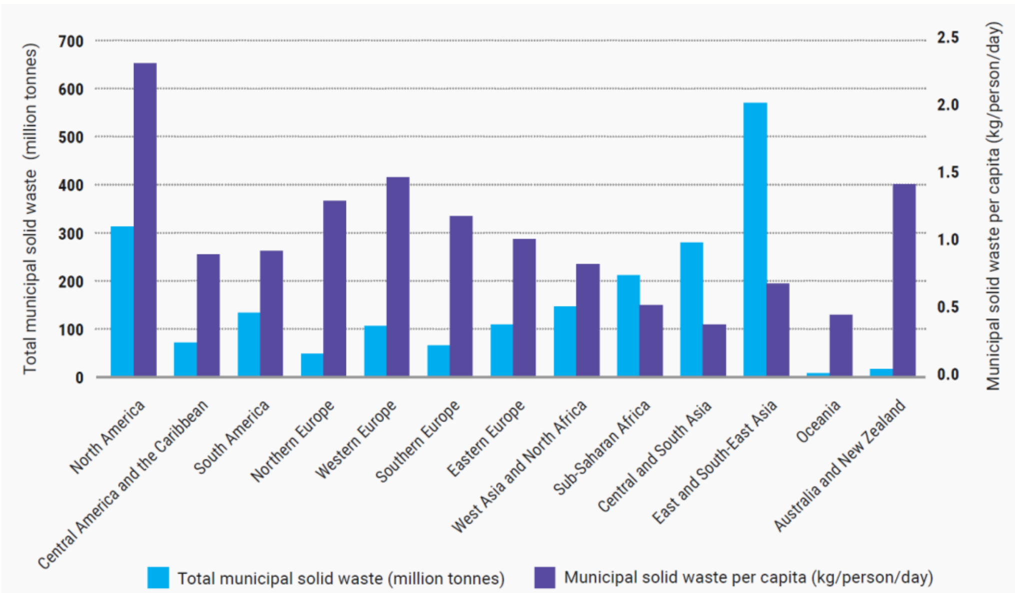


Figure 10. Municipal solid waste (MSW) generation by region: Total MSW (million tonnes) and MSW per capital (kg/person/day). Source: UNEP Global Waste Management Outlook 2024.

Municipal solid waste can be very heterogenous, containing from packaging to food waste, including personal hygiene products, clothing and footwear, broken furniture and electronic devices, as well as other domestic items.

In fact, the increased presence of certain materials is becoming an issue, in particular:

- Hazardous chemical waste
- Electrical and electronic waste (e-waste)
- Textiles
- Plastics
- Food waste
- End-of-life vehicles and waste from mechanics' garages

These are often difficult to manage (either collecting and/or treating) in compliance with health and environment standards (UNEP, 2024)

5.2. OFMSW/Bio-waste

- The definition of the organic fraction of municipal solid waste (OFMSW), referred to as "bio-waste" in the Waste Framework Directive (EU, 2008 and 2018a): includes biodegradable garden and park waste (green waste), food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants (food waste).
- Excludes forestry or agricultural residues, manure, sewage sludge or other biodegradable waste such as natural textiles, paper, processed wood or the output of mechanical biological treatment MBT plants.

Roughly speaking, bio-waste is the sum of two biodegradable fractions, green waste and food waste. According to a report of the European Environment Agency (EEA, 2020), in 2017, food waste accounted for 60% of the total EU-28 municipal bio-waste, garden waste for 35% and the rest (5%) was categorised as "Other bio-wastes".

In the same line, food waste accounted for sixty-six tonnes out of the 100 million tons of municipal organic waste found in USA (U.S FDA, 2023).

5.2.1. Globally

Bio-waste can be considered the most important fraction of MSW, as it is usually the largest fraction at planetary level. However, there is a clear difference in biowaste generation/MSW composition across the world depending on economic level of the country. Normally, the countries classified as "high-income countries" (> $14,005 in 2023) have lower percentages of organic waste (around 30%).

- In U.S ($80300), for example, more than one third (34%), it is 98 million tonnes out of 292, of municipal waste was organic in 2018 (EPA, 2020). Where around 63 million tonnes were food waste and 35 million tonnes yard and other tree trimmings (EPA, 2020).
- In the European Union ($40329), organic waste constituted 34% of municipal waste in 2017. Then, 86 million tonnes out of the 249 million tonnes of MSW generated in EU-28 Member States (including UK) were bio-waste (EEA, 2020).
- In China ($13400), a report from 2019 (World Bank Group), recorded that over the past few approximately 60% of MSW was food waste, although composition varies across regions.
- In India ($2540), the proportion of organic waste is at around 50% of MSW (GIZ GmbH, 2024). As well as in Nigeria ($1930), with some cities being as high as 80 % (Zimhelt et al., 2023).

Food waste

The fact that food waste is the most common material found in municipal organic waste, cannot be overlooked and efforts to reduce and prevent its generation should be made worldwide.
For that purpose, the United Nations Environment Programme (UNEP) has developed the Food Waste Index to track the global and national generation of food (edible and inedible) wasted at the retail and consumer - household and food service – levels (UNEP, 2024). Estimates of the average and daily

household food waste generated per capita in each region have been drawn from local studies (**Figure 11**)

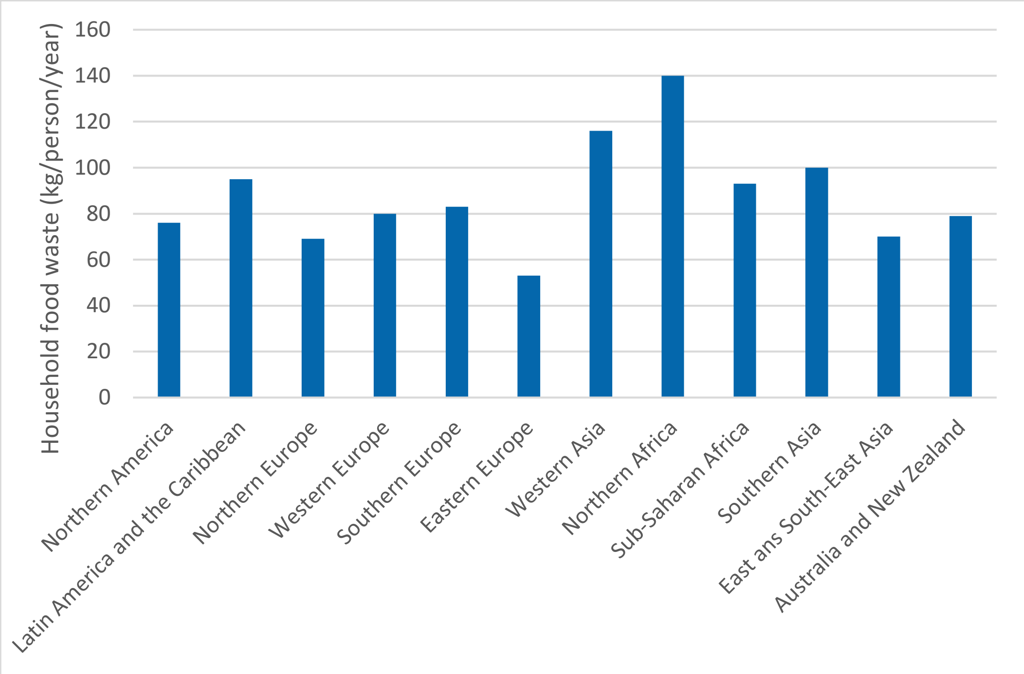


Figure 11. Average household waste in each reach region. Source: Food Waste Index Report. UNEP (2024).

Having said that, the food waste that is un-avoidable (mostly inedible parts) needs to be managed efficiently (see **Section 5.6**)

5.2.2. Europe

Figure 12 is included as a summary of what was described in previous sections regarding the municipal biowaste management in Europe.

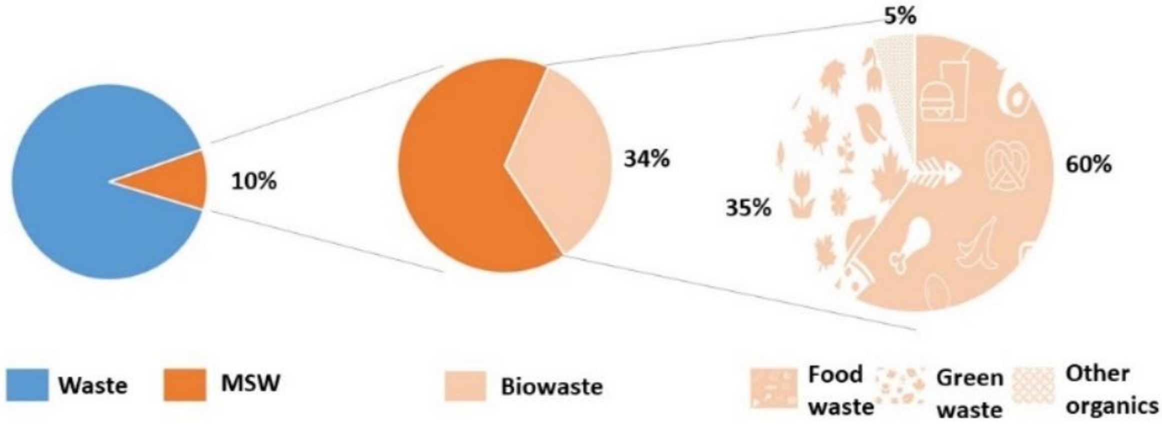
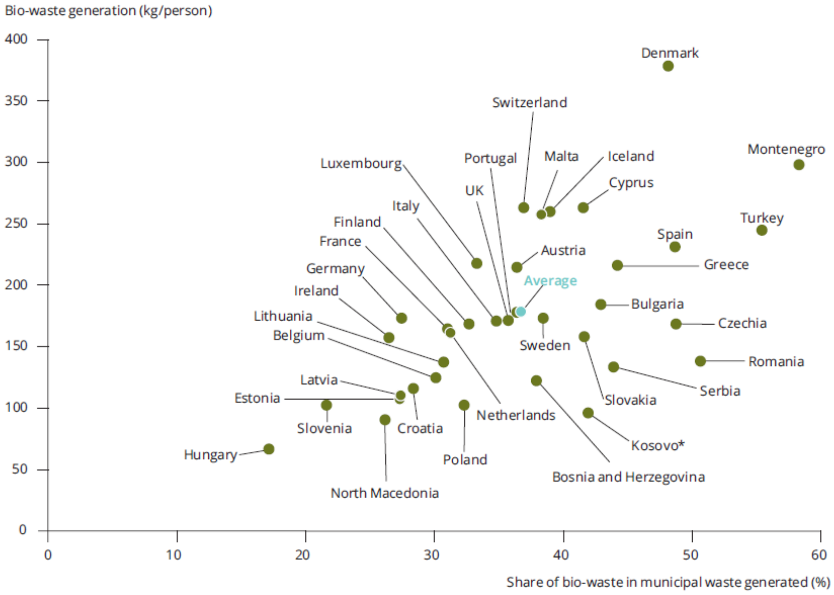


Figure 12. Shares of biowaste in Europe

With regard to the reality of the countries in the continent, **Figure 13** provides a snapshot of the bio-waste generated in 2017.

Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium
Co-funded by the European Union
UK Research and Innovation



Notes: *Kosovo under UN Security Council Resolution 1244/99. UK, United Kingdom. Excluding Albania, Liechtenstein and Norway due to lack of data. Bio-waste that is composted at home is not included in the data. The average is the weighted average of the 36 countries included in this figure.

Source: ETC/WMGE elaboration based on data provided by Eionet through an EEA-ETC/WMGE survey (ETC/WMGE, 2019a), Eurostat (2020) and the European Reference Model on Municipal Waste (ETC/WMGE, 2019b) for Belgium, Bulgaria, Croatia, Cyprus, Czechia, Estonia, Germany, Greece, Italy, Lithuania, Luxembourg, Malta, Poland, Spain and the United Kingdom.

Figure 13. Municipal bio-waste generation per person and share of bio-waste in municipal waste generated by country, 2017. Source: EEA (2020)

Then, the average European country, obtained as a weighted average of the 36 countries included in **Figure 13,** produced 175kg/person. Hungary was the European country that generated less bio-waste (around 60 kg/person) and Denmark the one generating the most (almost 400kg/person). The country with largest share of bio-waste in municipal waste is Montenegro (nearly 60% of MSW).

5.3. Biowaste handling

5.3.1. Generation

After years of requests from environmental organisations, Members of the European Parliament have finally voted and approved in March 2024 to raise legally-binding targets to reduce 20% food waste from processing and manufacturing sectors, and 40% in per capita food waste in retail, restaurants, and households by 2030.

Although ambitious, reaching a 40% reduction in municipal food waste can be feasible. According to the Prevent Waste Coalition (2024) “changes in retailer and producer policies such as offering smaller portion sizes and packages and communicating more clearly about food preservation and best-before dates on packaging”. Giving the importance of food waste within biowaste, this target might have a significant impact (up to a 24% reduction) in biowaste generation.

5.3.2. Collection

In 2017, an average of 43% of municipal bio-waste was collected separately in EU-28, whereas 57% was mixed with other municipal waste, making it unavailable for recycling. (EEA, 2020)

Starting January 2024, bio-waste in the European Union must either be separated and recycled at source or collected separately and not mixed with other types of waste, according to the obligation set by the Article 22 of the Waste Framework Directive (Zero Waste Europe, 2024).

Despite that mandate, the roll out of separate bio-waste collection is still partial, with different levels of implementation across EU regions. A publication of the (EEA, 2024) classifies EU 27 Member States in terms of the coverage and convenience of their bio-waste separate collection. The results of that classification are found in **Table 2**.

Table 2. Coverage of the population with high-convenience collection

Number of Member States

0 3 6 9 12 15 18 21 24 27

High		Medium		Low, not applied, or no information			
1 Germany 2 Austria 3 Slovenia 4 Netherlands	5 Luxembourg 6 Poland 7 Sweeden 8 Malta	1 Italy 2 Belgium 3 Denmark	4 Finland 5 Iceland 6 Latvia	1 Slovakia 2 Lithuania 3 France	4 Czechia 5 Spain 6 Bulgaria	7 Hungary 8 Croatia 9 Estonia	10 Portugal 11 Greece 12 Cyprus 13 Romania

Accordingly, there is large variation in the amount of separately collected bio-waste treated per person living in each country as illustrated by **Figure 14**. These records, ranging from a minimum of 28kg/capita/annum (Czech Republic) to a maximum of 328kg/capita/annum (Flanders-Belgium), account for municipal and industrial food waste.

Figure 14. Separately collected bio-waste per capita in selected countries grouped in quartiles (kg/capita/annum) Source: ECN (2022)

Another report of Zero Waste Europe (Favoino & Giavini, 2020) estimates that the EU-27 current bio-waste capture is only a percentage (34%) of the theoretical potential capture of bio-waste, highlighting that bio-waste currently disposed as mixed waste, can actually still be recovered.

5.3.3. Treatment

Landfilling is banned

Following the Waste Framework (EU, 2008 and 2018a) and Landfill (EU, 1999 and 2018b) Directives, landfilling bio-waste is banned. The environmental impact of this practice is very negative, as waste decomposition, especially in open landfills, emits methane a gas with high global warming potential (x20 times higher than carbon dioxide).

Hence, in those locations where bio-waste is not collected separately, any residual waste that is going to landfill (or EfW facilities) needs to undergo a pretreatment to recover recyclables and bio-waste. This is usually done at mechanical biological treatment (MBT) plants. The output of this process, similar to compost and known as "biostabilised", will no longer count towards meeting the recycling targets for municipal waste by 2027 (EEA, 2020).

Circular treatment routes: Composting and Anaerobic Digestion.

Other than landfilling or MBT, treatment of separately collected bio-waste is dominated by composting, but anaerobic digestion (AD), with biogas production, is increasing (EEA 2020). Composting and AD have been promoted from a circular economy perspective and may be classified as recycling when the compost or digestate produced is used as a recycled product, material or substance, that is beneficial to agriculture or ecological improvement" (EU, 2008 and 2018a).

A total of 38 million tonnes per annum of bio-waste was found to have been composted and anaerobically digested in the EU27, with 70% sent for composting and 30% sent for AD (ECN, 2022).

The preference of municipal bio-waste composting over AD is explained by diverse reasons: it is simpler, less expensive, avoids the risks of methane management, yields an end product ready to be sold and has been historically favoured by regulations and institutions like the European Compost Network.

However, the trend is shifting from "mono"-treatment towards integration of AD and composting, as it has been proven to be the best available technology option for bio-waste (Interreg Europe, 2021). This is normal practice in countries like Italy and Spain, where AD is always followed by a composting process (ECN, 2019).

Often digestate is not fit for application in fields. Its high levels of ammonium-N, soluble salts and easily degradable organic compounds can be phytotoxic (Cucina, 2023). Composting it allows for organic matter stabilisation and maturation, leading to a digestate with maximised agronomic properties and minimised release of ammonia and nitrates (EU Taxonomy Navigator, 2024).

An array of technical developments has emerged for the recovery of certain components found in intermediate AD fermentation stages and/or in the digestate, mainly hydrogen volatile fatty acids, and nutrients like phosphorous and ammonia (EEA, 2020)

Beyond AD and composting, there are other emerging technologies giving a second life to bio-waste resources. To name a few: bioconversion (using insects to produce animal feed), pyrolysis, gasification, hydrothermal carbonisation, alcoholic fermentation (for ethanol production) … Most of these are still in pilot/demo scale and have not passed the commissioning stage to be proven at large capacity yet (EEA, 2020)

5.4. Biowaste utilisation

Established routes of biowaste recycling (AD and composting) yield low-value products such as digestate, biogas and compost. Innovative processes, like those developed in LUCRA project, increase the valorisation ratio of the OFMSW (through pretreatment operations like hydrolysis) and give rise to higher value bio products, some of them shown in **Figure 15**.

Figure 15. Established and new products from OFMSW

The quality of bio-waste recycling products is highly affected by the level of contamination of the organic waste. The most obvious example is how impurities such as glass, metal and plastic will decrease the value of soil conditioners and compost. It is known that plastic contamination ranges from as little as 2% to as much as 15% in various regions around the EU (ECBPI, 2022).

When waste producers throw non-organic materials (either recyclable or not) in the "organics" bin, contamination occurs. Despite operations to remove these unwanted materials in the pretreatment of organic waste, its complete removal is nearly impossible, especially when the contaminants are broken down in smaller pieces.

5.5. Quantities and seasonality

Seasonality not only referred to the seasons, meteorological or astronomic, but also to the predictable variation in a time series lasting less than or equal to one year (ANEPMA, 2020). For example, events like school and university holidays (usually coincides with summer in the North Hemisphere), tourist seasons in coastal or inland areas, annual festivals, …

The impact of seasonality on OFMSW production and composition has been studied across a number of studies. Their scope is quite local though, probably because of the labour intensive and time-consuming procedures this type of research requires (Hanc et al.)

It is agreed that seasonality is more evident in the green share of OFMSW and variations in food waste are rarer (Thanh et al., 2010). The quantities and composition of green waste are remarkedly different from spring and summer (flowers, grass, clippings, hedge cuttings and soil) to autumn (leaves) winter (wood) (Boldrin & Christensen, 2010).

There seems to be similarities in the bio-waste production patterns around the world. In countries as distinct as Lithuania and Korea, the time with highest garden waste is normally autumn (Kang et al., 2020)

Food waste arising in municipalities of India (Pervez et al, 2021) and Pakistan (Kamran et al. , 2015) is lower in winter (or “low temperature season”). Same as in Chihuahua, Mexico, where researchers Gómez et al. (2009) believed it is due to a decrease in the consumption of drinks and fresh foods and vegetables.

5.6. Handling OFMSW efficiently

When it comes to analysing the hurdles and bottlenecks of OFMSW logistics, transport modes and associated infrastructure (**Table 3**), the first step is to assess the status of waste management at local level. There are difference priorities depending on the level of implementation of OFMSW separate collection and treatment:

- In those municipalities where these two components are not available or in their infancy, an integrated strategy must be designed appraising best practice options (LIFE BIOFEST, 2024).
- Where bio-waste collection and treatment have been in place for years, optimisation is mostly about data monitoring to track performance and evolution, as well as the introduction of innovative solutions, ranging from dynamic route planning to smart sorting technologies.

According to the 2nd Early Warning Report (2023) on the implementation of EU waste legislation in Member States (MS), "focus should be given to introducing or expanding effective capacity for the separate collection and treatment of biowaste", which highlights there is still a lot of work, with 18 out of 27 MS at risk of missing the target of 55% preparing for re-use and recycling of municipal waste and 65% recycling of all packaging waste to be achieved by 2025 (European Commission, 2023).

Nonetheless, the greatest obstacle in valorising the OFMSW, is none of the ones listed in **Table 3**, but at the very beginning of the value chain: the lacking biowaste sorting made at source (households and businesses). Contamination of biowaste with non-biodegradable materials force waste treatment facilities to implement additional steps to sort and remove contaminants, increasing processing costs. Despite their efforts to clean biowaste, some contaminants will remain, damaging waste processing equipment as well as reducing the overall process efficiency and the quality of the final products.

Some of the most effective actions that can be addressed to citizens in order to reduce contamination levels in OFMSW are (ZWE, 2022):

- Increasing communications, public education and awareness about what is allowed in the bio-waste bin and the impact of contamination in bio-waste valorisation. Households and businesses producing waste need to be informed about proper waste disposal practices.
- Implementing efficient and individualised waste disposal models (that identifies the user and allows controls of the collected material, such as transparent waste bags, door-to-door schemes, closed bins with restricted access,...)
- Mandating the use of compostable bags within the bins for the collection of biowaste. It has been proven that the use of conventional plastic bags, attracts higher contamination of food packaging (Favoino & Giavini, 2020). The bags must be biodegradable, this means they need to comply with the European Union's EN-13432 standard that certifies compostable bags.

Table 3. Hurdles and solutions of managing OFMSW

Hurdles		Solutions
Collection systems	• Separation collection is not implemented or inconvenient • Collection frequency is low or inconsistent, may lead to disposal in the wrong bin. • Some personnel may mistake bins.	• Start with pilot districts, provide tailored system adapted to the urban and building needs. Locate bins 100 m or less from all dwellings. Promote home composting in rural areas. Offer incentives: cuddies, compostable bags, reduced fees for those producing less and/or better quality OFMSW… • The collection frequency depends on the storage possibilities and the climate conditions (lower in winter), at least twice a week. • Train cleaners and binmen on proper separation
Intermediate storage	• Storage facilities are a source of environmental burdens (leachate, odours) and attract pests (birds, rats, insects…)	• When possible, treat as soon as collection occurs, to avoid OFMSW to deteriorate and lose its methane and nutrients potential. • When having storage is ineludible, place the OFMSW in an impermeable surface that collects leachates, fully cover the piles, install air deodorization systems and pest control solutions.
Transport modes	• Different waste trucks have various capacity and cost considerations. • Conventional carburants are expensive and pollutants	• Choose trucks as large as possible, including compaction systems, to decrease journeys to the treatment plant, but allowing for sizes that fit in narrow streets. • When possible, invest in fleet powered by fuels produced in biowaste recycling plants, such as compressed natural gas (GNC), hydrogen or electricity
Associated infrastructures	• Treatment facility not available, undersized or lacking key equipment	• Ensure that infrastructure is designed to handle the specific characteristics of OFMSW, including automatic cleaning equipment and air treatment systems. • Introduce innovative sorting techniques in plants (magnets, wind shifters, sieves, NIR sensors, optical detectors, density separation, ballistic machines and other technologies such as artificial intelligence) to ensure efficient contaminants removal.
Safety aspects	• Sharp and infectious materials; high level of particulates and toxic gases at treatment areas; explosive atmospheres (specially AD plants)…	• Implement strict safety protocols and procedures for handling OFMSW. • Provide appropriate personal protective equipment for workers. • Install air treatment and fire prevention systems in key areas.

	Hurdles	Solutions
Regulatory and compliance issues	• If animal by-products are in the municipal bio-waste, processes in recycling facilities must comply with strict thermophilic requirements. • Problems with end-of-life treatment whether the final products can be classified as 'product' or 'waste'.	• Include alternative transformation parameters in EU legislation so products derived from waste containing animal by-products are accepted in EU markets. • Set harmonised end-of-waste criteria for biowaste derived products to provide a high level of environmental protection and remove unnecessary administrative burden.
Market and demand fluctuations	• No market or insufficient incentives for OFMSW recycling products. • Temporary low market demand due to low prices of fossil feedstocks.	• Implement proper incentives such as taxes for competitive products and subsidies. A stable market for outputs would defray bio-waste operational costs and incentivise the outputs' quality improvements. • Adopt a biorefinery approach so OFMSW treatment processes can derive multiple products and there is no dependence on only one market.

5.7. A case study: OFMSW in Madrid city

The EU LUCRA project studies the OFMSW generated in the capital of Spain, Madrid. The next points describe the bio-waste management in the city.

5.7.1. Generation

Madrid started the separate collection of OFMSW in October 2017, the full-scale rollout being completed on September 2020. From that date, more and more citizens segregate their organic waste at home and dispose it in the “brown-lid bin”. **Figure 16** shows the type of bins that can be found on the kerbside. In districts, like the Centre, that have narrow streets and are densely populated, wheelie bins are taken out for collection and kept inside the building block afterwards.

Two wheeled, rear loading individual bins

(140-360l capacity)

Four wheeled, rear loading communal bins

(800l capacity)

Fixed, side loading, communal bins

(2.400 – 3200l)

Figure 16. Type of brown bins

The Recycling Guidelines of the City (Ayuntamiento de Madrid, 2020) specifies the objects and materials that can go in the brown bin:

<u>*Accepted*</u> - All food waste, cooked or raw, including:

- Meat and fish – including bones and carcasses if they can fit in the bin
- Fruit and vegetables
- Bread, pasta and cereal
- Tea bags and coffee grounds – including coffee filter paper
- Small garden waste
- Egg, seafood and nuts shells
- Pet food
- Cork stopper, matches and sawdust
- Used paper kitchen towel and napkins

<u>*Non accepted*</u>:

- Plastic bags
- Food packaging – such as aluminium foil, cardboard or plastic
- Liquid food waste – including cooking oil
- Garden waste
- Cat litter, dog, cat or pet waste, dead animals
- Swipings,toilet wipes, animal waste, cat litter, nappies, sanitary towels, hair, cigarette butts

5.7.2. Collection

Brown bins are emptied daily, with quantities collected increasing every year (**Figure 17**)

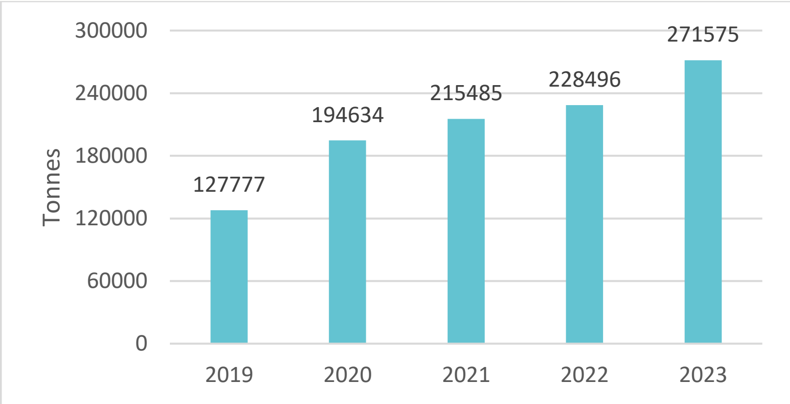


Figure 17. Tonnage of bio-waste collected yearly. Source: Ayuntamiento Madrid (2024)

Trucks, like the ones in **Figure 18**, drivers and binmen take part in the operation:

a) Binmen, equipped with personal protective equipment, approach wheelie bins to the lifting points of rear loading trucks, that then detect the bins and automatically lift them.
b) With side loading trucks everything is automated, as the vehicle can get close enough to lift the fixed bins, damp their content and drop them back to where they sit.

Rear loading truck **Side loading truck**

Figure 18. Vehicles for bio-waste collection.

5.7.3. Treatment

The Anaerobic Digestion Plant Las Dehesas (**Figure 19**) - located in Valdemingómez Technological Park (VTP), the complex where all MSW from Madrid is treated - receives nowadays 95% of the city's bio-waste.

In this facility, bio-waste undergoes an almost automated pre-treatment stage where it goes through different machines such as trommels, a bag opener and a magnet, with the purpose of separating non-organic (rejects) from organic materials. At this point, rejects are removed and taken to landfill.

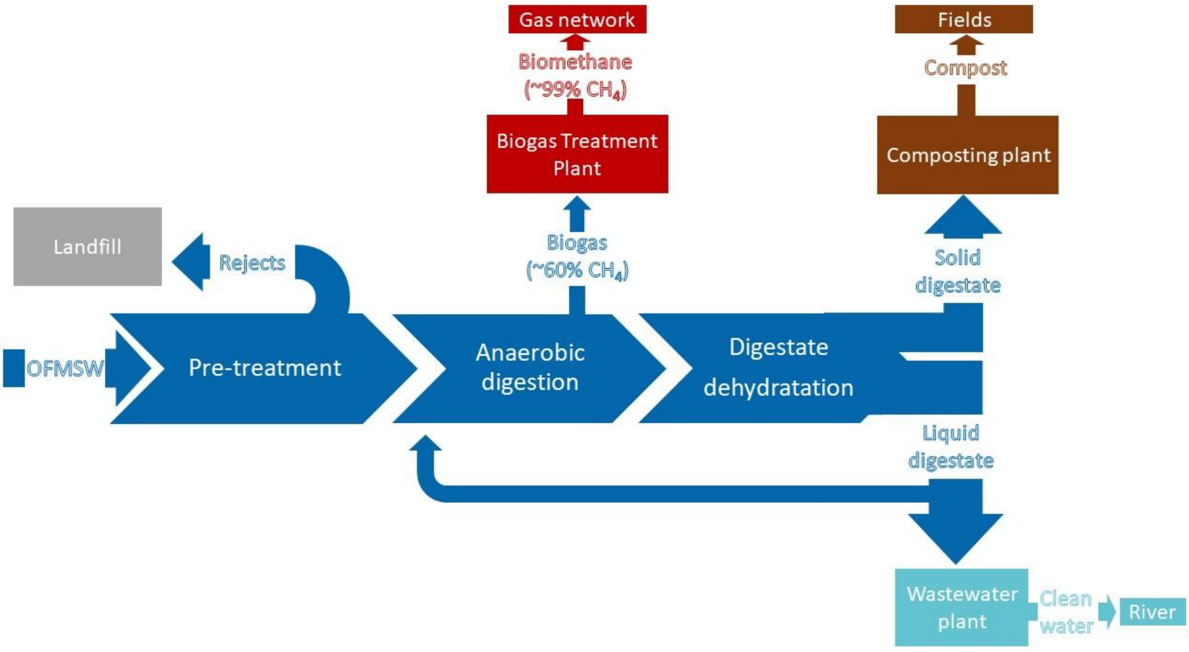


Figure 19. Process and products obtained in the Anaerobic Digestion Plant Las Dehesas

Next, pretreated waste is mixed with steam liquid recirculated from the downstream process, to become a warm and pumpable fluid ready to enter in the digesters. Once in, waste remains for approximately 21 days in a mesophilic, anaerobic, agitated, and unlighted environment, where a percentage of organic matter will be converted into a biogas (~60% methane). After this time, digested material, also known as “digestate”, leaves the digesters to be dehydrated and divided in a solid stream and liquid stream. The solid digestate is mixed with tree trimmings and sent to a Composting Plant in the VTP. The liquid digestate, rich in nutrients and contaminants, needs to be further treated in wastewater plants. The biogas generated is transferred to another plant in the VTP where it is upgraded and transformed into biomethane for injection into the national gas grid.

5.7.4. Quantities and seasonality

In the LUCRA project, OFMSW from Madrid is studied making a distinction between the main OFMSW streams arriving in the AD plant Las Dehesas:

- (1) fruit and vegetables from the wholesale market of Madrid, “Mercamadrid”;
- (2) expired food, kitchen, and post-consumer waste from supermarkets.
- (3) bio-waste from households,

Seasonal variations in tonnage input

The tonnage of each stream received in the last years is presented in **Figure 20**. It is observed how quantities have increased yearly, except for the last couple of years (2022-2023) when the material coming from Mercamadrid and Supermarkets bio-waste has decreased.

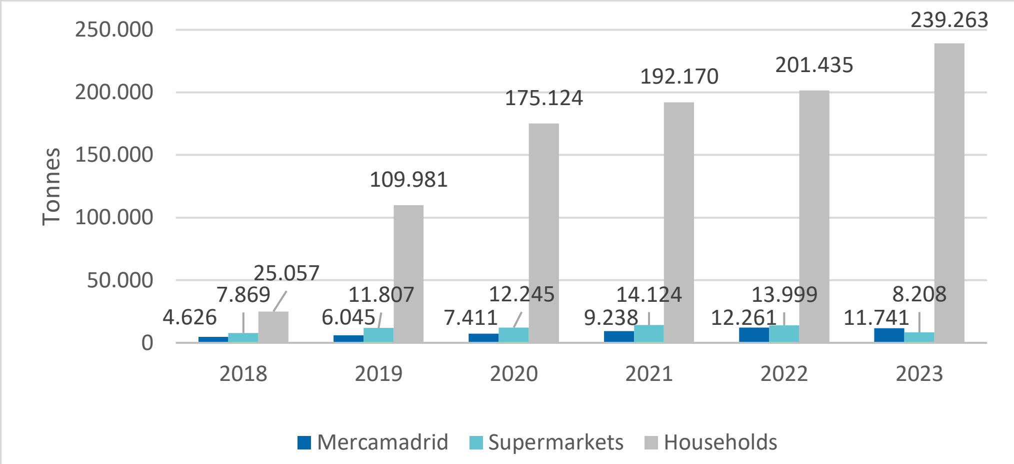


Figure 20. Tonnes of each OFMSW stream treated annually.

The figures included in **Figure 21** are obtained when the total of waste streams tonnage in the years 2018 to 2023 is aggregated per season. Autumn (22/23 September – 20/21 December) is the most "wasteful" season, followed by Spring (20 March – 20/21 June), winter (20/21 December – 20/3 March) and summer (20/21 June – 22/23 September). The highest tonnage of autumn might be explained by the increase in green waste (mainly leaves) that happens during the season. Summer is the time of the year when Madrid has less activity, as tourist and residents tend to go away from the hot temperatures recorded in the city.

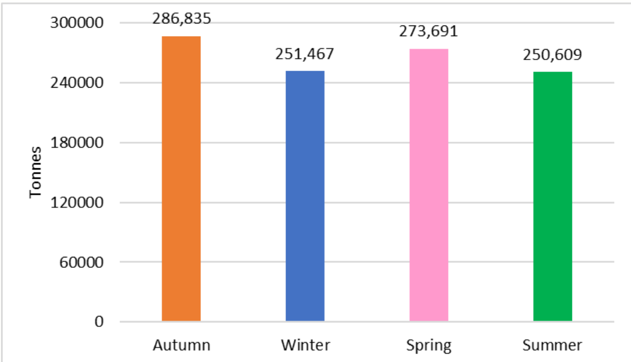


Figure 21. Total tonnes of OFMSW in the years 2018-2023

Disaggregating the above data by waste stream (**Figure 22**) reveals the patterns of each waste producer:

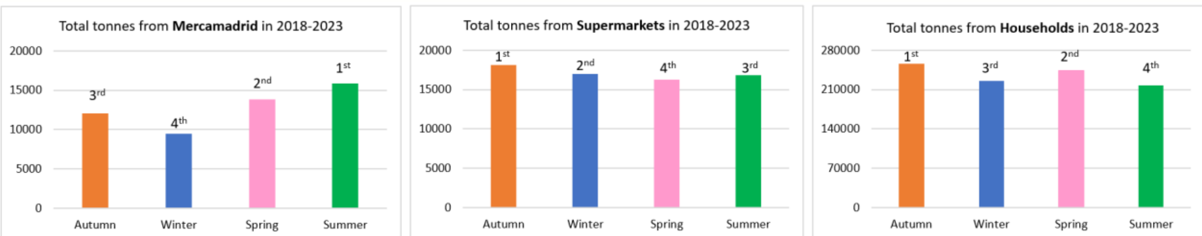


Figure 22. Total tonnes of OFMSW in the years 2018-2023 disaggregated by waste producers

It makes sense that winter is the time that less waste comes from Mercamadrid, as it is the season with lower fruits and vegetable production in the north hemisphere, and viceversa with summer, the season when nature has more, especially fruits, to offer.

Both, supermarkets and households produce most in autumn, however the season with least supermarkets food waste (spring) is the second most wasteful for household. And the same pattern applies in winter and summer: when bio-waste generated in supermarkets is higher (winter) it is lower in households. This leads to thinking that food being bought from supermarkets will be wasted at home.

Seasonal variations in composition

In the same way the amount of biowaste generated varied throughout the year, bio-waste composition may follow a seasonal behaviour. FCC MA arranged the characterisation of each bio-waste stream in all the four seasons in between July 2023 and August 2024. This was done by an external company that sampled and carried the work on site on the dates shown in **Table 4**:

Table 4. Dates of characterisation

	AUTUMN	WINTER	SPRING	SUMMER
Household	Tue. 31/10/23	Mon. 22/01/24	Wed. 17/04/24	Thu. 27/06/24
Supermarkets	Tue. 31/10/23	Mon. 22/01/24	Wed. 20/03/24	Thu. 27/06/24
Mercamadrid	Tue. 07/11/23	Mon. 22/01/24	Wed. 17/04/24	Wed. 21/08/24

The procedure was as follows (see **Figure 23**): the content of a truck bringing a certain waste stream (Mercamadrid, Supermarkets or Household) was damped aside. Then, the characterisation team sampled ca. 100 kg waste and separate the materials in 4 principal categories (OFMSW, plastic packaging, other wastes with separate collection and refuse like materials) and up to 25 subcategories (See **Annex 3**). Every category was weighed and from weight data, composition percentage were calculated.

Figure 23. Characterisation process in a nutshell

For the purpose of easy visualisation, the results are presented (Figure **24**) grouping seasonal composition in 3 categories: “organics”, “recyclables” and “refuse”.

The first and most evident result is that, for all three organic waste streams, the presence of organics is lowest in winter. The contrary applies for recyclables and refuse materials, which are at their highest value then

Mercamadrid is the cleanest waste, with the organics share in between 94-97%. Winter is the season when this is more contaminated (6% of recyclables). The presence of refuse-like-material is minimum in this type of waste throughout the whole year, oscillating between 0-1%

Regarding **Supermarkets**, it is worth highlighting that no refuse-like-material (0%) was found in summer, after a maximum of 13% in spring. Contamination levels of recyclables and refuse are in the same order in autumn and spring., In winter contamination with recyclable is almost twice the refuse share (21 against 11%)

Opposed to supermarkets bio-waste, waste from **Households**, contains generally roughly two times more recyclables than refuse-like-materials, except for spring, when the share of one and the other contaminants are virtually the same (17-18%).

The overall conclusion is that impurities are more prone to be recyclable (packaging made of plastic, paper or glass) than refuse like materials (cellulose, textile, wood, no packaging plastic and no packaging glass).

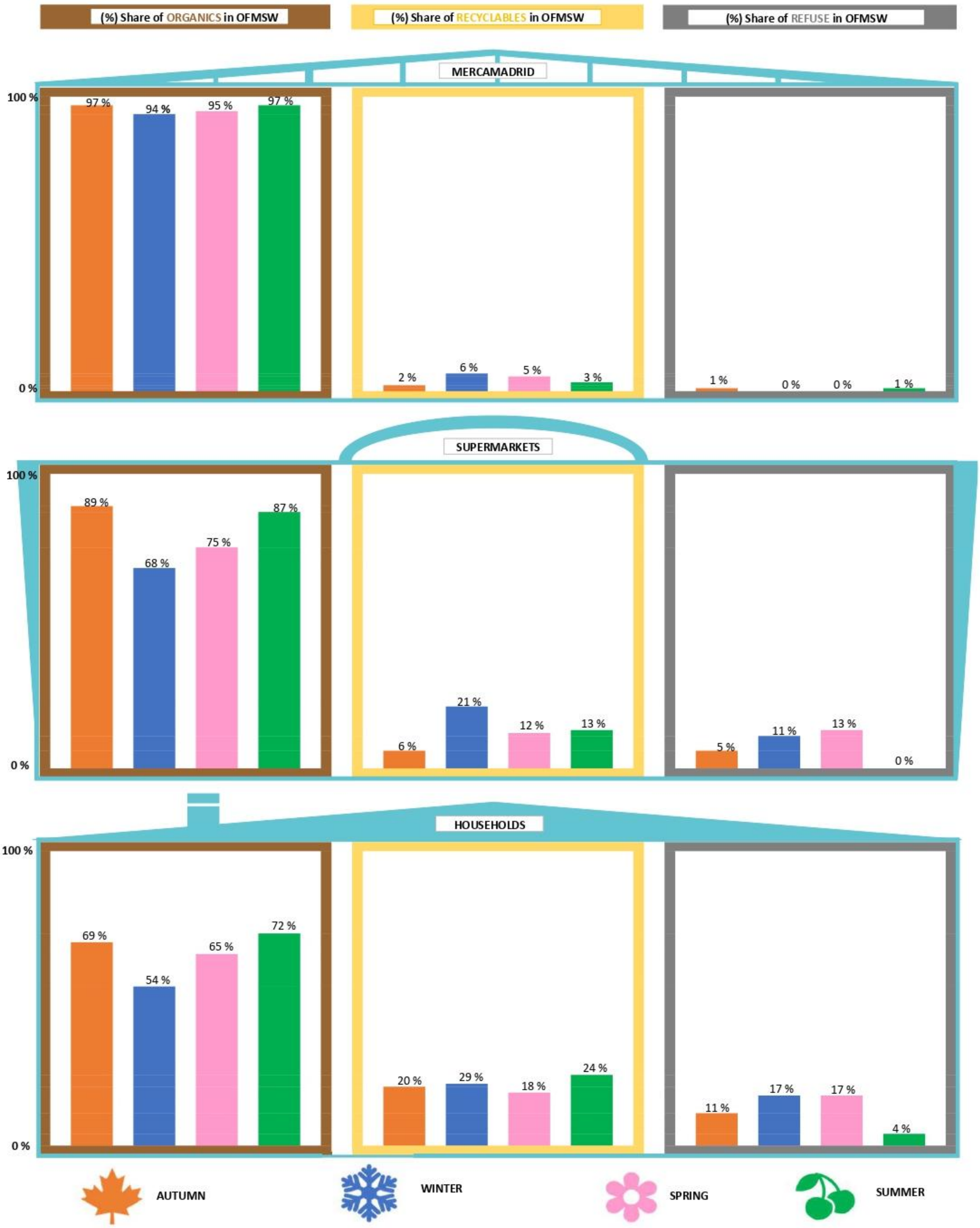


Figure 24.Results of seasonal characterisation by material category.

The seasonal variation of composition was further investigated by colleagues in AUA in another task of this LUCRA Work Package. AUA determined the biochemical composition of OFMSW, in particular, they conducted compositional analyses in every season and quantify the components included in **Table 5** for all the three waste streams:

Table 4. Components in AUA compositional analysis

INORGANIC COMPOUNDS	Moisture		Ash		
SACCHARIDES	Starch	Pectin	Glucan	Free sugars (sucrose, glucose, fructose)	Hemicellulose (Xylan, Galactan, Arabinan, Mannan)
OTHER MACROMOLECULES	Proteins		Lipids		
PLANT MOLECULES	Lignin		Total Polyphenol Content (TPC)		
MICROMOLECULES	Organic acids (lactic, acetic, citric)				

For these analyses, additional samples were collected and processed prior to be sent to AUA on the dates recorded in **Table 6**:

Table 5. Waste sample collection dates

	SUMMER	AUTUMN	WINTER	SPRING
Household	Tue. 12/09/23	Tue. 14/11/23	Tue. 12/03/24	Thu. 16/05/24
Supermarkets	Tue. 12/09/23	Tue. 14/11/23	Tue. 12/03/24	Thu. 16/05/24
Mercamadrid	Tue. 12/09/23	Tue. 14/11/23	Tue. 12/03/24	Fri. 17/05/24

Summer and Autumn samples were obtained after passing each waste flow (household, supermarket or Mercamadrid) through the pretreatment line 5 of the Biomethanisation Plant. This line includes a feeder, triage cabin, a shredder (bag opener), and a trommel screen.

In Winter and Spring samples the pretreatment consisted in passing the bags content of the different waste streams through a specialist depacker machine (**Figure 25**), which removed packaging and flexible materials from smaller chunks of biowaste.

Figure 25. Samples preparation in Winter and Spring

Whatever the type of pretreatment waste had undergone, a sample of approximately 5kg sample was taken and prepared for shipment:

- Summer samples were sent dehydrated. Freshly collected waste was placed in trays, weighed, and kept for 24h inside an oven at 105º C. Once cooled, trays were weighted again to determine their humidity.
- For the remaining seasons, samples were placed in containers and frozen in a domestic freezer for at least 12 hours (see **Figure 25**). Upon parcel preparation containers were labelled with tags and placed inside isothermal boxes to maintain the samples frozen during the shipment which usually took 24 hours, always through air freight.

The laboratory Methods that AUA followed as well as the Results of their analyses, have been presented in LUCRA's Deliverable 2.2, ***Report on the feedstock composition, variability and requirements.***

6. Discussion

This report aims at understanding the supply chain limitations of using sawdust and OFMSW as feedstocks in the LUCRA process. Although both are residual and biodegradable, the challenges of using one or the other waste stream are quite different.

On one hand, evidence suggests that sawdust production is steady, and, in spite of its natural origin, it is barely affected by seasonality. On the other hand, studies on OFMSW have shown that its generation varies throughout the year, with winter often the season accounting with lower OFMSW volumes and autumn with higher ones.

While weather and local characteristics influence the production of the two, there are unique aspects determining the available quantities of each feedstock, like sawmill size and milling output for sawdust or festivities and consumption trends for OFMSW.

In the same way, with regard to the management supply chain of each waste type, despite the fact that some elements are identical (like the benefits of implementing cutting-edge collection technologies or the presence of fire hazards,…), others are contrary, for example: sawdust is usually stored and OFMSW is not; there is a high market demand for sawmill residues which is non-existent for OFMSW.

Unlike sawdust, whose availability is closely related to fluctuations in renewable energy markets and wood trade dynamics, at the moment there is no competition for OFMSW as this a difficult stream, suffering from lots of impurities. If its quality was greater and it had no contamination, OFMSW will be subject to similar unpredictable variables. Therefore, the biggest challenge in using these feedstocks is their price. The moment this increases, LUCRA process may be unprofitable. An in-depth analysis of this issue will be carried out in WP6 "Sustainability, economic and safety assessment ".

Sawmill residues and OFMSW can be used in multiple and very diverse applications, but the most extended and established valorisation routes, which are based on relatively low-maintenance and simple processes, are those obtaining energy and agricultural products. The goal of LUCRA project and other emerging biorefinery processes is to yield higher value end user products.

After price, the next and most important aspect to consider about sawdust, is that its production is restricted to certain regions of the world. Considering that its water content is around 50% (and after undergoing delignification pretreatment, it becomes even higher, closer to 70%) transportation of sawdust for long distances may not be cost effective, nor drying it before haulage, as it is an excessively energy demanding operation. Therefore, it is advisable to locate sawdust valorisation facilities close to production areas.

In contrast to sawdust, OFMSW is guaranteed anywhere close to human settlements, however for the material to be suitable as a feedstock, current contamination levels in the stream need to be highly reduced. This cannot be achieved without strongly engaging with OFMSW producers, i.e. households and businesses, the very first link in the OFMSW supply chain. Awareness activities as well as incentives for them to separate biowaste correctly are essential.

7. Conclusion

The feasibility of using sawmill residues and OFMSW as feedstocks in the LUCRA process has been partly confirmed. This report has demonstrated that both feedstocks are available all the year round to a greater or lesser extent and their supply chain can be robust and streamlined, provided that they are generated in proximity. The greatest threats to their guaranteed supply, might be the rise of sawdust prices and severe contaminations of OFMSW at source.

While it has been proven that the logistics of these waste streams can be integrated in the LUCRA project, the suitability of destining these specific materials for microorganisms' growth still needs to be tested.

The next task in Work Package 2, seeks to ascertain whether sawdust and OFMSW have a nutritional profile fit for the fermentation process yielding SA, regardless of seasonality changes. For that purpose, AUA has studied how the different fractions of these biomasses – such as cellulose (main source of fermentable sugars), hemicellulose, lignin, protein, etc – vary throughout the year. The results of this study are gathered in Deliverable 2.2, Report on the feedstock composition, variability and requirements.

The final tasks of Work Package 2, deepen in how to maximise the release of sugars and nutrients present in OFMSW and lignocellulosic forestry waste through a hydrolysis step prior to fermentation. The goal is to improve the quality of the hydrolysate to be fermented so the highest SA productivity can be reached. Research conducted by AUA and INEUVO, will provide insight into the optimal operation conditions of the thermal and/or enzymatic hydrolyses that increase fermentable sugars and nutrients in the cultivation broth. Their findings will be presented in Deliverable 2.3, Waste pre-treatment process description and Deliverable 2.4, Results of the waste pre-treatment operation and optimisation.

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9. Annex 1: Flows of wood material 2022 (Except from Natural Resources Institute Finland report)

In 2022, the total consumption of wood dry-matter in Finland was 36.8 million tonnes. The amount decreased by 9% from the previous year. Of all wood dry-matter used in Finland in 2022, 39% was tied up in forest industry products. At the turn of the millennium, the share was about 50%. After the recession in 2008, the annual amount of wood dry-matter tied up in forest industry products has been continuously lower than that used in energy generation.

In 2022, 9% of all used wood dry-matter was tied up in paperboard and 6% tied up in paper. The share of paper has decreased in the 21st century. In 2022, the share of wood pulp was 10%, the share of sawn goods 12%, and the share of wood-based panels 2%. According to the forest sector's mass balance, as much as 60% of all wood dry-matter used in Finland ended up for energy generation (+1% from the previous year). The majority of the wood dry-matter that ended up in energy production consisted of either:

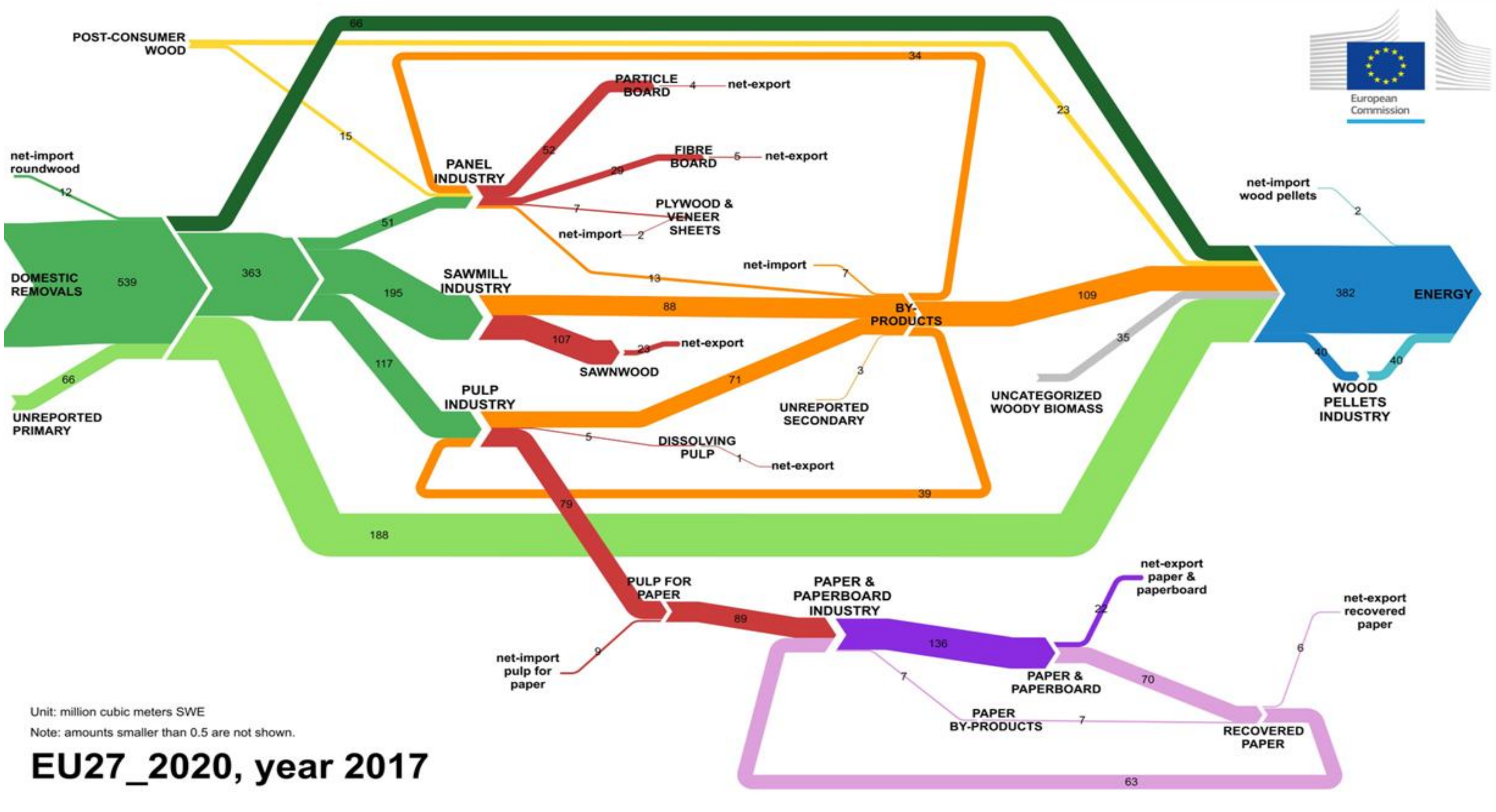
1. forest industry by-products or various wood residues or
2. black liquor and other concentrated liquors from wood pulp industry.

At the turn of the millennium, energy generation accounted for only 48% of wood dry-matter. Increase in energy generation in heating and power plants are the reason for this change. In addition to this, small-scale housing also consumes energy wood, but their share of the use of wood dry-matter has been quite stable.

In 2022, 14.2 million tonnes of wood dry-matter were exported from Finland. From this, the share of forest industry products was 13.2 million tonnes, and the share of roundwood and wood residues 0.9 million tonnes. The most significant changes in the 21st century have been the increase in exports of wood pulp and the decrease in paper. The volume of wood dry-matter imports was 3,5 million tonnes. Of this, roundwood and wood residues consisted of 2.5 million tonnes, and forest industry products 1.0 million tonnes.

The data of the wood flow statistics for 2017-2021 have been corrected on 29.11.2023. The supply of wood in the mass balance is on average 0.6% lower than previously published. The change is due to corrections in the imports of forest industry by-products and wood residues and the supply of energy wood. The correction of total roundwood removal in 2019 and 2020 reduced the supply of logs and pulpwood in the mass balance and the use balance. The data is based on the Flows of wood material statistics by Natural Resources Institute Finland (Luke). The supply and consumption volumes of different products are converted into the same unit of measurement: dry-matter tons of wood. This makes it possible to compare the amounts of wood material bound directly in wood and in forest industry products.

10. Annex 2: Sankey diagram of woody biomass flows in EU



Note: SWE, Solid Wood Equivalent, defined “as the amount of solid wood fibre contained in the product. It is the roundwood equivalent volume (green volume prior to any shrinkage) needed to produce the product when there are no losses or wood residues.”

11. Annex 3: Categories in OFMSW characterisation

		Quantity (kg)	**Weight** *(%)*
ORGANIC MATTER			
Organic matter			
Organic matter (unpackaged avoidable food waste)			
Paper & cardboard stained (food, oils...)			
Green waste & tree trimmings			
PLASTIC PACKAGING			
PET			
HDPE			
PVC			
Film			
Rest of plastics (PP, PS, EPS)			
Steel			
Aluminium			
Brick			
Wood			
OTHER WASTES WITH SEPARATE COLLECTION			
Glass packaging			
Paper & cardboard			
WEEEs			
Batteries			
Construction and demolition waste (minor works)			
REFUSE MATERIALS			
Hygienic cellulose (nappies, wet wipes...)			
Glass (No packaging)			
Textiles			
Plastic (No packaging)			
	PET		
	PEAD		
	PVC		
	Film		
	Rest of plastics *(PP, PS, EPS)*		
Wood			
Steel			
Aluminium			
Others *(Describe in "Remarks")*			