Identification, quantification, and assessment of different biomass waste streams

CA 20127

Waste biorefinery technologies for accelerating sustainable energy processes (WIRE)

Date 31 October 2024

Author(s) Eduardo Robles

Editor (s) Eduardo Robles

Funded by the European Union

Table of contents

List of acronyms

AW	Agricultural Waste
BCG	Bio-Circular-Green
C&D	Construction and Demolition
CO2	Carbon Dioxide
EWC-Stat	European Waste Classification for Statistics
FW	Food Waste
GHG	Greenhouse Gas
MBT	Mechanical Biological Treatment
MSW	Municipal Solid Waste
R&D	Research and Development
SSW	Sewage Sludge Waste
WG1	Working Group 1
WIRE	Waste and Industrial Resources COST Action
WW	Wood Waste
WMO	World Meteorological Organization

List of tables

Executive summary

This report examines the potential of biomass waste streams, particularly organic and wood residues, in supporting a bio-circular-green (BCG) economy. It highlights the importance of efficient pretreatment, harvesting, and collection systems for transforming biomass into bioenergy and bioproducts. The report identifies key biomass categories, outlines the challenges of contamination and logistics, and recommends improvements in source separation, pretreatment technologies, and regional supply chain management. By enhancing biorefinery capacity and standardizing regulations, Europe can leverage biomass waste to contribute significantly to carbon neutrality and sustainable energy production.

1. Introduction:

Human activities have reached a critical point where the impacts of global climate change, mainly driven by these activities, are becoming increasingly severe on both regional and global scales. The rising use of fossil fuels is significantly contributing to the increase in carbon dioxide (CO_2) emissions, which in turn leads to global temperature increases due to the well-documented greenhouse gas (GHG) effect (Rehman et al., 2019; Sohaib J. Mohammed & G. Ali Mansoori, 2017). Recent reports from the World Meteorological Organization (WMO) suggest that global temperatures are likely to temporarily exceed 1.5°C above pre-industrial levels within the next five years, highlighting the urgency of addressing climate change more aggressively (World Meteorological Organization, 2023). This trend underscores the growing risk that the targets set under the Paris Agreement may be breached, further exacerbating the environmental challenges faced by our planet. To mitigate the ongoing threat of global warming, expanding the use of sustainable and clean bioenergy in these critical sectors is essential. Among the various alternatives, bioenergy stands out as an up-and-coming solution. The large availability of biomass resources presents an opportunity to develop renewable energy systems that can replace a significant portion of fossil fuel use, particularly in sectors like heating, cooling, and transportation. Biomass not only serves as a renewable resource capable of producing sustainable liquid fuels but also offers the potential to integrate waste management with energy production, thereby contributing to a circular economy. In 2023, the global population exceeded 8 billion. With an additional billion people expected by 2040 and another billion by 2060 (Population Connection, 2023), the strain on the planet's resources, especially in terms of food, water, and energy, is intensifying. The rising demand for resources and the subsequent increase in waste generation pose critical challenges for sustainable development. One of the most pressing issues is the management of unavoidable biomass wastes, which include agricultural waste (AW), wood waste (WW), food waste (FW), municipal solid waste (MSW), and sewage sludge waste (SSW). These wastes are integral to the essential processes that support human society. The most popular and traditional ways for managing these types of waste include open dumps, river and ocean dumping, sanitary landfills, and incineration. However, these methods are largely associated with odor production and release of greenhouse gases (CO_2, SO_2, and NO_2). In addition, these toxic gaseous pollutants hurt human health, causing asthma, respiratory disorders, stroke, heart attack, and early death (Sinharoy & Pakshirajan, 2020). In addition, they cause contamination of underground water when wastes are buried (Ayilara et al., 2020). Another method, composting, while environmentally beneficial, also has several drawbacks. It typically takes several weeks to months to complete and generates unpleasant odors, toxic leachate, and methane emissions during the process (Wang & Tester, 2023). Modern sustainable waste treatment systems prioritize converting waste into energy, fuels, and products to maximize the use of biomass resources and foster a circular economy around lignocellulosic biomass. This technology is considered a more efficient way to process biomass and organic wastes (Begum et al., 2024). Several categorization methods exist for biomass wastes and the source-based method is the most used. As mentioned previously, AW, WW, FW, MSW, and SSW are the five categories of unavoidable biomass wastes. This report will focus on two primary categories of biomass waste: Organic Residue and Wood Residue.

Organic waste, a low-cost and abundant substrate, includes several types of waste from the five categories mentioned. Specifically, it includes AW, FW, and the organic fractions of MSW, and SSW. These wastes are rich in organic materials such as carbohydrates, proteins, and nutrients, making them ideal for use as feedstock in biohydrogen production. Organic waste, which is abundant and cost-effective, can be sourced from a variety of origins including agricultural and agro-industrial processes, food processing, municipal activities, and even wastewater treatment (Urbaniec & Bakker, 2015). Biohydrogen produced from natural organic materials (biomass) is a promising alternative as a low-carbon fuel option. Hydrogen offers a significantly higher energy yield—2.75 times greater than other fuels, at 122 kJ/g of biomass—when compared to fossil fuels or other carbon-based combustion fuels. Moreover, the combustion of hydrogen does not release toxic air pollutants or greenhouse gases (GHGs), with water being the only by-product (Kumar et al., 2017).

Wood Residue, while also considered a type of organic waste, is distinct in its origin and composition. It includes AW and wood waste (WW) generated from forestry operations, wood processing, and other activities producing lignocellulosic biomass, which primarily consists of lignin, cellulose, and hemicellulose (Hosoya et al., 2007). Additionally, it contains moisture, ash, and trace elements like lipids, starch, sugars, oils, and acids (Wang & Tester, 2023). Global crop residue production is substantial, with lignocellulosic biomasses such as rice straw, wheat straw, corn stover, and sugarcane bagasse dominating agricultural waste (Jayakumar et al., 2023). WW includes materials like leaves, branches, bark, sawdust, and shavings, as well as discarded furniture, building materials, pallets, and wood packaging. Timber harvesting results in significant waste wood, making it an important energy resource, including heat and electricity through direct combustion in biomass power plants. Additionally, wood waste can be converted into biofuels like bio-oil via pyrolysis and syngas through gasification. It can also be used for biohydrogen production, a clean fuel with a high energy yield (Dodić et al., 2012). However, WW contains a significant amount of lignin (18% to 35%), which necessitates the use of pretreatment prior to biohydrogen production for higher yield and conversion efficiency (Saravanan et al., 2021).

Biomass resources, whether organic or wood wastes exhibit a wide range of physical and chemical characteristics that directly affect their suitability for bioenergy production (Koppejan et al., 2019); factors such as moisture content, volatile organic compounds, and heating values determine the most appropriate conversion pathway—physicochemical, biochemical, or thermochemical (Gumisiriza et al., 2017). After necessary pretreatment, conversion, and purification processes become critical, addressing biomass utilization challenges while contributing to the bio-circular-green (BCG) economy (Eigenraam, 2022).

This report will identify and describe various biomass waste streams, such as agricultural residues, forestry residues, and urban organic waste, analyzing their sources and composition. It will quantify these waste streams, present data on their volume or mass, and explain the estimation methods used. Additionally, the report will assess and promote sustainable waste biomass supply chains, compare different methodologies for pretreatment, harvesting, and collection, and evaluate the logistics and cost-efficiency of these processes. The goal is to provide a comprehensive overview of biomass waste streams and their potential to support a sustainable and circular economy.

1.1 Background

The WIRE COST Action, established under the European Cooperation in Science and Technology (COST) framework, was developed in response to the increasing need for sustainable and innovative waste management solutions. This initiative is particularly focused on the valorization of biomass and waste streams, aiming to transform these underutilized resources into energy, biofuels, and other valuable products. The creation of the WIRE COST Action reflects a broader recognition within the European Union of the critical importance of transitioning to a bio-circular-green (BCG) economy.

The decision to form WIRE was driven by the realization that existing knowledge and technological advancements in biorefinery processes were fragmented across Europe. While individual research groups and projects had made significant strides in understanding and developing biorefinery technologies, there was a clear need for a coordinated effort to consolidate this knowledge and address the challenges of scalability, economic viability, and integration into existing industrial frameworks.

WIRE brings together experts from academia, industry, and technology transfer organizations across Europe, organized into four key working groups. These groups focus on raw materials, biorefinery conversion technologies, applications, and communication and dissemination. The collaborative framework established by WIRE is designed to promote research and innovation in bioenergy and bioeconomy, foster the application of advanced technologies, and engage with policymakers and industry stakeholders to ensure that biorefinery technologies are implemented effectively and widely.

The work undertaken by WIRE is essential not only for advancing scientific and technological frontiers but also for supporting policy goals related to sustainability and carbon neutrality. This report, therefore, seeks to build on the foundation laid by WIRE by focusing on the identification, quantification, and assessment of biomass waste streams. The insights gained from this analysis will be critical for informing future biorefinery developments and ensuring that Europe can lead the way in sustainable waste management and renewable energy production.

1.2 Objectives

The WIRE COST Action aims to establish a robust collaborative platform that will serve as the foundation for bringing together the diverse community involved in the Action. This platform will be instrumental in collecting and sharing a broad spectrum of resources, including training materials, experimental data, peer-to-peer contact forms, reports, and documentation. Given the significant technical challenges in this field, the availability of comprehensive data is crucial for technological development and knowledge transfer. By facilitating the exchange of knowledge among participants from various countries, the Action seeks to foster a new generation of researchers who approach their work with a cross-sectoral perspective.

One of the central focuses of the WIRE Action is on biomass waste feedstocks for biorefineries, which encompass a wide range of underused and undervalued residual streams, including organic wastes, forestry wastes, and agro-industrial wastes. Identifying and mapping the availability and distribution of these feedstocks are critical steps for the successful implementation of biorefinery technologies.

In this context, the primary objectives of Working Group 1 (WG1) are to assess and promote sustainable waste biomass supply chains. This includes comparing different methodologies for pretreatment, harvesting, or collection and evaluating the general logistics and cost-efficiency of waste biomass supply chains. By addressing these objectives, WIRE aims to streamline the supply chain processes that are essential for the development and implementation of efficient biorefineries, thereby advancing the BCG economy.

2. Methodology

The process of compiling this report was a collaborative effort undertaken by the members of Working Group 1 (WG1) of the WIRE COST Action. The methodology began with a video meeting on July 26th, 2024, where each member introduced themselves and defined their specific tasks for contributing to the report. During this meeting, roles were assigned to ensure that all aspects of the report were covered comprehensively.

Following the initial meeting, each member was responsible for gathering data from a variety of sources, both national and international. These sources included scientific databases, peer-reviewed journal articles, books, and government or private sector reports. Additionally, data were collected from industry publications, conference proceedings, and case studies. Relevant websites, such as those from environmental agencies, energy organizations, and research institutions, were also consulted to ensure a thorough compilation of information. Members utilized databases like Scopus, Web of Science, Google Scholar, and institutional repositories to access the most current and relevant data available.

All collected data were then entered into a shared Excel sheet, which was accessible to all members of WG1. This Excel sheet was designed to facilitate the organization and classification of data according to specific criteria, including the country of origin, the category of biomass (whether Organic or Wood residue), and the specific type and subtype of biomass involved. Additionally, each entry was classified by the type of waste biomass, the annual production figures, the year the data were collected, and the source of the information, whether it be academic, industrial, or governmental.

The Excel sheet served as the foundation for constructing data tables, which were meticulously organized to support the analysis presented in this report. These tables provided a structured overview of the biomass waste streams, allowing for easy comparison and evaluation of the data. The organization of the data was crucial for identifying patterns, assessing the availability and distribution of biomass resources, and evaluating the feasibility of different biorefinery technologies across various regions.

By following this systematic approach, the WG1 team ensured that the report was based on accurate, comprehensive, and well-organized data, reflecting the collaborative efforts of all participants. This methodology not only facilitated the creation of a detailed and informative report but also laid the groundwork for future research and collaboration within the WIRE COST Action.

3. Quantification of Biomass Waste Streams:

According to the manual for the Implementation of Regulation (EC) No 2150/2002 on Waste Statistics (Eurostat, 2024), out of the 51 waste types, the following are classified as organic: Animal and mixed food wastes (09.1), vegetal wastes (09.2), animal feces, urine, and manure (09.3), common sludges (11), animal and mixed food sludges (09.1, 11), canteen and kitchen wastes, green wastes, compostable organic waste fractions, bio-waste from food industries, waste from fruit and vegetable processing, separately collected biodegradable waste, organic sludge from wastewater treatment, and agricultural organic waste, making a total of 13 organic waste types. Table 1 shows the production of some of this waste.

Table 1.Quantifying the production of some of the organic waste.

Country	Type of Biomass	Subtype of Biomass	Waste Biomass	Annual Production	Year of Data	Source	Comments
France	AW	Agri-food industrial waste	Chicken feathers	60,303 tonnes	2020	D2.1-Analysis-of-Feather-Waste-Sources-and-Management-in-the-EU	Example data
France	AW	Livestock effluents	Manure	25 tons/ha	2023	Hauts-de-France Chamber of Agriculture	Pig slurry
France	FW	Biowaste	Green waste	—	—	—	—
France	MSW	Sanitation waste	Sewage sludge	1.1 million tons	2010	Report Z	—
France	SSW	Plant materials	Algae	—	—	—	—
France	AW	Biomass waste	Cereal straw	383,459 tonnes	2022	SAA 2022 définitive, page 9	Oat straw
	AW	Food waste		129 Kg/capita/year	2021	https://ec.europa.eu/eurostat/databrowser/view/cei_pc035/default/table?lang=en	
	MSW	Municipal waste		513 Kg/ capita	2022	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics	
France	AW	Biomass waste	Cereal straw	11,005,153 tonnes	2022	SAA 2022 définitive, page 9	Maize residues
France	AW	Forage	Maize forage	13,745,040 tonnes	2022	SAA 2022 définitive, page 10	France

According to the manual for the Implementation of Regulation (EC) No 2150/2002 on Waste Statistics (Eurostat, 2024), out of the 51 waste types, the following are classified as wood residue: wood wastes (07.5), wood wastes (hazardous) (07.5), sawdust and wood shavings (from wood processing), residue from wood processing (from construction), non-hazardous wood packaging waste, residue from the forestry industry, hazardous wood waste with chemicals, and packaging waste (wood), making a total of 8 wood residue waste types. Table 2 shows the identification of some of this waste.

Table 2.Identifying some of the wood waste.

Country	Type of Biomass	Subtype of Biomass	Waste Biomass	Annual Production	Year of Data	Source	Comments
France	WW	Forest Wood	Related wood processing	—	—	—	—
France	WW	Woodland Biomass	Orchard biomass	—	—	—	—
France	WW	End-of-life wood	Discarded furniture	—	—	—	—
France	WW	Vineyard biomass	Vineyard prunings	—	—	—	—
France	WW	Related wood processing	Sawdust	—	—	—	—

4. Assessment of Biomass Waste Streams:

4.1 Agricultural Waste (AW)

Sources: Crop residues (straw, husks), animal manure, agri-food industrial waste.

Potential Uses:

Agricultural waste can be used for a variety of bioenergy applications, such as biofuel production through anaerobic digestion or bioethanol production through fermentation. Manure is also a valuable feedstock for biogas production in anaerobic digesters, which produces both energy and nutrient-rich digestate for use as fertilizer.

Challenges:

The seasonal nature of agricultural residues, like straw, poses logistical challenges for continuous energy production. Furthermore, proper collection and storage systems must be established to minimize losses during harvesting. The high moisture content in some residues (e.g., manure) may also require costly drying before conversion.

Limitations:
Agricultural residues often contain a high amount of lignocellulosic material, which can be difficult to break down during biochemical conversion processes without proper pretreatment (e.g., enzymatic hydrolysis).

4.2 Wood Waste (WW)

Sources: Forestry residues (branches, bark), sawdust, wood processing residues, construction and demolition (C&D) wood waste.

Potential Uses:
Wood waste is a valuable feedstock for energy production, especially through thermochemical conversion processes like pyrolysis, gasification, and direct combustion. These methods can generate heat, electricity, and bio-oils. Wood residues are also used in the production of wood-based panels (e.g., particleboard) and can be recycled into new wood products.

Challenges:
Contamination of wood waste, especially from C&D sites (e.g., treated with chemicals or paints), complicates recycling and limits its use in bioenergy production. Clean wood must be separated from contaminated material, which increases the processing time and cost.

Limitations:
Wood residues contain a significant amount of lignin (18-35%), which can hinder biochemical conversion processes such as biohydrogen or ethanol production. Pretreatment processes (e.g., steam explosion, acid hydrolysis) are necessary to overcome lignin barriers but can be expensive and energy-intensive.

4.3 Food Waste (FW)

Sources: Household and commercial food waste, food processing by-products.

Potential Uses:
Food waste is rich in carbohydrates, proteins, and fats, making it suitable for energy production through anaerobic digestion, which generates biogas (methane) and digestate. It can also be used

for composting, creating a nutrient-rich soil conditioner. Additionally, food waste can be converted into bioethanol or biodiesel, depending on its composition.

Challenges:
One of the primary challenges with food waste is contamination and separation. Many food wastes are mixed with non-biodegradable materials (e.g., plastics), which can lower the efficiency of composting or energy conversion. Seasonal variations in food waste availability can also pose logistical challenges for continuous feedstock supply.

Limitations:
High moisture content in food waste often requires dehydration or other pretreatment before it can be efficiently processed in some energy recovery systems. Additionally, food waste has a lower energy yield compared to other biomass types, limiting its large-scale application for bioenergy.

4.4 Municipal Solid Waste (MSW)

Sources: Organic fraction of household and commercial waste, sanitation waste (sewage sludge).

Potential Uses:
The organic fraction of MSW can be used for composting, anaerobic digestion, or incineration with energy recovery. Sewage sludge, a significant part of MSW, is rich in organic matter and can be processed in biogas plants to produce renewable energy or treated for use as soil amendments.

Challenges:
The main challenge is the variability and contamination of the organic fraction of MSW. This waste stream often includes non-biodegradable materials (e.g., plastics), metals, and hazardous substances that require additional sorting and separation. The logistical complexities of collection and processing also increase operational costs.

Limitations:
Low calorific value and high moisture content in the organic fractions of MSW limit the energy yield when compared to other biomass types, such as wood or agricultural residues. Treatment of sewage sludge may also generate toxic by-products, complicating its disposal.

4.5 Sewage Sludge Waste (SSW)

Sources: Sludge from wastewater treatment plants, industrial effluent sludges.

Potential Uses:
Sewage sludge is a suitable feedstock for biogas production through anaerobic digestion. After treatment, the remaining solid digestate can be applied to agricultural fields as fertilizer or further processed for land reclamation. Sludge incineration is another option, which can generate both heat and electricity.

Challenges:
Sewage sludge can contain heavy metals, pathogens, and hazardous chemicals, making its safe disposal and treatment more complex. Strict regulations govern its use, particularly when applied to land, and additional treatment is often required to neutralize potential risks.

Limitations:
The high water content in sewage sludge increases the cost and energy consumption of drying or dewatering processes. Additionally, the handling and storage of sludge require specialized infrastructure, which can be expensive to develop and maintain.

5. Pretreatment, Harvesting, and Collection:

Pretreatment: The manual provides detailed methodologies for the pretreatment of organic and wood residues, including the mechanical and biological processes used to prepare these materials for recycling, energy recovery, or disposal.

5.1 Pretreatment of Organic Residues:

1. Biological Treatment: Composting: Organic waste, such as food and plant residues, undergoes aerobic biological treatment to break down biodegradable materials. Composting is one of the key processes used for converting organic waste into a soil conditioner.
2. Anaerobic Digestion: This is a biological process in which organic waste is decomposed in the absence of oxygen, producing biogas (methane) and digestate. This process is commonly used for animal and food waste.
3. Mechanical Biological Treatment (MBT): In the case of mixed organic waste from households, MBT combines mechanical sorting with biological treatment. The biological stage

reduces the volume and the organic content, stabilizing the waste for safe disposal or energy recovery.

4. Stabilisation of Organic Residue: After the treatment, the organic matter content is reduced, and the resulting materials are prepared for further usage, such as landfilling or as secondary raw materials in agriculture.

5.2 Pretreatment of Wood Residues:

1. Mechanical Treatment: Shredding and Crushing: Wood residues from construction or demolition activities are mechanically reduced in size through shredding and crushing. This step prepares wood waste for either recycling (e.g., production of particleboard) or energy recovery (e.g., as biomass fuel).
2. Sorting: Wood wastes are sorted based on whether they are contaminated with hazardous substances, such as paints, preservatives, or chemicals. Clean wood waste can be reused or sent for energy recovery, while contaminated wood requires special handling and disposal.
3. Recycling of Wood Waste: Wood materials can be reclaimed and reused in construction, packaging, or the production of new wood-based products. Hazardous wood wastes (those treated with chemicals) undergo a separate treatment process to remove or neutralize harmful substances before recycling.

5.3 Energy Recovery:

Both organic and wood residues may undergo energy recovery processes like incineration or use as biofuel. Organic waste is commonly processed into biogas through anaerobic digestion, while wood waste may be converted into fuel for biomass energy production.

The combination of biological and mechanical treatment ensures the effective pretreatment of both organic and wood residues, allowing for their reuse, recycling, or safe disposal.

The methodologies for harvesting organic and wood residues, as outlined in the manual, focus on identifying, collecting, and processing these materials for either recycling or energy recovery. Below is a one-page summary:

5.4 Organic Residue Harvesting:

Agricultural and Food Wastes: Organic residues from agriculture and food production (e.g., animal and mixed food wastes) are often collected directly from farms, food processing plants, and kitchens. The collection methods vary but generally involve separating biodegradable organic waste at the source.

Municipal Organic Waste: Households and commercial entities contribute significantly to organic waste streams. Collection schemes typically include curbside collection of green waste (e.g., food scraps, garden trimmings) or dedicated organic waste bins. In some regions, community composting schemes also serve as collection points.

Wastewater Sludge: Sludge from wastewater treatment facilities is a significant source of organic material. These residues are typically harvested through mechanical dewatering or biological treatment processes before being sent for further treatment, such as composting or anaerobic digestion.

Forestry Residues: Organic residues from forestry, such as branches, leaves, and other non-wood organic materials, are collected during logging operations. These materials are usually left on-site and later transported to processing facilities for composting or energy recovery.

5.5 Wood Residue Harvesting:

1. Construction and Demolition (C&D) Sites: Wood waste from construction and demolition activities is collected at source. This involves separating wood from other materials, such as metal or concrete, to ensure clean wood residues can be reused or processed. Sorting is typically manual or mechanical, depending on the scale of the operation.

2. Wood Processing Facilities: Wood residues such as sawdust, shavings, and offcuts are generated in wood processing plants and furniture manufacturing facilities. These residues are collected on-site and are often directly fed into recycling or energy production processes, such as creating particleboard or biomass fuel.

3. Wood Packaging and Pallets: Discarded wooden pallets and packaging are harvested from industrial and commercial sectors. These materials are collected through dedicated take-back schemes or at waste management facilities. They are then sorted for reuse or recycling, with damaged wood typically going to biomass or composting facilities.

In both cases, source separation and transportation logistics are crucial to minimize contamination and ensure the quality of the harvested residues. For organic waste, proper segregation is key to facilitate biological treatment processes like composting or anaerobic digestion. For wood residues, clean separation from other C&D materials helps ensure the wood can be reused or transformed into secondary materials without extensive pretreatment.

5.6 Organic Residue Collection:

1. Source Separation: Organic waste collection begins with proper segregation at the source. Households, businesses, and agricultural entities are encouraged to separate biodegradable organic waste such as food scraps, garden trimmings, and agricultural residues. This helps minimize contamination and facilitates effective biological treatment processes like composting or anaerobic digestion.

2. Curbside Collection Systems: In many regions, separate bins are provided for organic waste collection. Municipalities often manage this process, collecting biodegradable waste regularly and transporting it to designated composting or treatment facilities.

3. Bulk Collection from Food Industry and Agriculture: Large producers of organic waste, such as food processing industries and agricultural operations, often have dedicated collection systems. These industries may directly transport their organic waste to composting or anaerobic digestion facilities or use specialized collection services.

4. Community Composting Programs: In areas with limited centralized collection services, community composting programs can serve as an alternative. Residents bring their organic waste to local composting centers, where it is processed for reuse in landscaping or agriculture.

5.7 Wood Residue Collection:

1. Construction and Demolition (C&D) Waste Collection: Wood residues from C&D activities are collected directly from building sites. The process involves sorting wood from other construction materials, such as metal, concrete, or hazardous materials, to ensure the collection of clean wood that can be reused or recycled.

1. Collection from Wood Processing Facilities: Wood residues like sawdust, wood shavings, and offcuts from wood processing plants or furniture manufacturers are collected on-site. These residues are typically gathered in bulk containers and transported directly to recycling facilities or used as biomass for energy generation.

2. Take-Back Systems for Wooden Pallets: Wooden pallets and packaging materials used in logistics are often subject to take-back systems. These are collected, repaired, or recycled, depending on their condition. Damaged wood may be sent to biomass facilities for energy recovery.

3. Municipal Collection Systems: In some regions, municipal waste collection services include the pickup of bulky wood waste from households, such as old furniture or wood packaging. This material is then sorted and processed accordingly.

In both organic and wood residue collection, minimizing contamination is crucial for ensuring that the materials can be effectively processed for composting, recycling, or energy recovery.

Conclusions and Recommendations

This report underscores the critical role of biomass waste streams, particularly organic and wood residues, in contributing to a bio-circular-green (BCG) economy. Key findings reveal the importance of effective pretreatment methods, efficient harvesting techniques, and proper collection systems for maximizing the potential of biomass for bioenergy production. Pretreatment, through mechanical, biological, and chemical processes, is essential for optimizing waste conversion. Efficient harvesting and collection, especially of agricultural and forestry residues, ensures minimal contamination and maximizes usability. Challenges remain in logistics, especially in rural and forestry areas, where optimizing supply chains can reduce costs and improve efficiency.

To address these challenges, we recommend enhancing source separation systems for organic residues, investing in advanced pretreatment technologies, and developing regional hubs to streamline logistics. Expanding biorefinery capacity and harmonizing regulations across the EU are also essential for maximizing biomass potential. By implementing these measures, Europe can make significant progress in sustainable biomass management and contribute to its carbon neutrality goals while promoting renewable energy production.

Acknowledgements

This Report is based upon work from COST Action CA20127 - Waste biorefinery technologies for accelerating sustainable energy processes (WIRE) supported by COST (European Cooperation in Science and Technology).

References

1. Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability (Switzerland)*, *12*(11), 1–23. https://doi.org/10.3390/su12114456
2. Begum, Y. A., Kumari, S., Jain, S. K., & Garg, M. C. (2024). A review on waste biomass-to-energy: integrated thermochemical and biochemical conversion for resource recovery. *Environmental Science: Advances*. https://doi.org/10.1039/d4va00109e
3. Dodić, S. N., Vasiljević, T. Z., Marić, R. M., Kosanović, A. J. R., Dodić, J. M., & Popov, S. D. (2012). Possibilities of application of waste wood biomass as an energy source in Vojvodina. *Renewable and Sustainable Energy Reviews*, *16*(5), 2355–2360. https://doi.org/10.1016/j.rser.2012.01.079
4. Eigenraam, M. (2022). *Understanding the Bio-Circular-Green (BCG) Economy Model*. *August*. www.ideeagroup.com (Accessed date: 01.08.2024).
5. Eurostat. (2024). *Manual for the Implementation of Regulation (EC) No 2150/2002 on Waste Statistics (2024 ed.)*. https://ec.europa.eu/eurostat/product?code=ks-gq-24-009 (Accessed date: 01.08.2024).
6. Gumisiriza, R., Hawumba, J. F., Okure, M., & Hensel, O. (2017). Biomass waste-to-energy valorisation technologies: A review case for banana processing in Uganda. *Biotechnology for Biofuels*, *10*(1), 1–29. https://doi.org/10.1186/s13068-016-0689-5
7. Hosoya, T., Kawamoto, H., & Saka, S. (2007). Cellulose-hemicellulose and cellulose-lignin interactions in wood pyrolysis at gasification temperature. *Journal of Analytical and Applied Pyrolysis*, *80*(1), 118–125. https://doi.org/10.1016/j.jaap.2007.01.006
8. Jayakumar, M., Gindaba, G. T., Gebeyehu, K. B., Periyasamy, S., Jabesa, A., Baskar, G., John, B. I., & Pugazhendhi, A. (2023). Bioethanol production from agricultural residues as lignocellulosic biomass feedstock's waste valorization approach: A comprehensive review. *Science of the Total Environment*, *879*(March), 163158. https://doi.org/10.1016/j.scitotenv.2023.163158
9. Koppejan, J., Cremers, M., & Gl, D. (2019). *Biomass pre-treatment for bioenergy Policy report*.
10. Kumar, G., Park, J. H., Sivagurunathan, P., Lee, S. H., Park, H. D., & Kim, S. H. (2017). Microbial responses to various process disturbances in a continuous hydrogen reactor fed with galactose. *Journal of Bioscience and Bioengineering*, *123*(2), 216–222. https://doi.org/10.1016/j.jbiosc.2016.08.006
11. Population Connection. (2023). Population and Climate Change: What Are the Links? In *Population Connection*. https://populationconnection.org/resources/population-and-climate/. (Accessed date: 05.08.2024).
12. Rehman, A., Rauf, A., Ahmad, M., Chandio, A. A., & Deyuan, Z. (2019). The effect of carbon dioxide emission and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance: evidence from Pakistan. *Environmental Science and Pollution Research*, *26*(21), 21760–21773. https://doi.org/10.1007/s11356-019-05550-y
13. Saravanan, A., Senthil Kumar, P., Khoo, K. S., Show, P. L., Femina Carolin, C., Fetcia Jackulin, C., Jeevanantham, S., Karishma, S., Show, K. Y., Lee, D. J., & Chang, J. S. (2021). Biohydrogen from

organic wastes as a clean and environment-friendly energy source: Production pathways, feedstock types, and future prospects. *Bioresource Technology*, *342*(x), 126021. https://doi.org/10.1016/j.biortech.2021.126021

14. Sinharoy, A., & Pakshirajan, K. (2020). A novel application of biologically synthesized nanoparticles for enhanced biohydrogen production and carbon monoxide bioconversion. *Renewable Energy*, *147*, 864–873. https://doi.org/10.1016/j.renene.2019.09.027
15. Sohaib J. Mohammed, & G. Ali Mansoori. (2017). A Unique View on Carbon Dioxide Emissions around the World. *Global Journal of Earth Science and Engineering*, *4*(312), 8–17. https://doi.org/10.15377/2409-5710.2017.04.01.2
16. Urbaniec, K., & Bakker, R. R. (2015). Biomass residues as raw material for dark hydrogen fermentation - A review. *International Journal of Hydrogen Energy*, *40*(9), 3648–3658. https://doi.org/10.1016/j.ijhydene.2015.01.073
17. Wang, K., & Tester, J. W. (2023). Sustainable management of unavoidable biomass wastes. *Green Energy and Resources*, *1*(1), 100005. https://doi.org/10.1016/j.gerr.2023.100005
18. World Meteorological Organization. (2023). *Global temperature likely to exceed 1.5°C above pre-industrial level temporarily in next 5 years*. https://wmo.int/news/media-centre/global-temperature-likely-exceed-15degc-above-pre-industrial-level-temporarily-next-5-years. (Accessed date: 05.08.2024).