Review of feedstock supply for bioenergy in IEA Bioenergy

Task 43 Member Countries

IEA Bioenergy: Task 43

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Overview

Understanding the potential biomass supply for available for bioenergy and biofuel production is challenging. Required datasets are often missing or generated inconsistently, making it difficult to understand year-to-year availability. A number of different units are used to track biomass in different sectors, and converting between these units is confounded as yields, densities, and energy content varies from feedstock to feedstock. Typically, bioenergy capitalizes on feedstocks that are not suitable for higher value applications, are available in suitable quantities at centralized locations, and are economically viable. A significant gap exists in terms of understanding the flow of diverse feedstocks to bioenergy production, and in terms of understanding potentially accessible and inaccessible fibre. This lack of information serves as a barrier, preventing policymakers and decisionmakers from substantiating the role of bioenergy in the wider circular bioeconomy, and in terms of understanding residues and waste streams within the production systems.

This report has two primary objectives: (1) to define and inform a framework for tracking biomass feedstocks and potential availability for bioenergy, biofuel, and bioproduct use; and (2) to provide an update on the availability of different types of biomass feedstocks that are (or can be) used for bioenergy within Task 43 countries.

Approach

The report first considers different approaches to categorizing feedstocks for bioenergy use. Key documents used here include IEA Bioenergy Country Reports, the UNECE/FAO Joint Wood Energy Enquiry, and domestic assessments of feedstock (e.g. the Billion Ton report from USA). These are summarized in Section 1.

In Section 2, feedstocks that are or may be used for bioenergy (e.g., wood and crop residues, pulping liquor, municipal solid waste, etc.) as well as feedstocks transformed into specific bioenergy products (wood pellets, ethanol, biodiesel, biogas) are quantified. A framework is developed, building off of existing international data reporting frameworks, to help guide the collection of this data.

Finally, Section 3 uses these data to assemble country-level reports for each of the eight countries engaged in Task 43. This includes an overview of energy use, bioenergy application, and the current availability of biomass that might be used in these systems. Biomass flows are described using Sankey diagrams and conventional charts. Summary tables for each country are included in the Appendix.

Section 1 - Background

INTERNATIONAL ENERGY AGENCY

The International Energy Agency produces substantial reporting on bioenergy use, both through the parent agency ('IEA') and through the Implementing Agreement on Bioenergy ('IEA Bioenergy'). The IEA recently published the Solid biofuels consumption estimation model, based on a European Commission-funded project and describing potential biofuel consumption in 10 African nations (IEA, 2022). The statistics unit provides energy balances that incorporate bioenergy (IEA, 2024) and also publishes a report on World renewables and waste energy supply (IEA, 2023). These data series provide a good overview of bioenergy production but offer less insight into biomass consumption for energy production.

IEA Bioenergy Technology Collaboration Program (TCP) produces semi-annual reports on the implementation of bioenergy across member countries. The most recent set of reports were produced in 2021 (and reflect data taken from 2019), although IEA Bioenergy also produces an annual report on overall TCP activities (IEA Bioenergy, 2021). These reports do not focus on biomass supply, but rather on the use of different biomass categories for energy purposes – solid biomass production and imports, municipal solid waste, biogas/biomethane, and liquid biofuels. Much of the data presented in annual reports is drawn from the International Energy Agency's statistics unit (IEA, 2024).

Within individual IEA Bioenergy country reports, much information is included which provides context to describe changes in biomass supply. Of particular value is the analysis of policy and the impact that new or changing policy has on bioenergy use and supply. These reports also often provide detailed timeseries of energy use and bioenergy consumption by sector, which supports deeper analysis into biomass supply.

Tasks within the IEA also provide good reports on bioenergy use. For example, IEA Bioenergy Task 39 provides regular implementation updates on transportation biofuels, most recently in February 2022 (IEA Bioenergy, 2022a). IEA Bioenergy Task 43 has produced a number of reports examining biomass supply, including deep dives into logging residue cost and availability in New Zealand (IEA Bioenergy, 2023) and the development of biohubs in private forests in Australia (IEA Bioenergy, 2022b). While these are excellent reports, they do not propose a consistent methodology or framework for data collection.

JOINT WOOD ENERGY ENQUIRY

The Joint Wood Energy Enquiry (JWEE) is a combined effort of the United Nations Economic Commission for Europe (UNECE) and the Food and Agriculture Organization (FAO), originally launched in 2006 and published biannually (UNECE/FAO, 2024). The most recent version of this report was released in 2019. The JWEE provides data on biomass sources as well as on wood energy production/consumption. To collect these data, a survey is distributed to member states. In 2019, respondents to the survey included Austria, Cyprus, Czech Republic, Finland, France, Germany, Norway, Serbia, Slovenia, Sweden, Switzerland, United Kingdom, and United States; in previous years, countries including Canada also participated.

Data in the JWEE is organized and presented within an aggregated matrix, where four broad sources of biomass (including direct [unprocessed fibre], indirect [processed fuels], recovered [post-industrial and post-consumer waste], and unspecified [unknown origin]) are linked to four specific uses (including power and heat, industrial energy, residential heat, or other). To generate this matrix, four detailed data tables are used to collect data on wood fibre, wood products, wood fuels, and wood energy. The organization of these tables is shown in Figure 1.

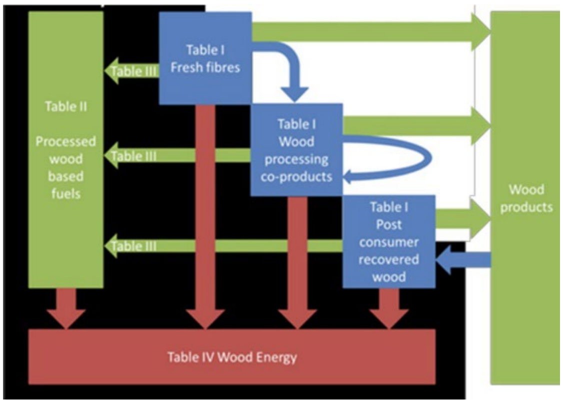


Figure 1 Structure of the Joint Wood Energy Enquiry (Source: UNECE/FAO, 2023)

A strength of the JWEE is that it draws information directly from experts in national governments and academia. This means that data describing bioenergy feedstock sources and bioenergy use, often only presented in aggregate in national datasets, is broken down and clearly specified. The detailed tables describing wood sources, products, fuels, and energy use are very helpful in describing bioenergy feedstocks.

A challenge when using the JWEE is that the aggregate summary table, which is the default presentation of data given to users, oversimplifies the flows of fibre and makes it difficult to understand exactly what the sources of fibre are in energy supply. Data is presented in cubic metres rather than mass, which makes it easy to compare JWEE data with other forest harvest data, but difficult to compare with other feedstock sources. Because only wood fibre is examined, other feedstocks (agriculture, municipal wastes) are not included in this summary, which also makes it hard to understand the relative role of different feedstock types.

Another major challenge is that JWEE data often does not match publicly available datasets, even when the series should be closely related. For example, roundwood removals are consistently given different estimates within the JWEE than in FAOStat. This is confusing in part because the JWEE draws original data from the Joint Forest Sector Questionnaire (JFSQ); however, data within FAOStat are often updated years after the fact and thus numbers can change over time, while the JWEE provides a data 'snapshot' from the year of publication. Thus, when looking back through the data, the older FAOStat data may not align with JWEE data.

BILLION-TON REPORT (UNITED STATES)

The Billion-Ton report, issued in 2016 and again in 2024 (USDOE, 2024; USDOE 2016), details potential biomass feedstocks to support the bioeconomy. The overall categories of biomass considered within the 2016 Billion-Ton report are shown in Figure 2 (USDOE, 2016); this taxonomy is not dramatically changed in the 2024 report, although the 2024 report considers energy crops, microalgae, macroalgae, and point-source carbon as additional potential feedstocks. The primary categories of feedstock considered are forestry, agricultural, and waste resources.

The 2024 Billion-Ton report combines a number of geospatial biomass production models to examine specific types of biomass resources with an econometric approach to evaluate the cost of different feedstocks. Empirical data from crop and forestry trials are used to support these models and generate the overall projections of biomass availability, with projections built around the concepts of near-term availability, the amount of market pull (low, medium, high), and the development of evolving and emerging technologies. The study takes stock of current conversion of biomass to energy but focuses on the expansion of biomass resources through strategies to increase recovery of residues and waste, implement energy crops and plantation-style forestry, and develop emerging technologies such as algae production. The Billion-Ton report represents a high-end analysis of current and potential bioenergy feedstocks.

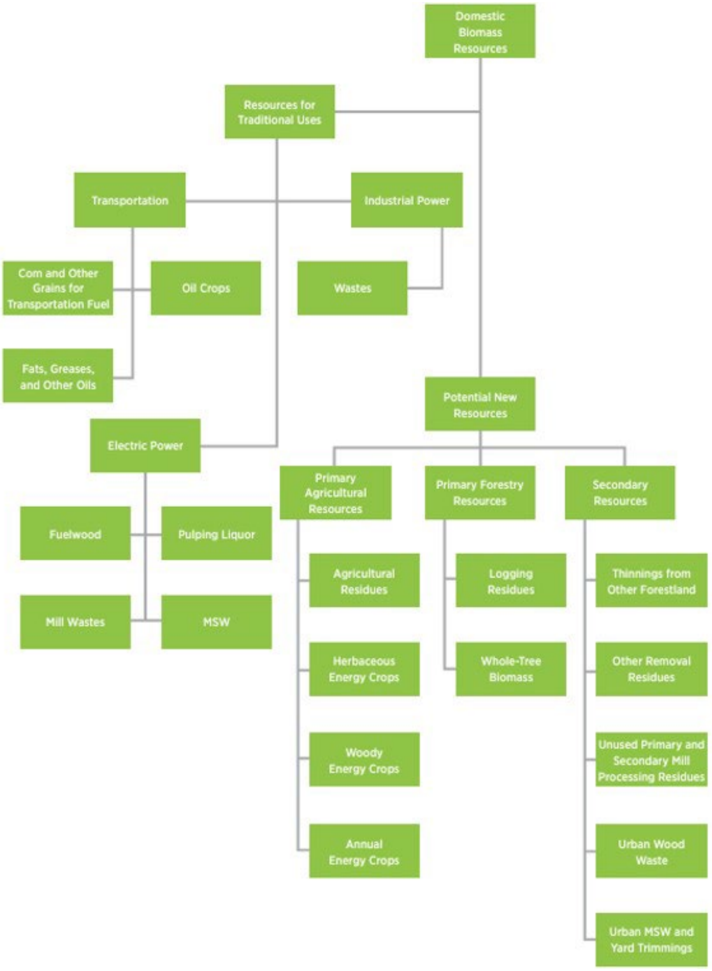


Figure 2: Taxonomy of biomass resources, Billion-Ton report (Source: USDOE 2016, p.8)

It is important to note that the Billion-Ton report is primarily a modelling exercise rather than an annualized data collection exercise. While excellent datasets have been assembled to support this exercise, these data are not produced on an annual basis and thus cannot be easily used to assess changing patterns of biomass production or impacts of variation in annual production. Second, certain categories of biomass are currently included in this analysis that are not regularly collected by other countries – for example, woody energy crops or thinnings – which makes international comparisons difficult. Finally, the separation of current use and future availability, from a material flow perspective, creates the opportunity for inadvertent double-counting of biomass resources – a challenge with assessing these resources.

Section 2 - Framework for assessing biomass resources

Based on the existing frameworks identified in the previous section, and using widely available datasets, the following framework for assessing biomass resources has been developed.

This section details each component of this framework as described in Figure 3. Subsections include agricultural biomass, forest biomass, and municipal solid waste. Key recommendations about future data collection are provided throughout this section and highlighted in a box.

Using this framework, the various datasets have been compiled for each Task 43 member country and are presented in Section 3.

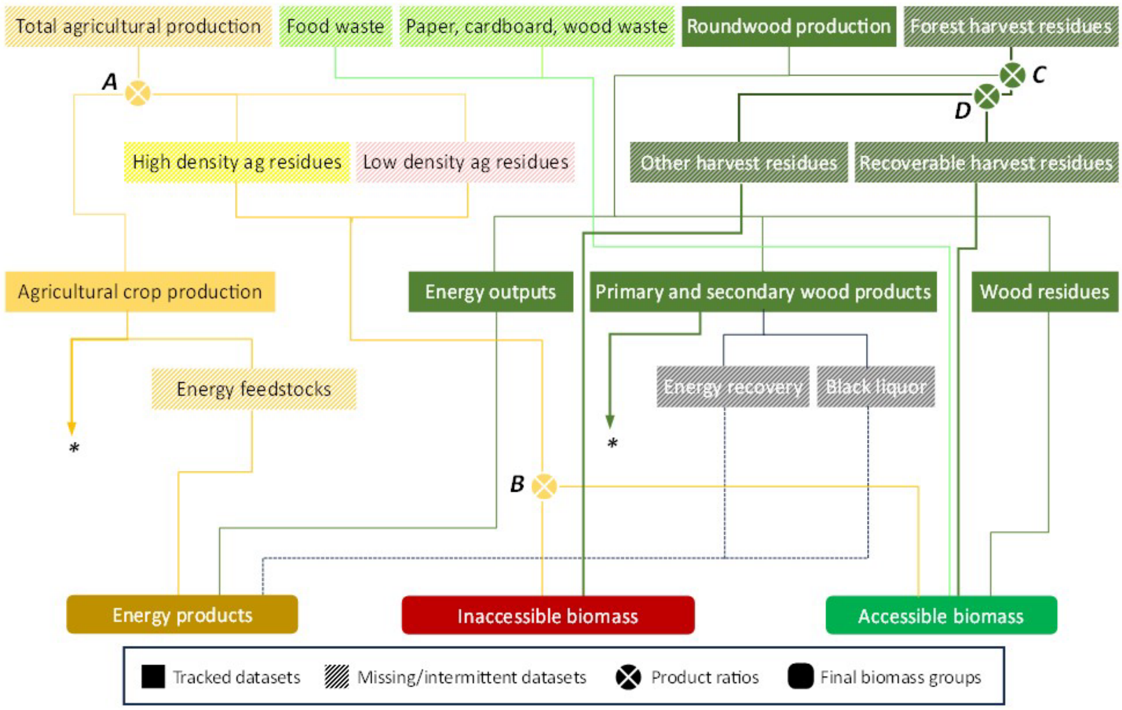


Figure 3: Proposed biomass feedstock classification system (simplified).

The proposed biomass feedstock classification system differs from that used by other agencies in that it is focused on mass of feedstock rather than units of energy or volume. This approach is meant to simplify communication and avoid confusion about conversion factors, which can often lead to challenges in understanding the actual flows of biomass into different categories.

The three primary feedstock sources (agriculture, forestry, and post-consumer waste) are each classified and incorporated into this framework, which categorizes biomass flows into one of the following groups: existing energy products, 'accessible' or theoretically available biomass, and 'inaccessible' or biomass likely to be left behind for sustainability purposes or for reasons of economic accessibility. The following sections describe each element of the framework.

AGRICULTURAL BIOMASS

Total agricultural production: This is the total amount of agricultural production including food product (payload) as well as agricultural residue generation. Food production is well documented (see Agricultural crop production below) but residue generation is usually estimated using a ratio (denoted in Figure 1 as ***A***) which is applied to agricultural crop production. Different crops and various locations have specific residue generation ratios which can be averaged over jurisdictions. For the purpose of this report, ratios are drawn from Lal (2005), Table 5 and applied by crop production at the country level to determine residue production in each case. The sum total of residue production (at the country level) is then added to that country's crop production to determine total agricultural production.

Agricultural crop production: This is the sum production of different agricultural crops on an annual basis. This dataset is tracked widely; for the purpose of the present study we utilized Food and Agriculture Organization statistics (FAOStat, 2024) but national organizations track this data on a regular basis and similar datasets can be found in most countries. Note that this study considers actual agricultural crop production (i.e., not including net trade effects) as this is the figure necessary to calculate residue production as discussed in the previous section. This figure could also include the production of energy crops. Within the FAO nomenclature, most energy crops (e.g. switchgrass, miscanthus, hemp) are not tracked as a food source but rather as a nonwood fibre source (FAOStat, 2024). Production of energy crops is currently very limited.

Recommendation #1: Although an important figure, it is unlikely that total agricultural production will be measured directly on an ongoing basis. Thus, it is important that the residue production ratio (A) is accurate, meaning that it reflects national or subnational residue generation rates, and that it is updated on a regular basis. Ideally, individual countries should monitor and validate these ratios on a per-crop basis, so that more accurate estimates of total agricultural production can be made. It is also important that energy crops be incorporated as they enter crop rotations, in order to track this biomass source over time.

High density agricultural residues: This is the total amount of residue generated by agricultural crops which leave a relatively large amount of biomass in the field after harvest. This dataset is not tracked but can be calculated using residue production ratios ***(A***) as described previously. For the purposes of the present study, 'high density' refers to agricultural residue generation rates of 3 t/ha or more (as defined in Lal (2005)). High density residue generating crops include barley, maize (corn), rice, wheat, sugarbeet, sugarcane, and sweet potato. High density residues are more likely to be economically viable sources of biomass. It is noted that 100% of residues cannot be collected; a portion of residues are generally left on the field to meet ecological considerations such as nutrient transfer and erosion control. Thus, a second ratio (***B***) must be applied to determine what portion of high-density agricultural residues are sustainably accessible, and what portion are not. For the purpose of the current study, sustainable residue recovery ratios are drawn from Muth et al. (2013). These ratios range from a low of 7.9% (sorghum) to a high of 39.5% (corn/maize).

Low density agricultural residues: This is the total amount of residue generated by agricultural crops that leave a relatively low amount of biomass in the field after harvest. This dataset is not tracked but can be calculated using residue production ratios ***(A***) as described previously. For the purposes of the present study, 'low density' refers to agricultural residue generation rates of less than 3 t/ha (as defined in Lal (2005)). Low density residue generating crops include millet, oats, sorghum, beans, broad beans, chick peas, groundnut, lentils, peas, pulses, soybeans, linseed, rapeseed, safflower, seed cotton, sesame, sunflower, tubers, and potato. Low density residues are less likely to be economically viable sources of biomass.

Recommendation #2: The current study definition of ‘high density’ and ‘low density’ residual feedstocks should be reviewed; it is included here as an arbitrary breakdown to help inform the likelihood of being able to access certain feedstocks. Crops which generate high amounts of residue will likely be preferred as the revenue per ha would increase for farmers. However, agricultural production is highly decentralized and distance from the plant may be a more important constraint on economically viable feedstocks. It is important that the ratio of high density to low density agricultural ratios (B) be accurate and reflect local situations.

Energy feedstocks: A certain proportion of agricultural crop production may be used for energy generation (usually biofuels or biogas), depending upon country and the availability of infrastructure. This dataset is not tracked and must currently be estimated by using average yields of different biofuels. For the purpose of the current study, yields used are 320 l/t cereal feedstock (ethanol) and 470 l/t oilseed feedstock (FAME/biodiesel). It is acknowledged that the use of these ratios to estimate the portion of food production that goes into biofuels is problematic; these feedstocks are widely traded and in many cases the feedstock may be imported rather than grown domestically.

Recommendation #3: A useful approach in data reporting is taken by Sweden, which includes country of origin for biofuels. This allows a more nuanced analysis of feedstock flows; a similar approach might be adopted by other countries to better show the portion of agricultural production that is ultimately used for energy.

FOREST BIOMASS

Roundwood production: This is the total amount of wood removed from the forest (including planted forests) for any purpose; it is sometimes referred to as ‘wood in the rough’ and is meant to provide a complete picture of wood harvest. Roundwood includes both industrial roundwood (meant for consumer products) and fuelwood (used for heat and energy production). Roundwood as a dataset is widely tracked, usually on a volumetric and cumulative basis (as the mass of wood changes dramatically based on moisture content) and reported at the national level. In the current study, we utilized Food and Agriculture Organization statistics (FAOStat, 2024) but national organizations track this data on a regular basis and similar datasets can be found in most countries. To estimate mass in the current study, an average specific gravity (SG) of 0.7 was used, although it is acknowledged that different species of wood can have higher or lower SGs. It should be noted that this best represents an air-dried (12% moisture content) wood sample.

Recommendation #4: The practice of volumetric reporting in the global forest sector is based on practicalities but makes it challenging to carry out mass balances and to compare biomass use with other key sectors. Thus, conversion of volume to mass is critical. This would be better facilitated by (a) a more detailed description of forest harvest, including harvest numbers by species, and/or (b) generally recognized specific gravity numbers for conversion.

Forest harvest residues: This is the amount of wood that is left behind after harvest in the form of debris (e.g. damaged trees, tree tops, branches). This dataset is not tracked and is generally determined through a ratio applied to the total amount of wood harvested. A good discussion of the literature on this subject is found in Konstantinavičienė (2023), who applies a 40% ratio to roundwood to determine overall residue production. For the purpose of the present study, a 40% ratio is also used (***C*** in Figure 1).

Recommendation #5: The generation of forest harvest residues is largely dependent upon the harvest system used, the type of forest (i.e. species composition) being harvested, and by local policy which may dictate collection of certain residue types. The ratio used in this study (C) is a generic figure. Ideally, these ratios should be monitored and validated by national governments and national or sub-national ratios should be applied to determine forest harvest residue generation rates.

Recoverable harvest residues: Only a portion of forest harvest residues are considered recoverable, as a portion of the residues need to remain on the land for ecological purposes (e.g. nutrient recycling, erosion control, etc.). This dataset is not tracked but can be estimated using an estimate of sustainable residue recovery (***D*** in Figure 1). Konstantinavičienė (2023) suggests a 60% recovery rate based on a thorough review of the literature. This study also employs a 60% recovery rate, although countries that are dominated by steeper slopes (such as New Zealand) might be more accurately represented using a 40% recovery rate.

Other harvest residues: The portion of estimated forest harvest residues that is not recovered makes up other harvest residues. This dataset is not tracked but can be inferred.

Recommendation #6: The recovery of forest harvest residues should be determined by localized conditions, including forest species composition, harvest method employed, and local ecological goals (e.g. erosion control or soil stabilization). Ideally, this ratio (D) should be determined by national governments based on real-world analysis, and monitored, validated and updated on a regular basis.

Energy outputs (forests): Multiple datasets are available that describe energy outputs from forests, and these sets are provided by both national agencies and by organizations such as the Food and Agriculture Organization (FAO). Examining FAO statistics, these datasets include wood fuel (or fuelwood) series which are further broken down by coniferous or non-coniferous wood; non-coniferous wood fuel is further divided into tropical and other non-coniferous wood fuel. It should be noted that hog fuel (a generic term for forest residues produced in the sawmill or pulpmill) is not tracked, as this is most often used on site and thus not measured. In this study, hog fuel is estimated by looking at overall bioenergy use within the country and subtracting those energy streams which are more completely detailed. Taken together, these series are a subset of roundwood production and describe wood harvested for the purpose of generating heat, cooking, or for power production. Note that while wood fuel includes wood that could be used to make pellets, it excludes actual wood pellets, agglomerates, or other wood energy products (FAO 2022). Instead, three additional series – wood charcoal, wood pellets, and wood briquettes and other agglomerates – are provided. For the purposes of the present study, FAO statistics are used (FAOStat, 2024) to describe these outputs, and these outputs are considered to be energy products within this framework.

Primary and secondary wood products: Multiple datasets are available that describe these outputs from forests. For the purpose of this study, FAO statistics are used (FAOStat, 2024). A detailed description of these products and categories can be found in FAO's classification of forest products manual (FAO, 2022).

Energy recovery: This dataset is not tracked consistently. A portion of wood being processed may be used for energy recovery within a facility, or for energy generation. As an example, woody biomass may be present in wastewater, which is then subjected to anaerobic digestion, producing biogas and ultimately energy. While energy used outside the facility is often identified within national statistics, biomass used to create energy within the facility itself may be included in wood fuel or residues, which raises the potential of double-counting these materials. For the purpose of the current project, no data was input for this series, but a placeholder is present in the flowchart to indicate the importance of this data series going forward.

Wood residues: This dataseries is monitored. Wood residues are co-products of wood processing that can be used for other wood products, including agglomerated panels or energy products such as pellets. FAO statistics are used in the current study to describe wood residues (FAOStat, 2024) and wood residues are considered to be accessible biomass for future use within energy systems.

Black liquor recovery: For countries with advanced sulphate (Kraft) pulp industries, recovery boilers are usually employed to generate energy within the mill. In some cases, the capacity of these boilers may exceed mill requirements and provide energy back to the grid. This dataset is not consistently tracked, but some countries do monitor black liquor use. The Joint Wood Energy Enquiry also tracks black liquor use but does so in terms of total energy provided through the combustion of this product. Black liquor is produced at rates of about 1.4 t/t of Kraft pulp produced (measured in terms of dry content) (Kim et al. 2019), although data from the JWEE suggests that the ratio of black liquor generation is variable from country to country. For the current study, we utilized sulphate pulp production values (FAOStat, 2024) and developed ratios of black liquor pulp consumption using data from the JWEE where available (Canada, Finland, Germany, Sweden, USA). Where no country-specific data was available, the 1.4 t/t ratio was utilized.

Recommendation #7: Better data on energy recovery, particularly hog fuel generation, and black liquor recovery within forest operations are needed on a consistent basis. This data should be measured in t of biomass diverted to these streams; in the case of energy recovery, it is important that care is taken to ensure that this data is not double counted against wood residue production or against wood fuel production.

MUNICIPAL SOLID WASTE

Food waste: There is a stream of food waste that could be recovered for bioenergy production, either through combustion or though anaerobic digestion. This dataset is not consistently monitored. Some reports are available that provide insight into these trends; for example, the World Bank (Kaza et al. 2018) produces a review of global municipal solid waste production, but this is not an annual series of data and includes a number of assumptions and projections. The World Bank report and the associated dataset do allow researchers to identify the percentage of food waste in MSW on a country-level basis. For the purposes of the current report, the Kaza et al. (2018) data were used to estimate food waste as a component of municipal solid waste. These waste streams are considered to be accessible for utilization.

Paper, cardboard, and wood waste: There are streams of forest products in municipal waste that could be recovered for bioenergy production, primarily through combustion. This dataset is not consistently monitored. Some reports are available that provide insight into these trends; for example, the World Bank (Kaza et al. 2018) produces a review of global municipal solid waste production, but this is not an annual series of data and includes a number of assumptions and projections. Note that the World Bank report allows researchers to identify the percentage of paper and cardboard waste in MSW as well as wood waste, on a country-level basis; these measurements are taken after diversion for recycling so represent available biomass. For the purposes of the current report, the Kaza et al. (2018) data were used to estimate forest products waste as a component of municipal solid waste. These waste streams are considered to be accessible for utilization.

Recommendation #8: The contribution of municipal solid waste to bioenergy is very difficult to track, as some of this energy is likely already being recovered in the form of landfill gas used for energy. In order to be used in an optimal manner, it is likely that some kind of waste diversion program would be required to isolate these streams. From the perspective of data collection, it is important that individual nations have ownership over the ratios used to determine organic components within municipal solid waste, which in turn requires new data collection. Individual nations should monitor and validate these figures.

Section 3 - Country-level analyses

AUSTRALIA

Australia has a diverse range of resources, reflecting a country with vast natural resources and a wide range of ecosystems. Total primary energy supply (TPES) is dominated by oil, coal, and natural gas but as of 2021 renewables supplied approximately 8.4% of the total. Of this, bioenergy supplies 43.1% of renewables, and renewables were 11% of energy consumption. Australia's renewable energy supply is composed of approximately half of biomass. The total bioenergy supply is comprised of biogases (7.5%) and bioethanol with a vast majority of bioenergy concentrated in primary solid biofuels (industry and power) and primary solid biofuels (residential, services, and other). Approximately 90% of bioenergy in Australia are solid biofuels which is primarily dedicated to for power production within industry (IEA Bioenergy, 2021). Authors of the country report note that bioenergy potential is disproportionately small relative to the potential of biomass, and indeed a review of the data shows that bioenergy contributions to TPES have declined slightly since 2015, while the cumulative contribution of renewables have increased over the past decade (Figure 4).

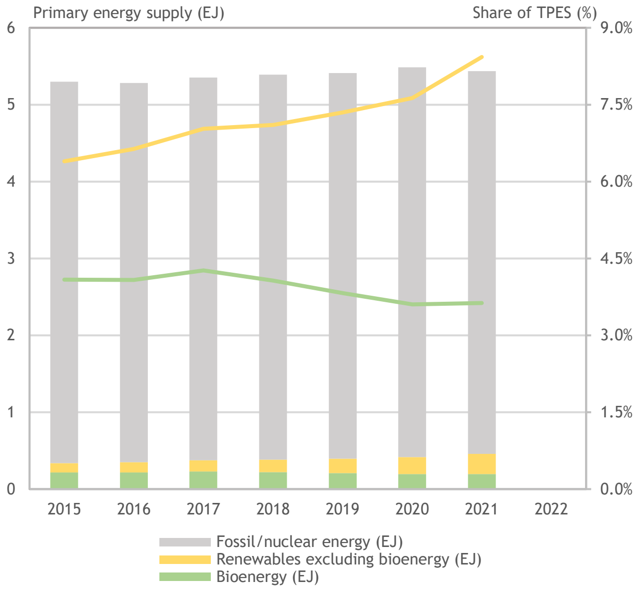
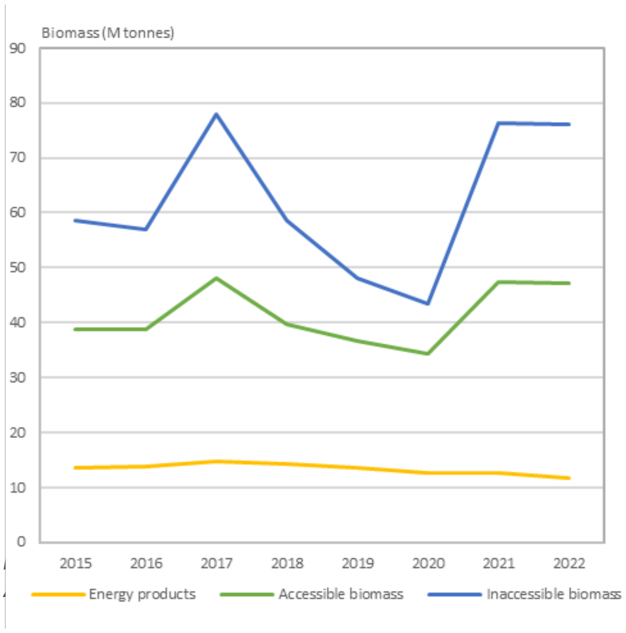


Figure 4: Total primary energy supply and role of renewables, Australia, 2015-2021 (Source: IEA, 2024)

The current study has assessed accessible and inaccessible biomass supply as well as the present contribution of biomass to energy products (Figure 5). Approximately 11.6 million tonnes of biomass are estimated to flow to energy products per year. Almost 40 Mt of biomass are estimated to be 'accessible', including forest harvest and wood processing residues, organic components of municipal solid waste, and agricultural residues. The estimates of inaccessible biomass are highly variable, with much of the variation explained by changes in crop production from year to year throughout the study period.



An overview of the flows of biomass are shown in Figure 6. At the top of the figure, agricultural production is divided into crops (payload) and agricultural residues, which are further divided into high density (>3 t/ha) and low density (<3 t/ha) residues. The majority of agricultural residues are considered to be inaccessible as they must be left on the field for sustainability purposes, as discussed in Section 2. However, a portion of these residues may be accessed, and this makes up the largest component of the accessible biomass stream. Organic components of municipal solid waste, including food and wood product waste, makes up the second-largest component of the accessible biomass. The majority of forest biomass goes to primary and secondary wood products, but both forest harvest residues and wood residues could contribute to accessible biomass. It is also estimated that a portion of the black liquor generated within the country is not yet used for energy production and could be accessed, and this is represented by the small grey line. A small portion of agricultural crop production flows to energy products in the form of ethanol and biodiesel production; some black liquor is also diverted to energy production, and both wood fuels (solid biomass) and processed wood products (like pellets) are currently used for energy outputs.

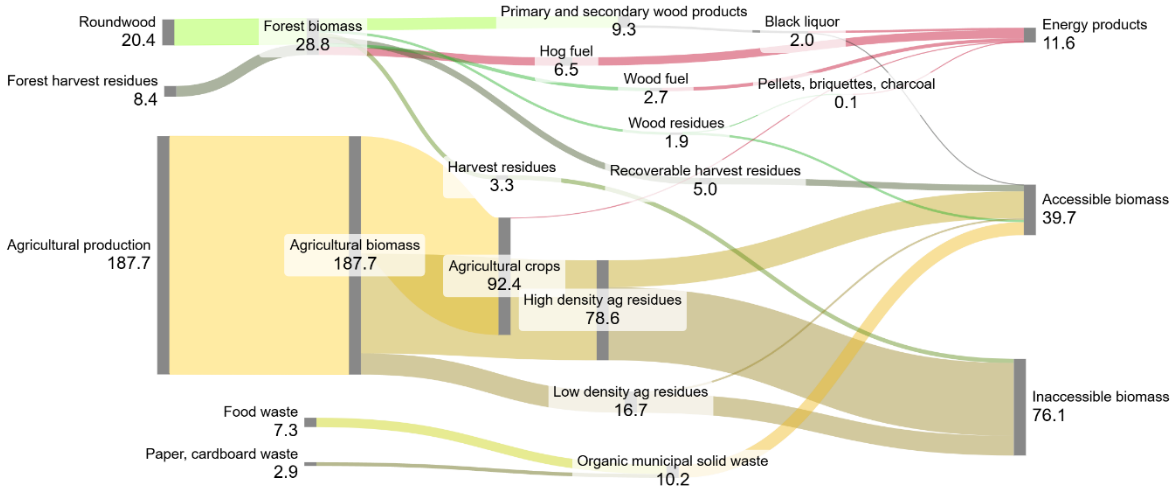


Figure 6: Sankey diagram of biomass flows (Mt), Australia, 2022

Figure 6 suggests that there is a large amount of accessible biomass that could be potentially available for energy production. Many of these feedstocks are widely distributed, however; both agricultural residues and forest harvest residues tend to be scattered over large areas and are costly to collect. More concentrated streams might include portions of municipal solid waste; in the case of Australia, food waste makes up about 48% of municipal solid waste (MSW) streams, while paper and cardboard contribute another 17% (Kaza et al., 2018); it may be difficult to utilize a mixed stream of MSW to capitalize on these streams. The most economically feasible sources of accessible biomass are likely to be wood residues (about 1.8 Mt/a) and black liquor (estimated at about 0.1 Mt/a). Utilizing these sources, however, would increase the amount of biomass going into energy products by 43% over the existing flow.

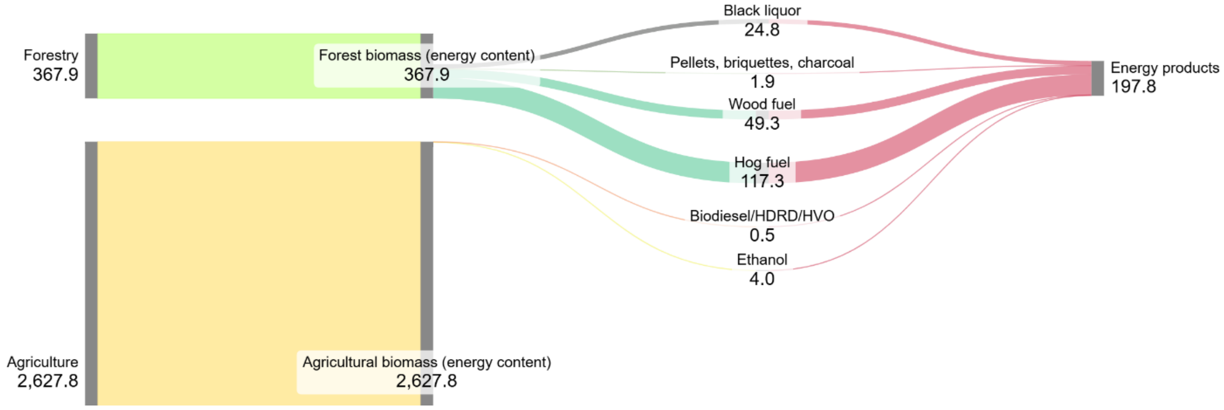


Figure 7 - Sankey diagram of biomass-to-energy pathways (PJ), Australia, 2022

Figure 7 shows the flow of energy products by energy content, as sourced from forest biomass and agricultural biomass. It should be noted that it is likely that some biodiesel production is sourced from organic waste streams, but a lack of data made it impossible to identify these flows. As shown in Figure 7, the largest contributor to energy products in Australia is wood fuel, including hog fuel (117.3 PJ) and firewood (49.3 PJ). Black liquor is also a large contributor. In all, it is estimated that 197.8 PJ of energy is provided, primarily from forest biomass.

Data for Australia is summarized in Table 1.

Table 1: Data summary sheet, Australia

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm^3)	29.9	31.0	36.8	[1]
Roundwood supply including net trade (Mm^3)	29.2	29.4	31.9	[1]
Roundwood supply including net trade (Mt)	20.4	20.6	22.3	c
Forest harvest residues (Mt)	8.4	8.7	10.3	c
Available forest harvest residues (Mt)	5.0	5.2	6.2	c
Wood residue production (Mm^3)	2.6	2.6	2.6	[1]
Wood residue production (Mt)	1.8	1.8	1.8	c
Agricultural production, high residues (Mt)		78.5	59.3	[1]
Agricultural production, low residues (Mt)		13.8	8.2	[1]
Agricultural residue production, high density (Mt)		78.6	48.2	c
Agricultural residue production, low density (Mt)		16.7	9.6	c
Available ag. residues, high density (Mt)		21.1	13.0	c
Available ag. residues, low density (Mt)		1.4	0.8	c
Municipal solid waste production (food) (t/c/a)	0.3	0.3	0.3	[2]
Municipal solid waste production (paper) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (food) (Mt)	7.3	7.2	7.0	c
Municipal solid waste production (paper) (Mt)	10.5	10.4	7.7	c
Total domestic supply of biomass (Mm^3)	104.2	104.5	77.9	c
Energy resources				

Total primary energy supply (TPES) (EJ)		5.4	5.4	[3]
Share of renewables (RES) in TPES (%)		8.4%	7.3%	[3]
Total bioenergy supply (EJ)		0.20	0.21	[3]
Share of bioenergy in TPES (%)		3.6%	3.8%	[3]
Share of bioenergy in RES (%)		43.1%	52.0%	[3]
Energy intensity				
Population (M)	26.0	25.7	25.3	[4]
Energy consumption (GJ/c/a)	209.3	211.7	213.6	c
Bioenergy consumption (GJ/c/a)	7.6	7.7	8.2	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2022

Note: c represents 'calculated value'; e represents 'estimated value'

Table 2: Data summary sheet, Australia (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	0.02	0.02	0.04	[1]
Wood fuel, non-coniferous (Mm^3)	3.89	3.89	4.06	[1]
Wood fuel total (Mt)	2.74	2.74	2.87	c
Wood fuel, coniferous including net trade (Mm^3)	0.02	0.00	0.00	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	3.89	3.89	4.06	[1]
Wood fuel including net trade total (Mt)	2.74	2.72	2.85	c
Briquettes and agglomerates production (Mt)	0.00	0.00	0.00	[1]
Charcoal production (Mt)	0.02	0.02	0.02	[1]
Wood pellet production (Mt)	0.10	0.10	0.06	[1]
Pellets, briquettes, charcoal total (Mt)	0.12	0.12	0.09	c
Briquettes and agglomerates including net trade (Mt)	0.01	0.01	0.00	[1]
Charcoal including net trade (Mt)	0.05	0.05	0.04	[1]
Wood pellets including net trade (Mt)	0.04	0.01	0.00	[1]
Pellets, briquettes, charcoal including net trade (Mt)	0.10	0.07	0.05	c
Sulphate pulp production (Mt)	1.08	0.99	1.08	[1]
Black liquor used for energy (Mt)	1.77	1.63	1.78	c
Black liquor surplus (Mt)	0.16	0.15	0.16	c
Hog fuel estimate (Mt)	6.51	7.75	8.21	e
Share of roundwood directly used for energy (%)	13.9%	13.5%	13.0%	c
Share of roundwood indirectly used for energy (%)	8.7%	7.9%	8.0%	c
Total roundwood used for energy (%)	22.6%	21.4%	20.9%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	175.0	175.0	239.0	[5,6]
Biodiesel production (FAME, HVO) (Ml)	15.0	25.0	28.0	[5,6]
Feedstock required (ethanol) (Mt)	0.49	0.49	0.66	c

Feedstock required (FAME, HVO) (Mt)	0.03	0.05	0.06	c
Total feedstock required (Mt)	0.52	0.54	0.72	c
Total agricultural production used for energy (%)	0.6%	0.6%	1.1%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2022

Note: c represents 'calculated value'; e represents 'estimated value'

CANADA

Canada's total energy supply primary energy supply is dominated by fossil fuels. At the present time, about 16% of TPES is drawn from renewables, and biomass provides about one quarter of this supply. Within the bioenergy supply a large portion (80%) are solid biofuels that are used in industry, but this supply is decline in comparison to other bioenergy supplies in the mix. Other bioenergy supply includes biofuels for transport (bioethanol and biodiesel) which are on the rise in recent years (IEA Bioenergy, 2021). The overall supply of renewables has declined in recent years, while the supply of bioenergy is also dropping overall, as shown in Figure 7. The utilization of bioenergy is disproportionate to the overall potential.

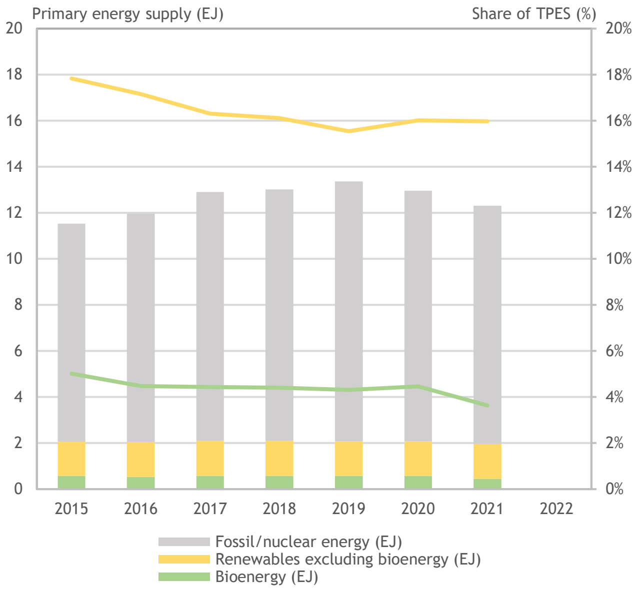
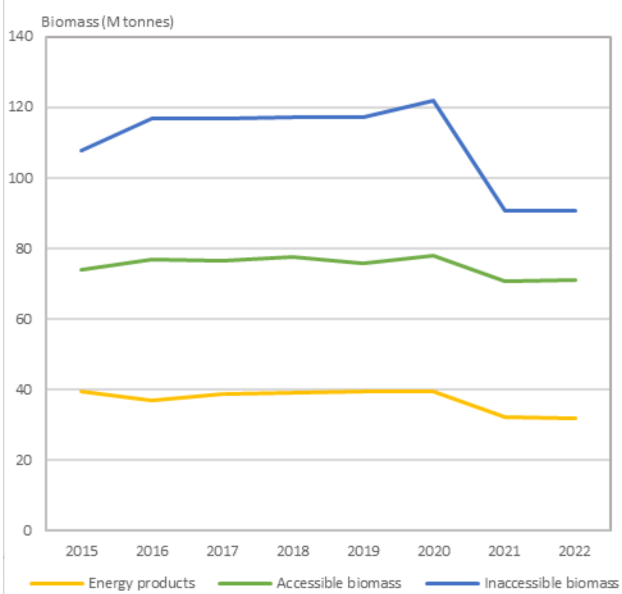


Figure 8 - Total primary energy supply and role of renewables, Canada, 2015-2021 (Source: IEA, 2024)



The current study has assessed accessible and inaccessible biomass supply as well as the present contribution of biomass to energy products (Figure 9). Approximately 32.1 million tonnes of biomass are estimated to flow to energy products per year. About 71 Mt/a of biomass are estimated to be 'accessible', including forest harvest and wood processing residues, organic components of municipal solid waste, and agricultural residues. The estimates of inaccessible biomass have dropped in recent years, largely because of changes in forest harvest related to the pandemic but remain high (about 91 Mt/a).

An overview of the flows of biomass are shown in the Sankey diagram in Figure 10. Canadian production of both agricultural and forest biomass is high, and large amounts of residues are generated from these activities. Forest biomass - specifically forest harvest residues - makes up the largest component of estimated accessible biomass in Canada. Potential recovery from municipal solid waste (food as well as paper, cardboard, and wood) is tied with agricultural residues as the second most abundant source of accessible biomass. Wood processing residues comprise the remainder of the estimated accessible fibre within Canada. A small amount of agricultural production supports biofuels (ethanol and biodiesel), while similar amounts of black liquor are covered in the form of energy. Solid wood fuels and energy products including wood pellets form the remainder of the biomass-to-energy pathways.

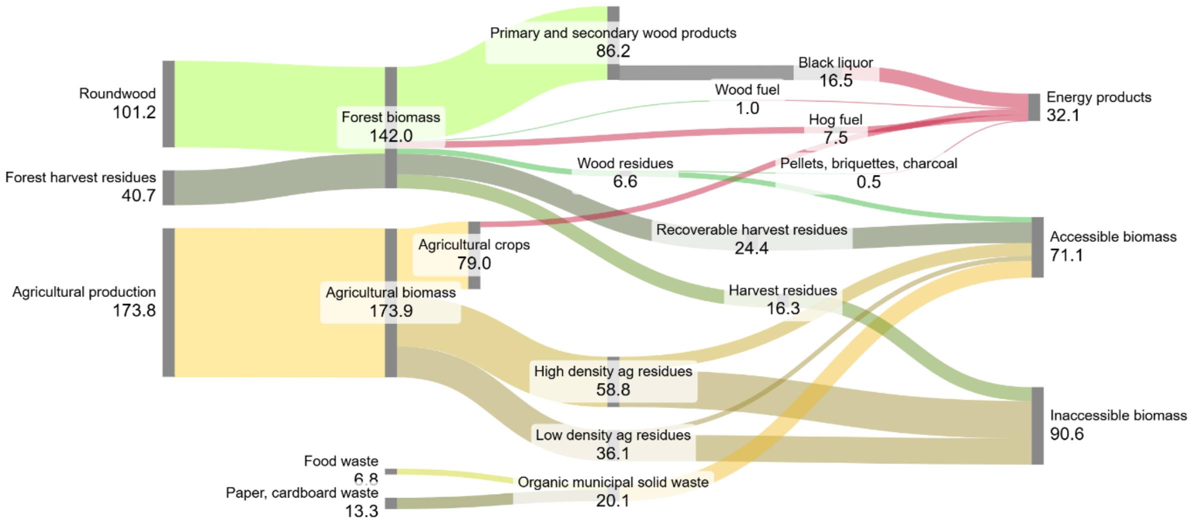


Figure 10 - Sankey diagram of biomass flows (Mt), Canada, 2022

Figure 11 highlights the relatively low uptake of bioenergy in Canada, compared to other biomass flows. While most of the accessible biomass sources are decentralized and spread over a large area, wood processing residues are highly concentrated, and utilizing these resources more effectively for energy would increase the biomass flow to energy by 38%. The use of black liquor for energy is likely close to it's maximum now, based on reporting from NRCan and the JWEE (UNECE/FAO, 2024). The other streams that are more concentrated and could be made use of include the organic portions of municipal solid waste. Canadian MSW is comprised of 24% food waste and 47% paper and cardboard (Kaza et al., 2018); the high proportion of wood products in MSW (higher than any other country assessed here) may make it easier to recover portions of this biomass for energy purposes.

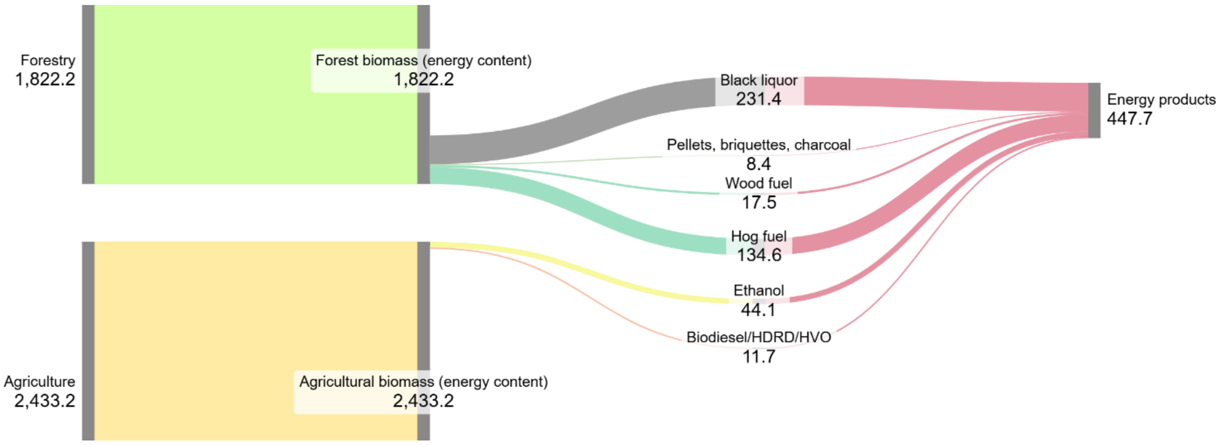


Figure 11 - Sankey diagram of biomass-to-energy pathways (PJ), Canada, 2022

In Figure 11, the flow of biomass to different energy products is shown by energy content., with black liquor dominating the total bioenergy flow (231.4 PJ). Hog fuel (134.6) and ethanol from corn and wheat (44.1 PJ) follow as the most dominant bioenergy sources in Canada. In all, about 447.7 PJ of bioenergy is estimated to flow through different energy products.

Data for Canada is summarized in Table 2.

Table 2: Data summary sheet, Canada

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm^3)	145.3	145.3	141.6	[1]
Roundwood supply including net trade (Mm^3)	144.6	144.5	138.6	[1]
Roundwood supply including net trade (Mt)	101.2	101.1	97.0	c
Forest harvest residues (Mt)	40.7	40.7	39.6	c
Available forest harvest residues (Mt)	24.4	24.4	23.8	c
Wood residue production (Mm^3)	8.8	8.8	8.8	[1]
Wood residue production (Mt)	6.1	6.1	6.1	c
Agricultural production, high residues (Mt)		45.0	57.7	[1]
Agricultural production, low residues (Mt)		34.0	43.4	[1]
Agricultural residue production, high density (Mt)		58.8	78.7	c
Agricultural residue production, low density (Mt)		36.1	49.3	c
Available ag. residues, high density (Mt)		15.1	20.5	c
Available ag. residues, low density (Mt)		5.5	6.4	c
Municipal solid waste production (food) (t/c/a)	0.2	0.2	0.2	[3]
Municipal solid waste production (paper) (t/c/a)	0.3	0.3	0.3	[3]
Municipal solid waste production (food) (Mt)	6.8	6.6	6.5	c
Municipal solid waste production (paper) (Mt)	13.3	13.0	12.7	c
Total domestic supply of biomass (Mm^3)	144.6	212.9	228.3	c
Energy resources				
Total primary energy supply (TPES) (EJ)		12.3	13.4	[3]
Share of renewables (RES) in TPES (%)		16.0%	15.5%	[3]

Total bioenergy supply (EJ)		0.45	0.58	[3]
Share of bioenergy in TPES (%)		3.6%	4.3%	[3]
Share of bioenergy in RES (%)		22.8%	27.8%	[3]
Energy intensity				
Population (M)	38.9	38.2	37.6	[4]
Energy consumption (GJ/c/a)		322.1	355.4	c
Bioenergy consumption (GJ/c/a)		11.7	15.3	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023a

Note: c represents 'calculated value'; e represents 'estimated value'

Table 2: Data summary sheet, Canada (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	0.69	0.69	0.80	[1]
Wood fuel, non-coniferous (Mm^3)	0.80	0.80	0.95	[1]
Wood fuel total (Mt)	1.04	1.04	1.23	c
Wood fuel, coniferous including net trade (Mm^3)	0.61	0.62	0.70	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	0.77	0.78	0.93	[1]
Wood fuel including net trade total (Mt)	0.97	0.98	1.14	c
Briquettes and agglomerates production (Mt)	0.15	0.15	0.15	[1]
Charcoal production (Mt)	0.00	0.00	0.00	[1]
Wood pellet production (Mt)	3.83	3.83	3.20	[1]
Pellets, briquettes, charcoal total (Mt)	3.98	3.98	3.35	c
Briquettes and agglomerates including net trade (Mt)	0.01	0.02	0.03	[1]
Charcoal including net trade (Mt)	0.09	0.17	0.03	[1]
Wood pellets including net trade (Mt)	0.37	0.71	0.59	[1]
Pellets, briquettes, charcoal including net trade (Mt)	0.47	0.89	0.66	c
Sulphate pulp production (Mt)	7.78	8.12	9.02	[1]
Black liquor used for energy (Mt)	16.53	17.26	18.80	c
Black liquor surplus (Mt)	0.00	0.00	0.00	c
Hog fuel estimate (Mt)	7.48	6.37	12.62	e
Share of roundwood directly used for energy (%)	1.4%	1.9%	1.8%	c
Share of roundwood indirectly used for energy (%)	16.3%	17.1%	19.4%	c
Total roundwood used for energy (%)	17.7%	18.9%	21.2%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	2100.0	2100.0	2013.0	[5,6]
Biodiesel production (FAME, HVO) (Ml)	357.0	416.0	359.0	[5,6]
Feedstock required (ethanol) (Mt)	5.83	5.83	5.59	c
Feedstock required (FAME, HVO) (Mt)	0.76	0.89	0.76	c
Total feedstock required (Mt)	6.59	6.72	6.36	c

Total agricultural production used for energy (%)	0.0%	8.5%	6.3%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023a

Note: c represents 'calculated value'; e represents 'estimated value'

CROATIA

Overall Croatia's energy supply is predominantly fossil fuel, with renewables accounting for about 28% of TPES in 2021. The biomass contribution to TPES was 19% in 2021, largely comprised of solid biofuels with a much smaller component of aggregates or important biofuels (IEA Bioenergy, 2021). In recent years, the contribution of renewable energy to TPES has seen fluctuations, largely due to the changing contribution of hydro power year to year; the bioenergy contribution has grown slightly in recent years (Figure 10).

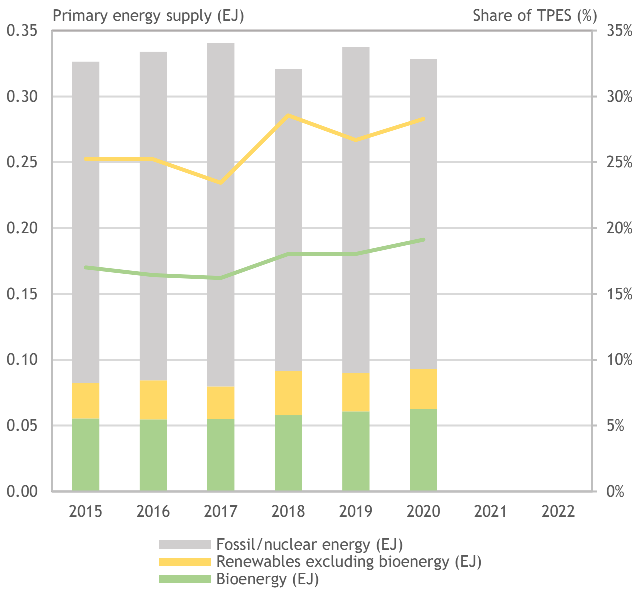
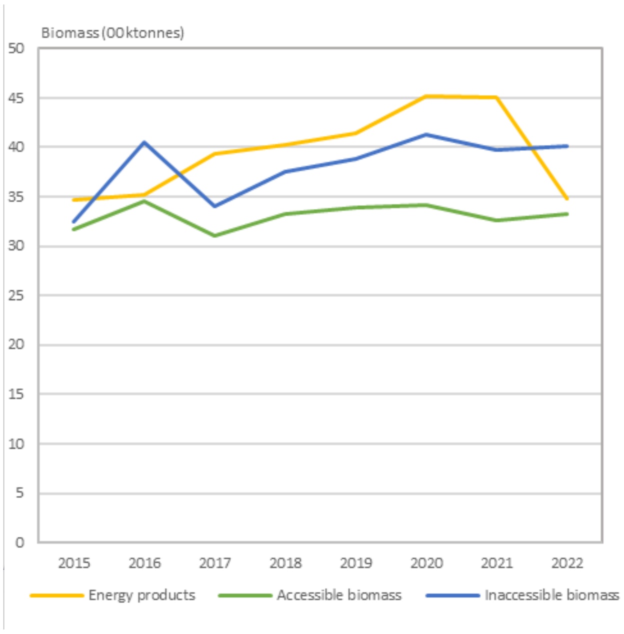


Figure 12 - Total primary energy supply and role of renewables, Croatia, 2015-2020 (Source: IEA, 2024)

The present study assessed accessible and inaccessible biomass supply as well as the present contribution of biomass to energy products as shown in Figure 12. About 3.5 million tonnes of biomass are estimated to flow to energy products per year. Another 3.3 Mt/a of biomass are estimated to be 'accessible', including forest harvest and wood processing residues, organic components of municipal solid waste, and agricultural residues. Inaccessible biomass is estimated to be as high as 4.0 Mt/a, in the form of residues that must be left in the field in order to meet sustainability criteria.



An overview of the flows of biomass across Croatia in 2022 are shown in the Sankey diagram in Figure 14. Agricultural biomass production is the largest contributor to overall biomass supply, with large portions of both accessible and inaccessible residues generated from these operations. At the present time, no agricultural biomass is being used for energy purposes. Relatively small amounts of municipal solid waste are also being generated and are considered to be accessible. Finally, forest production is substantial, and the bulk of energy products in Croatia are derived from these biomass sources. Solid wood fuels and a small portion of energy products including wood pellets form the entire biomass-to-energy pathway.

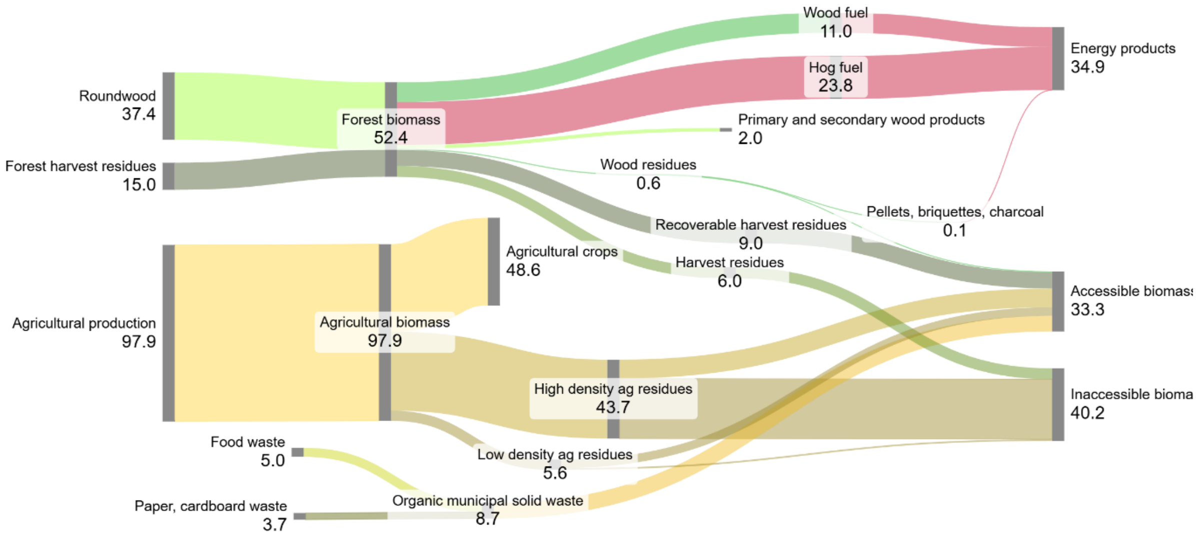


Figure 14 - Sankey diagram of biomass flows (100 kt), Croatia, 2022

As shown in Figure 15, forest biomass is the most important contributor to overall bioenergy production in Croatia, and the great majority of this is in the form of fuel wood or 'hog fuel' (which here refers to the total amount of biomass waste recovered at sawmills and used for residential energy purposes). The country currently has no biofuel production and no Kraft pulping industry, which means that little other forest biomass and no other agricultural biomass is currently used for energy purposes. In terms of available biomass, there may be some potential to gather the organic components of MSW, which in Croatia is comprised of 31% food waste and 23% paper and cardboard (Kaza et al., 2018). This potential serves as a feedstock for additional bioenergy production through anaerobic digestion or the diversion and processing of fibre products. Large amounts of forest harvest residues and agricultural residues are also potentially available, but exist in a highly decentralized form, which means that the cost of recovering and utilizing these feedstocks may reduce the economic feasibility of these pathways.

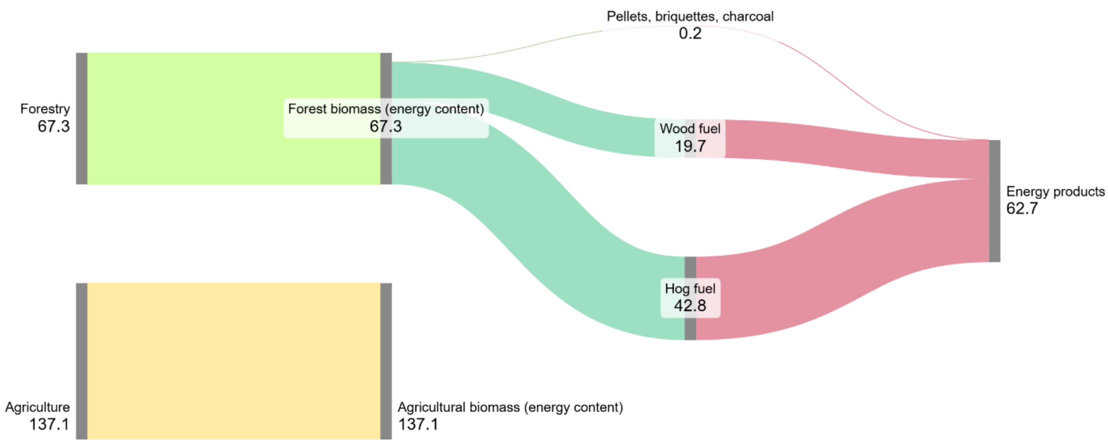


Figure 15 - Sankey diagram of biomass-to-energy pathways (PJ), Croatia, 2022

In Figure 15, the flow of bioenergy products on an energy basis is displayed. The primary source of biomass-to-energy is wood fuel, including firewood (19.7 PJ) and hog fuel (42.8 PJ); this energy is primarily used in residential heat. Pellets, briquettes, and charcoal make up a small fraction of available wood energy products. Data for Croatia is summarized in Table 3.

Table 3: Data summary sheet, Croatia

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (00 000 m^3)	53.4	49.9	54.0	[1]
Roundwood supply including net trade (00 000m^3)	53.4	42.4	48.4	[1]
Roundwood supply including net trade (00 000t)	37.4	29.7	33.9	c
Forest harvest residues (00 000t)	15.0	14.0	15.1	c
Available forest harvest residues (00 000t)	9.0	8.4	9.1	c
Wood residue production (00 000m^3)	0.7	0.7	2.1	[1]
Wood residue production (00 000t)	0.5	0.5	1.4	c
Agricultural production, high residues (00 000t)		42.5	41.0	[1]
Agricultural production, low residues (00 000t)		6.2	6.9	[1]
Agricultural residue production, high density (00 000t)		43.7	41.1	c
Agricultural residue production, low density (00 000t)		5.6	6.1	c
Available ag. residues, high density (00 000t)		10.4	9.7	c
Available ag. residues, low density (00 000t)		4.7	4.8	c
Municipal solid waste production (food) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (paper) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (food) (00 000t)	5.0	5.0	5.1	c
Municipal solid waste production (paper) (00 000t)	3.7	3.7	3.8	c
Total domestic supply of biomass (00 000m^3)	53.4	92.6	96.7	c
Energy resources				
Total primary energy supply (TPES) (EJ)			0.3	[3]
Share of renewables (RES) in TPES (%)			26.7%	[3]
Total bioenergy supply (EJ)			0.06	[3]
Share of bioenergy in TPES (%)			18.0%	[3]
Share of bioenergy in RES (%)			67.6%	[3]
Energy intensity				
Population (M)	3.9	3.9	4.1	[4]
Energy consumption (GJ/c/a)			83.0	c
Bioenergy consumption (GJ/c/a)			15.0	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

Table 3: Data summary sheet, Croatia (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (00 000m^3)	0.50	0.50	0.54	[1]
Wood fuel, non-coniferous (00 000m^3)	20.80	20.80	21.51	[1]
Wood fuel total (00 000t)	14.91	14.91	15.44	c
Wood fuel, coniferous including net trade (00 000m^3)	0.02	0.02	0.10	[1]
Wood fuel, non-coniferous incl. net trade (00 000m^3)	15.65	15.65	17.06	[1]
Wood fuel including net trade total (00 000t)	10.97	10.97	12.01	c
Briquettes and agglomerates production (00 000t)	0.69	0.69	0.78	[1]
Charcoal production (00 000t)	0.13	0.13	0.14	[1]
Wood pellet production (00 000t)	3.29	3.29	3.08	[1]
Pellets, briquettes, charcoal total (00 000t)	4.11	4.11	3.99	c
Briquettes and agglomerates incl. net trade (00 000t)	0.00	0.00	0.06	[1]
Charcoal including net trade (00 000t)	0.10	0.10	0.15	[1]
Wood pellets including net trade (00 000t)	0.00	0.00	0.49	[1]
Pellets, briquettes, charcoal incl. net trade (00 000t)	0.11	0.11	0.69	c
Sulphate pulp production (00 000t)	0.00	0.00	0.00	[1]
Black liquor used for energy (00 000t)	0.00	0.00	0.00	c
Black liquor surplus (00 000t)	0.00	0.00	0.00	c
Hog fuel estimate (00 000t)	23.79	33.92	28.76	e
Share of roundwood directly used for energy (%)	93.2%	37.4%	37.5%	c
Share of roundwood indirectly used for energy (%)	0.0%	0.0%	0.0%	c
Total roundwood used for energy (%)	93.2%	37.4%	37.5%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	0.0	0.0	0.0	[5,6]
Biodiesel production (FAME, HVO) (Ml)	0.0	0.0	0.0	[5,6]
Feedstock required (ethanol) (Mt)	0.00	0.00	0.00	c
Feedstock required (FAME, HVO) (Mt)	0.00	0.00	0.00	c
Total feedstock required (Mt)	0.00	0.00	0.00	c
Total agricultural production used for energy (%)	0.0%	0.0%	0.0%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

FINLAND

The total primary energy supply of Finland had 42% renewables in 2021, with 35% of TPES coming from biomass (Figure 16). The majority of bioenergy was sourced from black liquor and from solid wood, with the remainder originating from biofuels and biogases (IEA Bioenergy, 2021). Recent decades have seen the growth of solid biofuels for industry, biodiesel and bioethanol growth have fluctuated but on an upward trend, where biogas taken from the renewable municipal waste supply has also shown some growth. Finland saw renewables rise from 26% to 35% of TPES between 2010 and the present day. Across the countries considered in this study, the proportion of TPES from bioenergy is the highest in Finland.

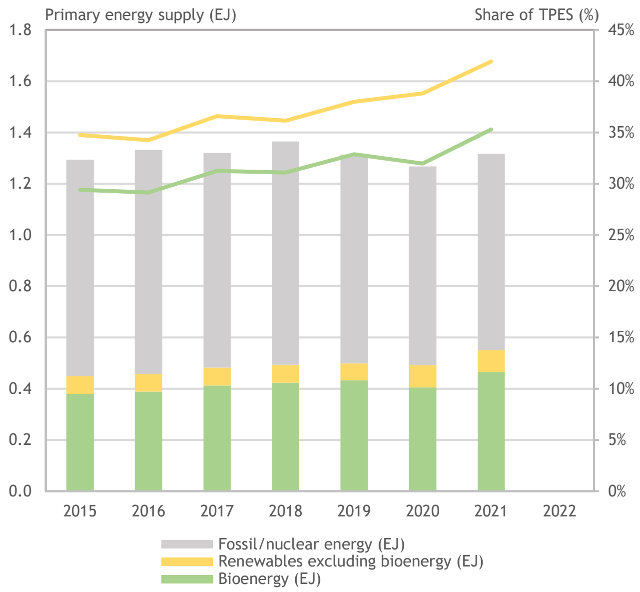


Figure 16 - Total primary energy supply and role of renewables, Finland, 2015-2021 (Source: IEA, 2024)

The assessment of accessible and inaccessible biomass supply as well as the present contribution of biomass to energy products is shown in Figure 17. About 27.4 million tonnes of biomass are estimated to flow to energy products per year, with another 20.1 Mt/a of biomass estimated to be 'accessible', primarily in the form of forest harvest and wood processing residues. These estimates have been fairly consistent in recent years, with a slight rise in the use of biomass to energy observed between 2015 and present day.

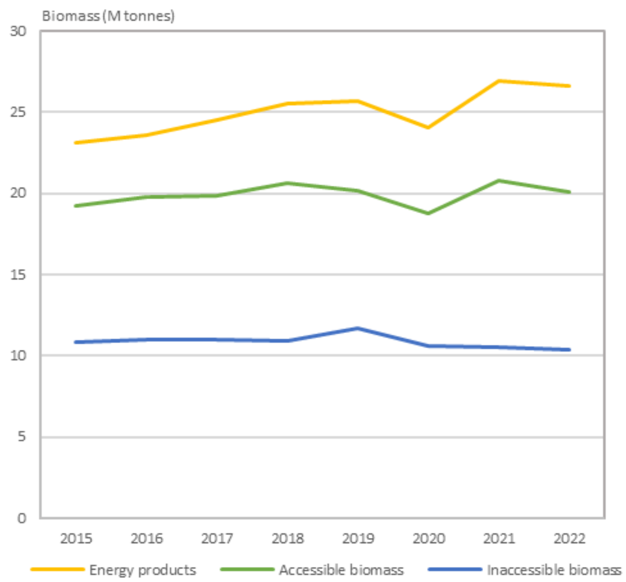


Figure 17 - Biomass by availability and biomass-to-energy, Finland, 2015-2022

Flows of biomass across Finland in 2022 are shown in the Sankey diagram in Figure 18. Finnish biomass supply is dominated by forest biomass is high. Large portions of harvest residues are presumed to be accessible, and these streams make up the largest component of estimated accessible biomass in Finland. The second greatest source of potentially available biomass are the organic portions of municipal solid waste, which includes food as well as paper, cardboard, and wood. Agricultural residues make up a very small portion of the overall biomass supply.

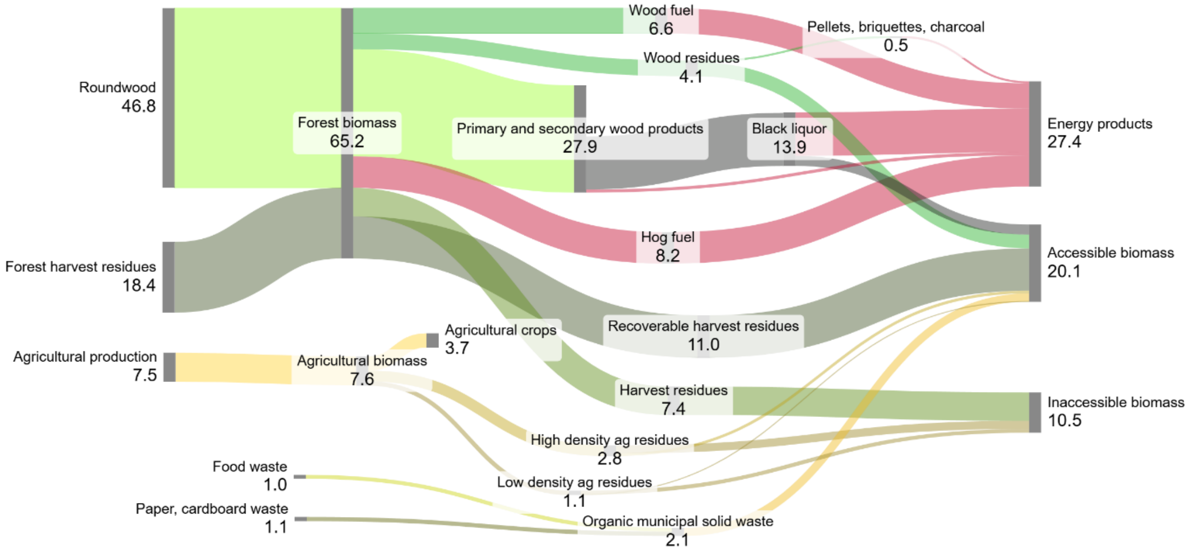


Figure 18 - Sankey diagram of biomass flows (Mt), Finland, 2022

Figure 18 highlights the very strong uptake of bioenergy in Finland, with wood fuel, hog fuel, and black liquor contributing the majority of this energy. Two concentrated streams of biomass are identified as 'accessible' – wood processing residues (3.6 Mt/a) and underutilized black liquor (1.4 Mt/a). Together, diverting these sources to energy would increase biomass-to-energy use. The organic portions of municipal solid waste include food waste (38%), paper and cardboard (36%), and wood (1%) (Kaza et al., 2018); the high proportion of wood products in MSW suggests that increased diversion for use in energy or valued-added products might be worthwhile.

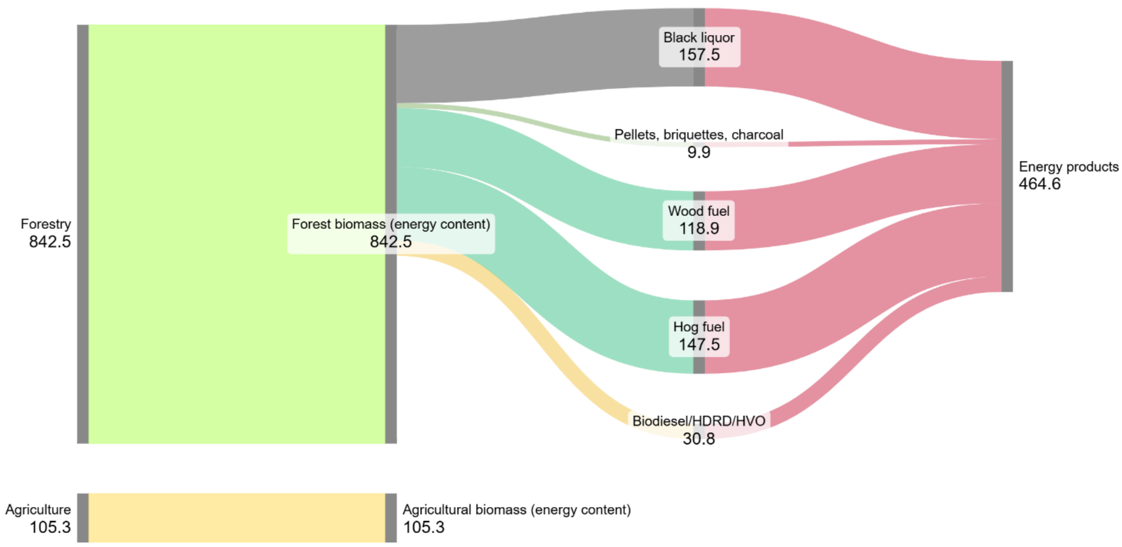


Figure 19 – Sankey diagram of biomass-to-energy pathways (PJ), Finland, 2022

In Figure 19, biomass to energy pathways are shown on an energy basis. The primary contributors to bioenergy in Finland are black liquor (157.5 PJ), wood fuel (118.9 PJ), and hog fuel (147.5 PJ). Current data suggests that all bioenergy products in Finland are sourced from forest biomass. Data for Finland is summarized in Table 4.

Table 4: Data summary sheet, Finland

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm³)	65.6	66.7	63.7	[1]
Roundwood supply including net trade (Mm³)	66.9	72.0	68.5	[1]
Roundwood supply including net trade (Mt)	46.8	50.4	48.0	c
Forest harvest residues (Mt)	18.4	18.7	17.8	c
Available forest harvest residues (Mt)	11.0	11.2	10.7	c
Wood residue production (Mm³)	5.1	5.5	5.0	[1]
Wood residue production (Mt)	3.6	3.8	3.5	c
Agricultural production, high residues (Mt)		2.2	3.3	[1]
Agricultural production, low residues (Mt)		1.5	1.9	[1]
Agricultural residue production, high density (Mt)		2.8	4.3	c
Agricultural residue production, low density (Mt)		1.1	1.5	c
Available ag. residues, high density (Mt)		0.7	1.1	c
Available ag. residues, low density (Mt)		0.1	0.1	c
Municipal solid waste production (food) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (paper) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (wood) (t/c/a)	0.0	0.0	0.0	[2]
Municipal solid waste production (food) (Mt)	1.0	1.0	1.0	c
Municipal solid waste production (paper) (Mt)	1.1	1.1	1.1	c
Municipal solid waste production (wood) (Mt)	0.0	0.0	0.0	c
Total domestic supply of biomass (Mm³)	66.9	74.7	72.6	c
Energy resources				
Total primary energy supply (TPES) (EJ)		1.3	1.3	[3]
Share of renewables (RES) in TPES (%)		41.9%	38.0%	[3]
Total bioenergy supply (EJ)		0.46	0.43	[3]
Share of bioenergy in TPES (%)		35.3%	32.9%	[3]
Share of bioenergy in RES (%)		84.2%	86.6%	[3]
Energy intensity				
Population (M)	5.6	5.5	5.5	[4]
Energy consumption (GJ/c/a)		237.6	237.9	c
Bioenergy consumption (GJ/c/a)		83.8	78.2	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

Table 4: Data summary sheet, Finland

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	4.61	4.30	3.72	[1]
Wood fuel, non-coniferous (Mm^3)	4.77	4.61	4.30	[1]
Wood fuel total (Mt)	6.57	6.24	5.61	c
Wood fuel, coniferous including net trade (Mm^3)	4.64	4.36	3.63	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	4.80	4.64	4.38	[1]
Wood fuel including net trade total (Mt)	6.61	6.30	5.61	c
Briquettes and agglomerates production (Mt)	0.00	0.00	0.02	[1]
Charcoal production (Mt)	0.00	0.00	0.00	[1]
Wood pellet production (Mt)	0.36	0.37	0.34	[1]
Pellets, briquettes, charcoal total (Mt)	0.36	0.37	0.36	c
Briquettes and agglomerates including net trade (Mt)	0.01	0.03	0.01	[1]
Charcoal including net trade (Mt)	0.00	0.01	0.00	[1]
Wood pellets including net trade (Mt)	0.54	0.55	0.41	[1]
Pellets, briquettes, charcoal including net trade (Mt)	0.55	0.59	0.43	c
Biodiesel production (HDRD) (Ml)	830.0	753.0	424.0	[5,6]
Feedstock required (HDRD) (Mt)	0.81	0.73	0.41	c
Sulphate pulp production (Mt)	7.68	8.32	7.92	[1]
Black liquor used for energy (Mt)	11.25	12.19	11.60	c
Black liquor surplus (Mt)	2.57	2.79	2.65	c
Hog fuel estimate (Mt)	8.19	7.88	8.06	e
Share of roundwood directly used for energy (%)	17.0%	15.1%	13.4%	c
Share of roundwood indirectly used for energy (%)	24.0%	24.2%	24.2%	c
Total roundwood used for energy (%)	41.1%	39.3%	37.6%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	0.0	0.0	0.0	[5,6]
Biodiesel production (FAME, HVO) (Ml)	0.0	0.0	0.0	[5,6]
Feedstock required (ethanol) (Mt)	0.00	0.00	0.00	c
Feedstock required (FAME, HVO) (Mt)	0.00	0.00	0.00	c
Total feedstock required (Mt)	0.00	0.00	0.00	c
Total agricultural production used for energy (%)	0.0%	0.0%	0.0%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

GERMANY

As of 2021, Germany's total primary energy supply was comprised of 17% renewables; 11% of TPES (or about 65% of renewables) were derived through biomass-to-energy pathways. The majority of biomass consumed was solid biomass, followed by biogas produced from agricultural residues (IEA Bioenergy, 2021). Smaller proportions of bioenergy come from renewable municipal waste, biodiesel, bioethanol, and other liquid biofuels. Since 2000, there has been a steady increase in the share of renewable energy sources within the larger energy supply in Germany, growing from 3% to 17% over the course of nearly two decades. In recent years, the growth of bioenergy within TPES has lagged behind the growth of overall renewables, as shown in Figure 20.

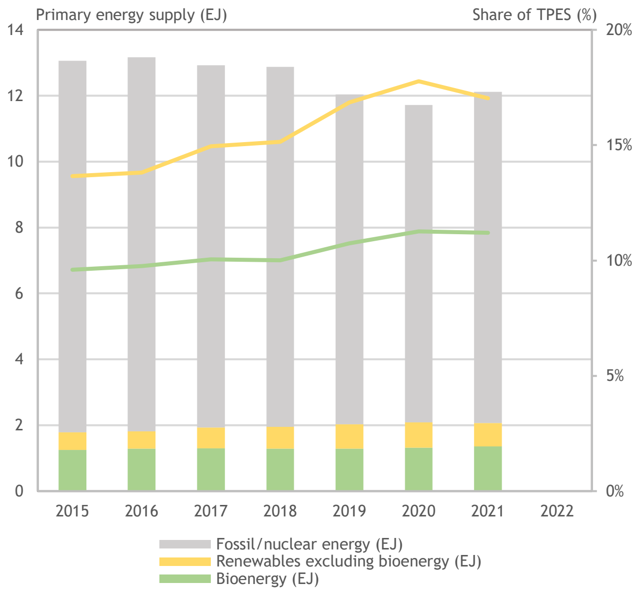
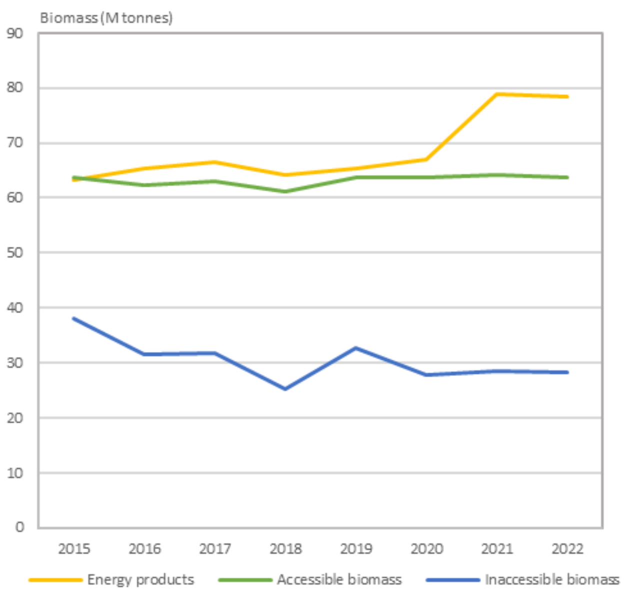


Figure 20 - Total primary energy supply and role of renewables, Germany, 2015-2021 (Source: IEA, 2024)

Germany makes good use of biomass for energy, as shown in Figure 21. About 78 million tonnes of biomass per year are estimated to be used for energy production; in addition, up to 64 Mt/a of biomass are estimated to be accessible with another 28 Mt/a deemed inaccessible, for sustainability and ecological reasons. Accessible biomass sources include forest harvest residues, and agricultural residues.



An overview of the flows of biomass are shown in the Sankey diagram in Figure 22. Germany biomass production is dominated by agricultural biomass, and a small portion of primary crop production is used to support biofuel production (particularly biodiesel). There is a substantive forest sector and significant portions of solid wood are used for energy production, accounting for about half of the total biomass-to-energy feedstock. Pellets and other aggregates are another important source of biomass, followed by black liquor. Potential recovery of from municipal solid waste (food as well as paper, cardboard, and wood) is the most abundant potentially accessible source of biomass, followed by agricultural residues and forest harvest residues. Very small streams of black liquor and wood residues are identified as accessible.

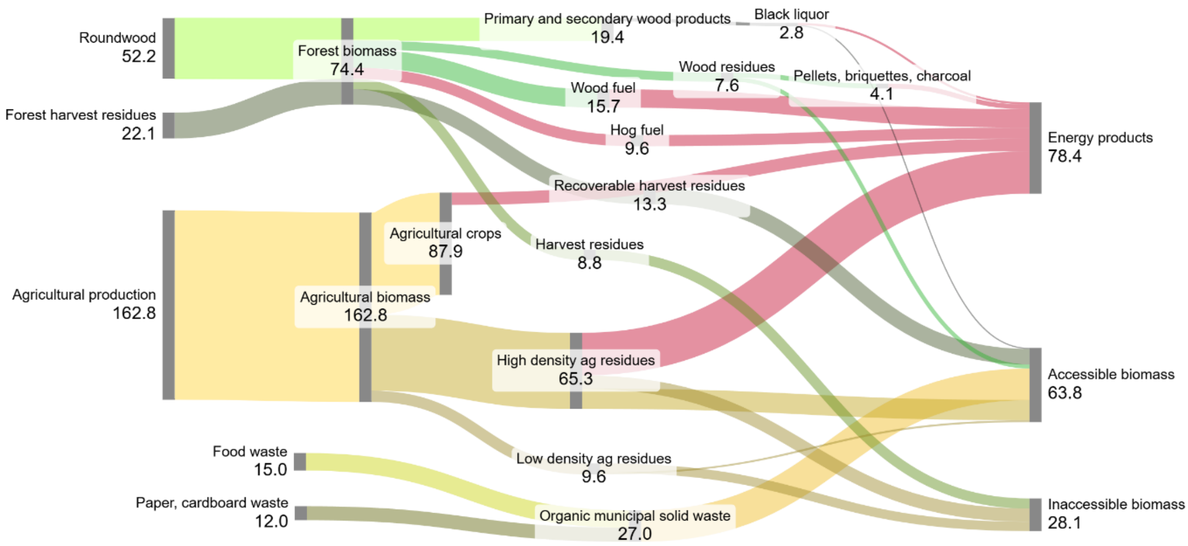


Figure 22 - Sankey diagram of biomass flows (Mt), Germany, 2022

As shown in Figure 22, Germany has been effective in capitalizing on biomass-to-energy, pathways. While there are large amounts of potentially accessible biomass identified, the most concentrated of these streams (wood processing residues, 3.5 Mt/a and unused black liquor, about 0.5 Mt/a) are not abundant. Utilizing these streams for energy would increase the biomass flow to energy products by only 12.5%. Municipal solid waste presents another opportunity; in Germany, MSW is comprised of 30% food waste and 24% paper and cardboard (Kaza et al., 2018). Additional opportunities for biogas production and/or other forms of bioenergy production could be supported through greater diversion strategies.

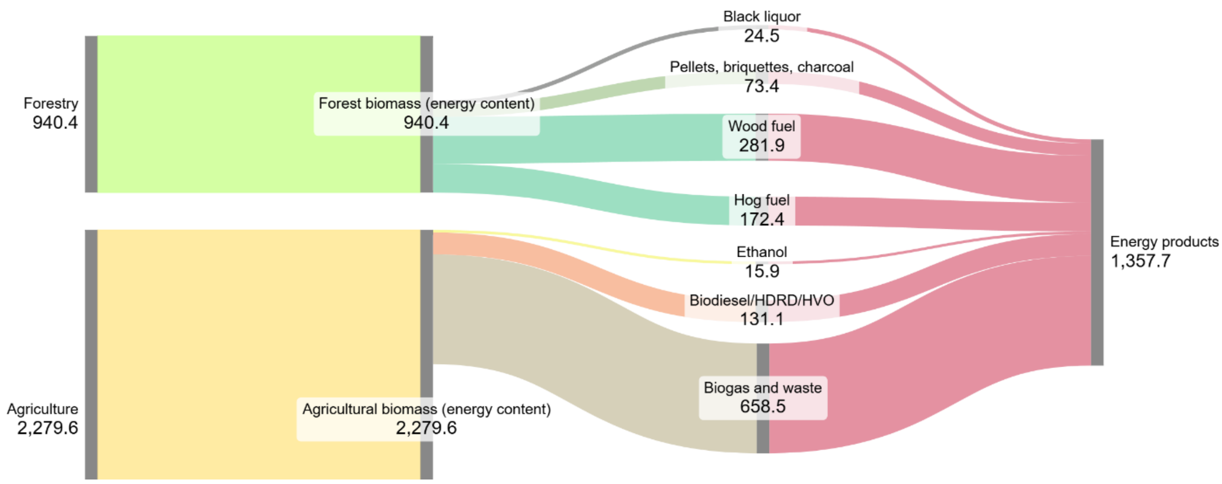


Figure 23 - Sankey diagram of biomass-to-energy pathways (PJ), Germany, 2022

In Figure 23, the flows of biomass-to-energy are shown on an energy basis. The primary contributor to energy products is wood fuel, including fuelwood and hog fuel, at 281.9 PJ and 172.4 PJ, respectively. Biodiesel products make up 131.1 PJ, primarily drawn from agricultural biomass. In total, biomass-based energy products are estimated to provide 1,357.7 PJ to the energy mix. Data for Germany is summarized in Table 5.

Table 5: Data summary sheet, Germany

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm^3)	78.9	82.2	77.8	[1]
Roundwood supply including net trade (Mm^3)	74.6	76.6	76.4	[1]
Roundwood supply including net trade (Mt)	52.2	53.6	53.5	c
Forest harvest residues (Mt)	22.1	23.0	21.8	c
Available forest harvest residues (Mt)	13.3	13.8	13.1	c
Wood residue production (Mm^3)	5.0	4.9	3.9	[1]
Wood residue production (Mt)	3.5	3.4	2.7	c
Agricultural production, high residues (Mt)		71.6	71.3	[1]
Agricultural production, low residues (Mt)		16.3	14.5	[1]
Agricultural residue production, high density (Mt)		65.3	68.0	c
Agricultural residue production, low density (Mt)		9.6	7.9	c
Available ag. residues, high density (Mt)		17.4	18.1	c
Available ag. residues, low density (Mt)		1.6	1.3	c
Municipal solid waste production (food) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (paper) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (food) (Mt)	15.0	15.0	15.2	c
Municipal solid waste production (paper) (Mt)	12.0	12.0	12.2	c
Total domestic supply of biomass (Mm^3)	74.6	139.8	141.2	c
Energy resources				
Total primary energy supply (TPES) (EJ)		12.1	12.0	[3]
Share of renewables (RES) in TPES (%)		17.0%	16.9%	[3]
Total bioenergy supply (EJ)		1.36	1.29	[3]
Share of bioenergy in TPES (%)		11.2%	10.7%	[3]
Share of bioenergy in RES (%)		65.8%	63.7%	[3]
Energy intensity				
Population (M)	84.1	83.2	83.1	[4]
Energy consumption (GJ/c/a)	0.0	145.7	144.8	c
Bioenergy consumption (GJ/c/a)	0.0	16.3	15.6	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

Table 5: Data summary sheet, Germany

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	8.83	9.10	9.61	[1]
Wood fuel, non-coniferous (Mm^3)	13.50	13.70	14.09	[1]
Wood fuel total (Mt)	15.64	15.96	16.59	c
Wood fuel, coniferous including net trade (Mm^3)	8.73	9.07	9.61	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	13.65	13.80	14.27	[1]
Wood fuel including net trade total (Mt)	15.66	16.01	16.72	c
Briquettes and agglomerates production (Mt)	0.45	0.98	0.84	[1]
Charcoal production (Mt)	0.03	0.03	0.03	[1]
Wood pellet production (Mt)	3.57	3.35	2.82	[1]
Pellets, briquettes, charcoal total (Mt)	4.05	4.36	3.69	c
Briquettes and agglomerates including net trade (Mt)	0.58	1.24	1.10	[1]
Charcoal including net trade (Mt)	0.13	0.15	0.22	[1]
Wood pellets including net trade (Mt)	3.36	2.94	2.37	[1]
Pellets, briquettes, charcoal including net trade (Mt)	4.08	4.33	3.69	c
Sulphate pulp production (Mt)	1.51	1.57	1.60	[1]
Black liquor used for energy (Mt)	1.75	1.83	1.86	c
Black liquor surplus (Mt)	0.96	1.00	1.01	c
Hog fuel estimate (Mt)	9.58	9.84	10.01	e
Share of roundwood directly used for energy (%)	37.8%	37.9%	38.1%	c
Share of roundwood indirectly used for energy (%)	3.4%	3.4%	3.5%	c
Total roundwood used for energy (%)	41.1%	41.4%	41.6%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	759.0	738.0	676.0	[5,6]
Biodiesel production (FAME, HVO) (Ml)	4010.0	3837.0	4070.0	[5,6]
Feedstock required (ethanol) (Mt)	2.11	2.05	1.88	c
Feedstock required (FAME, HVO) (Mt)	8.53	8.16	8.66	c
Feedstock required (other bioenergy) (Mt)	36.59	36.65	32.44	
Total feedstock required (Mt)	47.23	46.87	42.98	c
Total agricultural production used for energy (%)	0.0%	62.5%	58.1%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b

Note: c represents 'calculated value'; e represents 'estimated value'

NEW ZEALAND

New Zealand has a large portion of renewables within the total energy supply. In 2021, 42% of energy was supplied with renewables and the remaining 58% being supplied from fossil fuels. Bioenergy contributes 5.7% of TPES, and this contribution is dominated by sawdust and shavings at sawmills along with domestic firewood (60%), black liquor (32%), with the remaining from biogas (3.8%) and other minor contributors. Use of liquid biofuels is less than 1% (IEA Bioenergy, 2021). The country’s geography and population in proportion to biomass is moderate but has potential for improvements. In recent years the total energy supply has stabilized (including bioenergy) but between 2007 and 2011 there was an increase in renewables from 32 to 40% of the total share in energy. In recent years, TPES and the contributions of renewables and bioenergy have been stable, as shown in Figure 24.

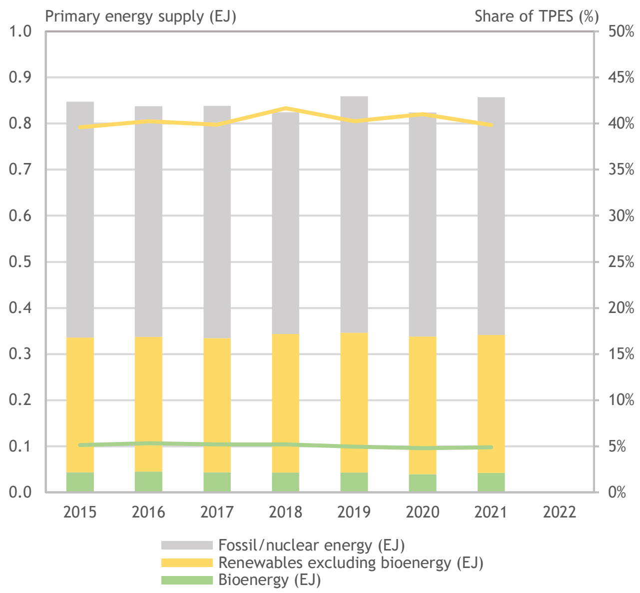


Figure 24 - Total primary energy supply and role of renewables, New Zealand, 2015-2021 (Source: IEA, 2024)

The present study provides estimates of accessible and inaccessible biomass supply as well as the present contribution of biomass to energy products (Figure 25). About 2.8 million tonnes of biomass are estimated to flow to energy products per year, while another 8.4 Mt/a of biomass are estimated to be ‘accessible’, including forest harvest and wood processing residues, organic components of municipal solid waste, and agricultural residues. The estimates of inaccessible biomass are about 5.3 Mt/a.

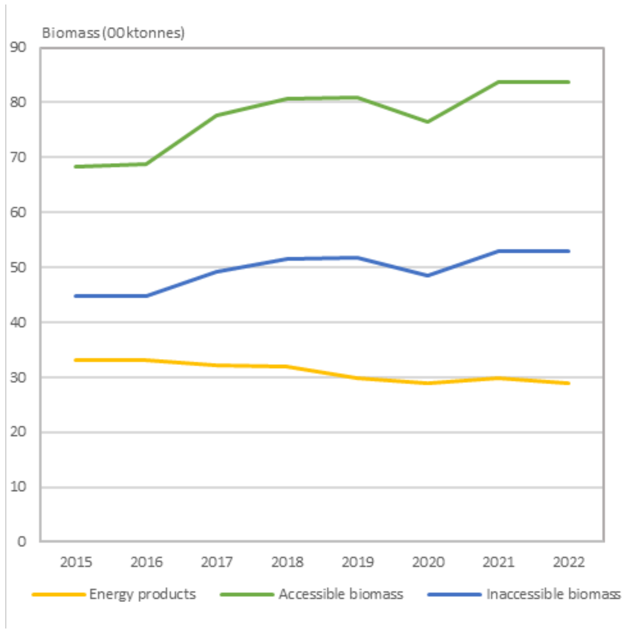


Figure 25 - Biomass by availability and biomass-to-energy, New Zealand, 2015-2022

An overview of the flows of biomass are shown in the Sankey diagram in Figure 26. Biomass flows are dominated by forest biomass; hog fuel and wood fuel make up the bulk of energy products, while forest harvest residues make up the bulk of accessible and inaccessible biomass sources. Agricultural production is the second-greatest sources of biomass; at the present time, no agricultural biomass is used for energy production as no biofuel plants are currently active. The availability of organic fractions of municipal solid waste is low. Black liquor is the primary biomass-to-energy pathway, followed by pellets and other aggregates. amounts of black liquor are covered in the form of energy. Solid wood fuels and energy products including wood pellets form the remainder of the biomass-to-energy pathway.

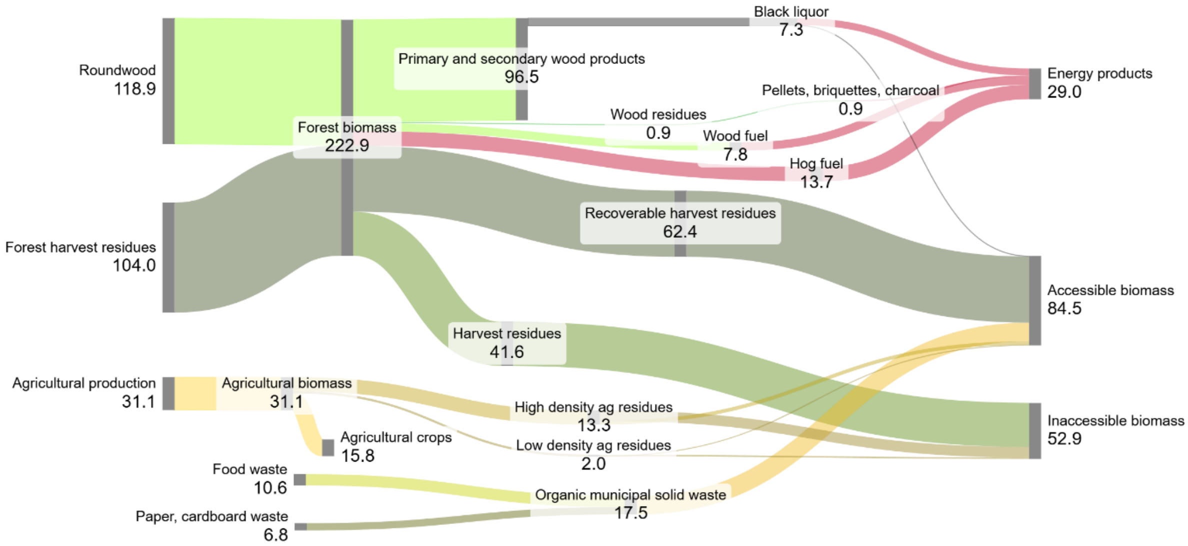


Figure 26 - Sankey diagram of biomass flows (100 kt), New Zealand, 2022

In Figure 27, the biomass-to-energy flows across New Zealand in 2022 are shown. There is potentially a large amount of biomass energy available in the form of forest harvest residues, although as in other countries it should be expected that these residues are widely distributed and thus likely to be costly. The largest stream of energy is taken from hog fuel at about 24.7 PJ, followed by wood fuel at about 14.0 PJ and black liquor at 9.3 PJ. Potential future energy might be sourced from municipal solid waste; in New Zealand, MSW is comprised of 28% food waste, 7% paper and cardboard, and 11% wood waste (Kaza et al., 2018). Diversion of these streams might create more accessible biomass for energy production or higher-value purposes.

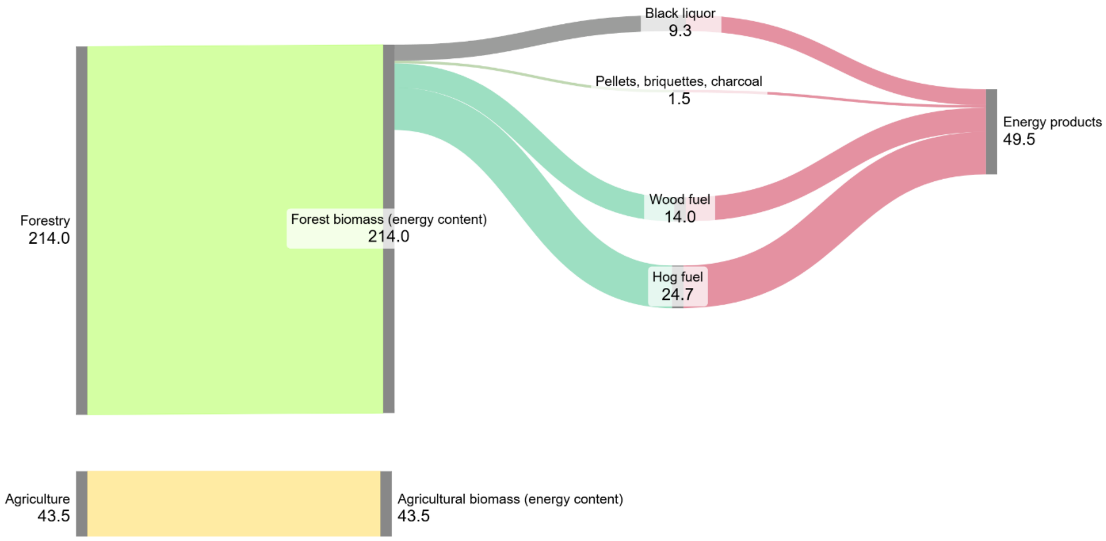


Figure 27 - Sankey diagram of biomass-to-energy pathways (PJ), New Zealand, 2022

Data for New Zealand is summarized in Table 6.

Table 6: Data summary sheet, New Zealand

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (00 000 m^3)	371.5	371.5	358.4	[1]
Roundwood supply including net trade (00 000m^3)	169.8	144.5	141.0	[1]
Roundwood supply including net trade (00 000t)	118.9	101.1	98.7	c
Forest harvest residues (00 000t)	104.0	104.0	100.4	c
Available forest harvest residues (00 000t)	62.4	62.4	60.2	c
Wood residue production (00 000m^3)	0.0	0.0	0.0	[1]
Wood residue production (00 000t)	0.0	0.0	0.0	c
Agricultural production, high residues (00 000t)		9.7	9.9	[1]
Agricultural production, low residues (00 000t)		6.1	5.8	[1]
Agricultural residue production, high density (00 000t)		13.7	13.3	c
Agricultural residue production, low density (00 000t)		2.0	1.9	c
Available ag. residues, high density (00 000t)		3.4	3.5	c
Available ag. residues, low density (00 000t)		0.5	0.5	c
Municipal solid waste production (food) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (paper) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (wood) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (food) (00 000t)	10.6	10.6	10.2	c
Municipal solid waste production (paper) (00 000t)	2.7	2.6	2.6	c
Municipal solid waste production (wood) (00 000t)	4.2	4.2	4.0	c
Total domestic supply of biomass (00 000m^3)	169.8	157.6	154.3	c
Energy resources				
Total primary energy supply (TPES) (EJ)			0.9	[3]
Share of renewables (RES) in TPES (%)			39.7%	[3]
Total bioenergy supply (EJ)			0.05	[3]
Share of bioenergy in TPES (%)			5.5%	[3]
Share of bioenergy in RES (%)			13.9%	[3]
Energy intensity				
Population (M)	5.1	5.1	5.0	[4]
Energy consumption (GJ/c/a)			181.7	c
Bioenergy consumption (GJ/c/a)			10.0	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018 ; [3] MBIE, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a

Note: c represents 'calculated value'; e represents 'estimated value'

Table 6: Data summary sheet, New Zealand (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (00 000m^3)	0.00	0.00	0.00	[1]
Wood fuel, non-coniferous (00 000m^3)	0.00	0.00	0.00	[1]
Wood fuel total (00 000t)	7.78	7.78	7.78	e
Wood fuel, coniferous including net trade (00 000m^3)	0.00	0.02	0.00	[1]
Wood fuel, non-coniferous incl. net trade (00 000m^3)	0.00	0.01	0.01	[1]
Wood fuel including net trade total (00 000t)	0.00	0.02	0.01	c
Briquettes and agglomerates production (00 000t)	0.00	0.00	0.00	[1]
Charcoal production (00 000t)	0.00	0.00	0.00	[1]
Wood pellet production (00 000t)	0.75	0.75	0.75	[1]
Pellets, briquettes, charcoal total (00 000t)	0.75	0.75	0.75	c
Briquettes and agglomerates incl. net trade (00 000t)	0.00	0.00	0.01	[1]
Charcoal including net trade (00 000t)	0.05	0.04	0.03	[1]
Wood pellets including net trade (00 000t)	0.80	0.77	0.76	[1]
Pellets, briquettes, charcoal incl. net trade (00 000t)	0.86	0.80	0.79	c
Sulphate pulp production (00 000t)	4.08	6.77	5.70	[1]
Black liquor used for energy (00 000t)	6.65	11.03	9.29	c
Black liquor surplus (00 000t)	0.00	0.00	0.00	c
Hog fuel estimate (00 000t)	13.70	10.34	11.98	e
Share of roundwood directly used for energy (%)	0.7%	0.8%	0.8%	c
Share of roundwood indirectly used for energy (%)	17.1%	21.1%	21.6%	c
Total roundwood used for energy (%)	17.8%	21.9%	22.4%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	0.0	0.0	0.0	[5]
Biodiesel production (FAME, HVO) (Ml)	0.0	0.0	0.0	[5]
Feedstock required (ethanol) (Mt)	0.00	0.00	0.00	c
Feedstock required (FAME, HVO) (Mt)	0.00	0.00	0.00	c
Total feedstock required (Mt)	0.00	0.00	0.00	c
Total agricultural production used for energy (%)	0.0%	0.0%	0.0%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] MBIE, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a

Note: c represents 'calculated value'; e represents 'estimated value'

SWEDEN

Total primary energy supply in Sweden during 2021 contained 47% renewables, which is the highest of all of the countries assessed in this study. Approximately 60% of renewables is comprised of various sources of bioenergy, with the majority of this (80%) being drawn from solid biomass and remaining is supplied from liquid biofuels, renewable municipal waste, and biogas (IEA Bioenergy, 2021). Sweden has recently seen slight declines in TPES, and increases in both renewable energy and in bioenergy, as shown in Figure 28.

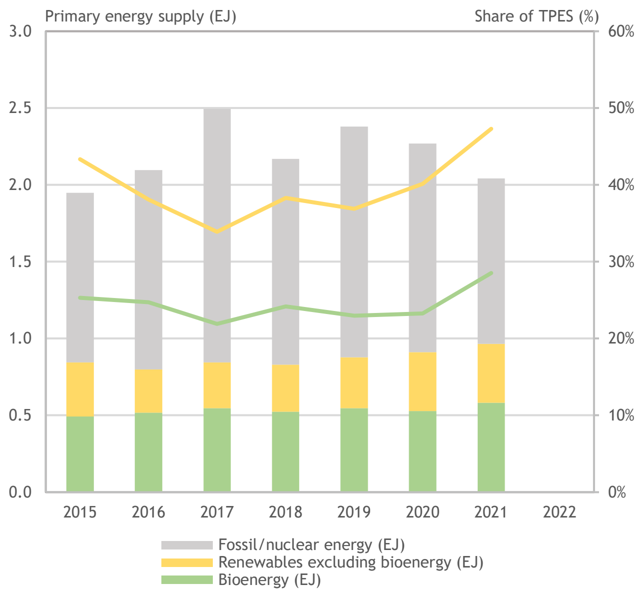


Figure 28 - Total primary energy supply and role of renewables, Sweden, 2015-2021 (Source: IEA, 2024)

As one would expect, the utilization of biomass for energy is very high, as shown in Figure 29. In 2022, approximately 34.9 million tonnes of biomass are estimated to flow to energy products, with another 25 Mt/a of biomass are estimated to be 'accessible' (including forest harvest and wood processing residues, organic components of municipal solid waste, and agricultural residues). The estimates of inaccessible biomass are mostly stable, and are currently around 15 Mt/a.

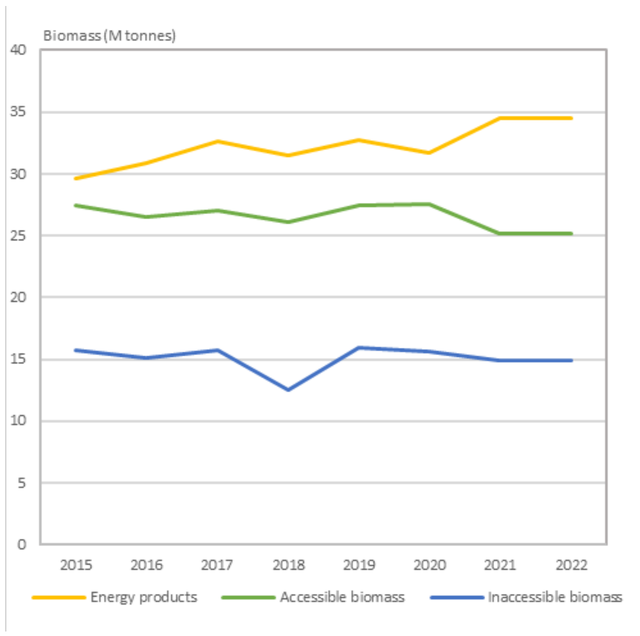


Figure 29 - Biomass by availability and biomass-to-energy, Sweden, 2015-2022

An overview of the estimated flows of biomass across Sweden in 2022 are shown in the Sankey diagram in Figure 30. Forest biomass dominates the Swedish biomass landscape, with relatively low production levels of agricultural material and very little municipal solid waste. As such, forest biomass makes up the majority of accessible fibre as well as inaccessible fibre, and is the primary source of biomass-to-energy. Black liquor recovery in particular plays an important role in energy generation, as does wood fuel and pellets and other aggregate products. A very small stream of agricultural biomass is used for biofuel production, primarily ethanol and biodiesel.

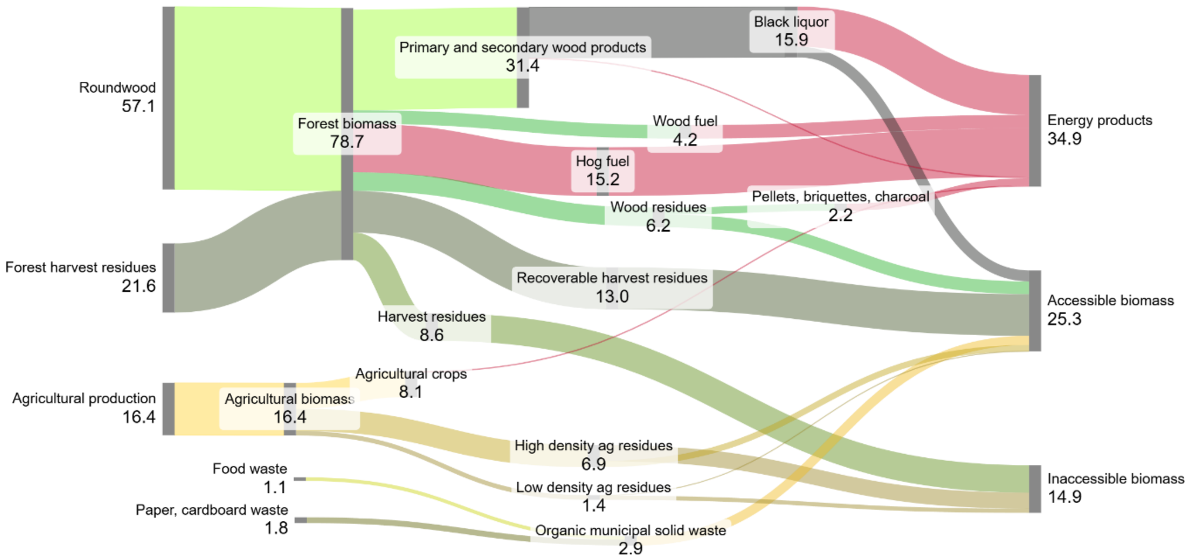


Figure 30 - Sankey diagram of biomass flows (Mt), Sweden, 2022

There is a substantive portion of biomass recovered for energy across Sweden, through black liquor recovery, wood-based and agriculture-based biofuels, solid wood fuels, and aggregates such as wood pellets. This reflects the relatively high uptake of bioenergy in Sweden. Some concentrated biomass sources may yet be available, including wood processing residues and black liquor for energy production. Using these sources for biomass-to-energy would represent an increase of 36% over the current use of biomass for energy. The recovery of the organic portions of municipal solid waste is likely to be more problematic, as Swedish MSW is comprised of 23% food waste and 36% paper and cardboard (Kaza et al., 2018), making it more difficult to isolate these streams for energy purposes without a diversion strategy. It should be noted that Sweden is already utilizing a portion of their forest harvest residues for energy – about 60% of forests in the south of the country are already subject to harvest residue recovery - and that this portion could increase over time (Eggers et al. 2020).

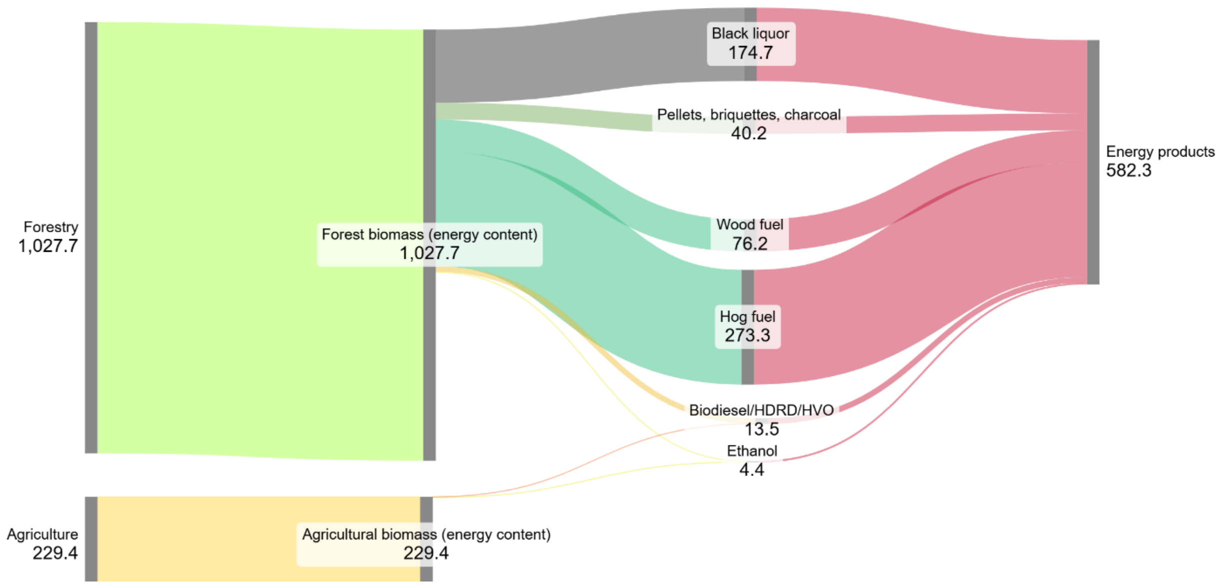


Figure 31 - Sankey diagram of biomass-to-energy pathways (PJ), Sweden, 2022

In Figure 31, the flows of biomass-to-energy are shown on an energy basis. The primary contributor to the bioenergy supply is hog fuel (273.3 PJ), followed by black liquor at about 174.7 PJ and by wood fuel at 76.2 PJ. The total supply of biomass-based energy is 582.3 PJ, almost entirely from forest biomass. Data for Sweden is summarized in Table 7.

Table 7: Data summary sheet, Sweden

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm^3)	77.2	77.3	74.4	[1]
Roundwood supply including net trade (Mm^3)	81.6	82.3	82.4	[1]
Roundwood supply including net trade (Mt)	57.1	57.6	57.7	c
Forest harvest residues (Mt)	21.6	21.6	20.8	c
Available forest harvest residues (Mt)	13.0	13.0	12.5	c
Wood residue production (Mm^3)	5.7	5.8	9.4	[1]
Wood residue production (Mt)	4.0	4.0	6.6	c
Agricultural production, high residues (Mt)		6.3	7.3	[1]
Agricultural production, low residues (Mt)		1.8	2.0	[1]
Agricultural residue production, high density (Mt)		6.9	8.4	c
Agricultural residue production, low density (Mt)		1.4	1.6	c
Available ag. residues, high density (Mt)		1.9	2.3	c
Available ag. residues, low density (Mt)		0.1	0.1	c
Municipal solid waste production (food) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (paper) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (food) (Mt)	1.1	1.1	1.1	c
Municipal solid waste production (paper) (Mt)	1.8	1.7	1.7	c
Total domestic supply of biomass (Mm^3)	81.6	88.9	90.4	c
Energy resources				
Total primary energy supply (TPES) (EJ)		2.0	2.4	[3]
Share of renewables (RES) in TPES (%)		47.3%	36.9%	[3]
Total bioenergy supply (EJ)		0.58	0.55	[3]
Share of bioenergy in TPES (%)		28.5%	23.0%	[3]
Share of bioenergy in RES (%)		60.3%	62.3%	[3]
Energy intensity				
Population (M)	10.5	10.4	10.3	[4]
Energy consumption (GJ/c/a)	0.0	196.0	231.6	c
Bioenergy consumption (GJ/c/a)	0.0	55.9	53.2	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b; [7] Swedish Energy Agency, 2023

Note: c represents 'calculated value'; e represents 'estimated value'

Table 7: Data summary sheet, Sweden (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	3.00	2.95	2.70	[1]
Wood fuel, non-coniferous (Mm^3)	3.00	2.95	2.70	[1]
Wood fuel total (Mt)	4.20	4.13	3.78	c
Wood fuel, coniferous including net trade (Mm^3)	2.99	2.95	2.74	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	3.06	2.94	2.72	[1]
Wood fuel including net trade total (Mt)	4.23	4.13	3.82	c
Briquettes and agglomerates production (Mt)	0.00	0.00	0.00	[1]
Charcoal production (Mt)	0.00	0.00	0.00	[1]
Wood pellet production (Mt)	1.81	1.76	1.70	[1]
Pellets, briquettes, charcoal total (Mt)	1.81	1.76	1.70	c
Briquettes and agglomerates including net trade (Mt)	0.03	0.00	0.00	[1]
Charcoal including net trade (Mt)	0.03	0.04	0.04	[1]
Wood pellets including net trade (Mt)	1.78	1.63	2.02	[1]
Pellets, briquettes, charcoal including net trade (Mt)	1.83	1.67	2.05	c
Biodiesel production (HDRD) (Ml)	350.0	312.0	208.0	[5,6]
Feedstock required (HDRD) (Mt)	0.34	0.30	0.20	c
Cellulosic ethanol production (wood) (Ml)	19.5	19.5	19.5	[5]
Feedstock required (cellulosic ethanol) Mt)	0.06	0.06	0.06	c
Sulphate pulp production (Mt)	8.80	8.54	8.40	[1]
Black liquor used for energy (Mt)	12.48	12.11	11.91	c
Black liquor surplus (Mt)	3.37	3.26	3.21	c
Hog fuel estimate (Mt)	15.18	15.86	14.31	e
Share of roundwood directly used for energy (%)	11.3%	10.7%	10.6%	c
Share of roundwood indirectly used for energy (%)	21.9%	21.0%	20.7%	c
Total roundwood used for energy (%)	33.2%	31.7%	31.3%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	130.0	130.0	102.2	[5,7]
Biodiesel production (FAME, HVO) (Ml)	15.0	15.0	24.7	[5,7]
Feedstock required (ethanol) (Mt)	0.36	0.36	0.28	c
Feedstock required (FAME, HVO) (Mt)	0.03	0.03	0.05	c
Total feedstock required (Mt)	0.39	0.39	0.34	c
Total agricultural production used for energy (%)	0.0%	4.5%	3.2%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] IEA Bioenergy, 2022a; [6] GAIN, 2023b; [7] Swedish Energy Agency, 2023

Note: c represents 'calculated value'; e represents 'estimated value'

UNITED STATES (USA)

As shown in Figure 32, the USA has a relatively low proportion of renewable energy within the total energy supply at 8%. Of the renewable energy supply in the United States approximately 60% is supplied by biomass, with solid biofuels being the primary bioenergy source comprising 55% of this total (IEA Bioenergy, 2021). The remaining components include liquid biofuels (38%) as well as biogas and renewable municipal waste, which both play minor roles within the overall bioenergy supply. Over the past two decades the share of renewable has grown from 4% to 8%, with a period of growth in bioenergy.

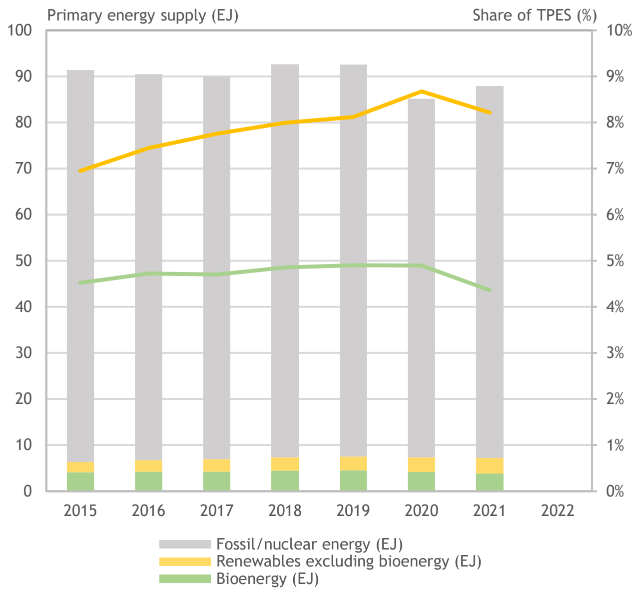


Figure 32 - Total primary energy supply and role of renewables, United States, 2015-2021 (Source: IEA, 2024)

The supply of accessible and inaccessible biomass across the USA, as well as the present contribution of biomass to energy products, are shown in Figure 33. In 2022, approximately 310 million tonnes of biomass are estimated to flow to energy products per year, while another 431 Mt/a are likely accessible. Note that these numbers, while derived using a different framework, are relatively close to those described in the Billion-Ton report: that report estimated 342 million dry tons (310 Mt/a) of 'currently used' biomass in 2023, with an additional 349 million dry tons (316 Mt/a) of accessible feedstocks including agriculture, forestry, and waste (USDOE, 2024) This totals 626 Mt/a, which is 115 Mt/a lower than this study's combined total (741 Mt/a). What this suggests is that some of the streams of accessible biomass identified in the current study are already being captured for biomass-to-energy but not recognized in the official statistics.

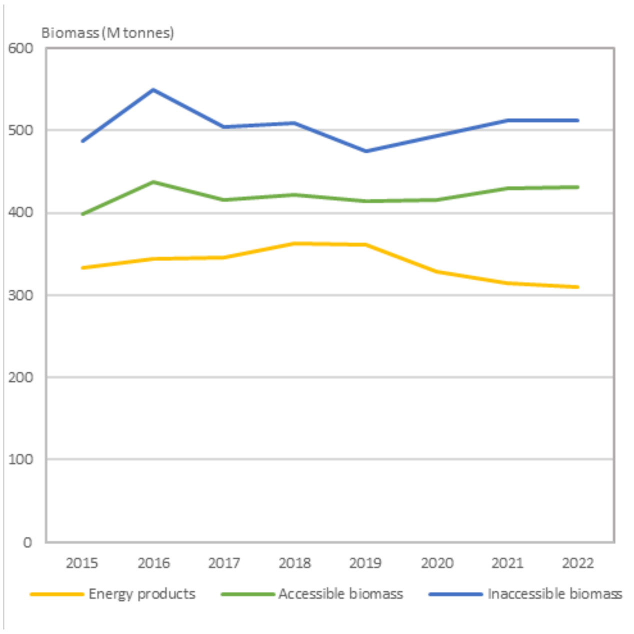


Figure 33 - Biomass by availability and biomass-to-energy, United States, 2015-2022

The flows of biomass in the USA are shown in the Sankey diagram in Figure 34. Agricultural biomass dominates the biomass flows in the USA, followed by forest biomass and finally solid wastes. The majority of inaccessible biomass resources are likely residues that must be left on the field for ecological reasons. The largest accessible biomass stream is potential recovery from municipal solid waste (food as well as paper, cardboard, and wood), followed by agricultural residues, forest harvest residues, and finally wood processing residues and black liquor not currently used for energy production.

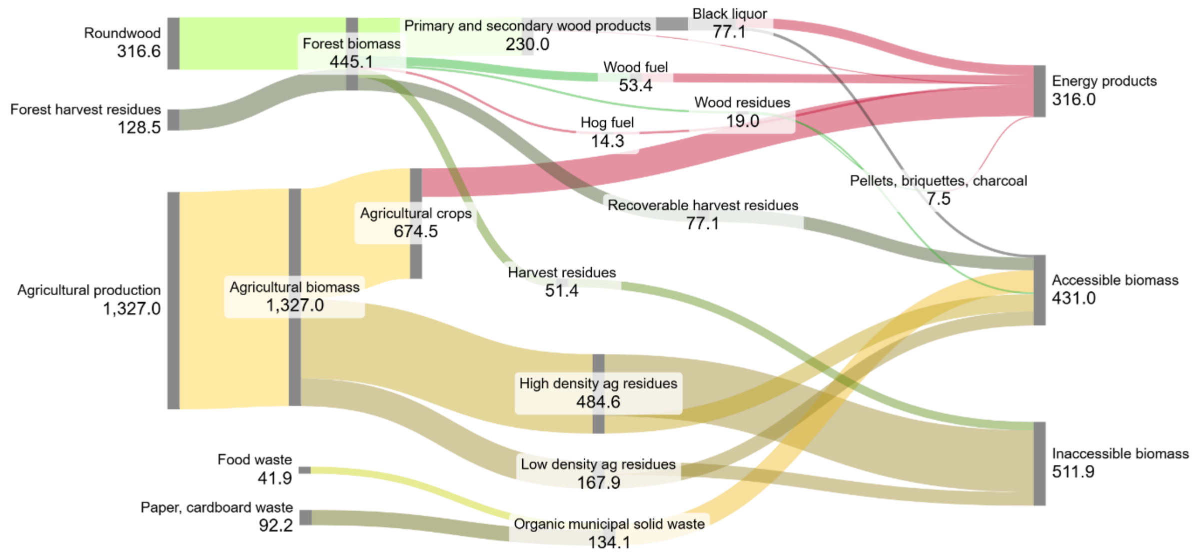


Figure 34 - Sankey diagram of biomass flows (Mt), United States, 2022

Figure 34 clearly shows the strong uptake of biomass-to-energy pathways in the USA, and specifically the role of agricultural products used to generate biofuels, which by far accounts for the largest flow of biomass-to-energy. In the USA, the majority of concentrated residues have already been accessed for energy or other products, which means that the majority of accessible biomass exists in a highly decentralized way and which would require new collection mechanisms to realize. The largest stream of accessible biomass comes from municipal solid waste, which in the USA is comprised of 15% food waste, 27% paper and cardboard, and 6% wood (Kaza et al., 2018). As in other countries, accessing these feedstocks would be best facilitated through diversion mechanisms designed to feed these materials into energy (or other value-added) production. The estimates presented here is closely aligned, and the breakdown of energy applications is similar to that presented in the Billion-Ton report.

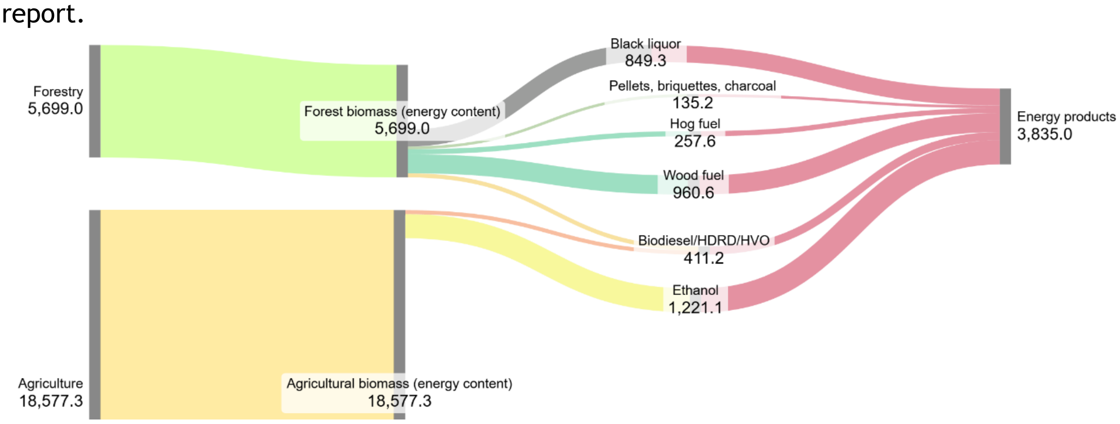


Figure 35 - Sankey diagram of biomass-to-energy pathways (PJ), United States, 2022

In Figure 35, the different pathways and sources of bio-based energy are shown on an energy basis. The USA uses both forest and agricultural biomass to support bioenergy production; from forest biomass, the two primary pathways are through wood fuel (including firewood and hog fuel, 960.6 PJ) and black liquor (849.3 PJ). For agricultural biomass, the largest single source of bioenergy is ethanol, at 1,221.1 PJ. Total energy products in the USA supply 3,835 PJ to the energy mix.

Data for the USA is summarized in Table 8.

Table 8: Data summary sheet, USA

	2022	2021	2019	Source
Biomass supply				
Roundwood removals (Mm^3)	458.8	453.5	459.1	[1]
Roundwood supply including net trade (Mm^3)	452.3	445.0	452.2	[1]
Roundwood supply including net trade (Mt)	316.6	311.5	316.5	c
Forest harvest residues (Mt)	128.5	127.0	128.6	c
Available forest harvest residues (Mt)	77.1	76.2	77.1	c
Wood residue production (Mm^3)	16.4	16.3	15.3	[1]
Wood residue production (Mt)	11.5	11.4	10.7	c
Agricultural production, high residues (Mt)		504.9	467.4	[1]
Agricultural production, low residues (Mt)		169.7	146.1	[1]
Agricultural residue production, high density (Mt)		484.6	457.6	c
Agricultural residue production, low density (Mt)		167.9	143.5	c
Available ag. residues, high density (Mt)		106.5	101.7	c
Available ag. residues, low density (Mt)		85.4	76.3	c
Municipal solid waste production (food) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (paper) (t/c/a)	0.2	0.2	0.2	[2]
Municipal solid waste production (wood) (t/c/a)	0.1	0.1	0.1	[2]
Municipal solid waste production (food) (Mt)	41.9	41.5	40.7	c
Municipal solid waste production (paper) (Mt)	74.8	74.1	72.6	c
Municipal solid waste production (wood) (Mt)	17.4	17.3	16.9	c
Total domestic supply of biomass (Mm^3)	452.3	1084.7	1045.7	c
Energy resources				
Total primary energy supply (TPES) (EJ)		87.9	92.6	[3]
Share of renewables (RES) in TPES (%)		8.2%	8.1%	[3]
Total bioenergy supply (EJ)		3.83	4.54	[3]
Share of bioenergy in TPES (%)		4.4%	4.9%	[3]
Share of bioenergy in RES (%)		53.1%	60.4%	[3]
Energy intensity				
Population (M)	333.3	332.0	328.3	[4]
Energy consumption (GJ/c/a)		264.8	282.0	c
Bioenergy consumption (GJ/c/a)		11.5	13.8	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] EIA, 2023

Note: c represents 'calculated value'; e represents 'estimated value'

Table 8: Data summary sheet, USA (con't)

	2022	2021	2019	Source
Role of wood energy in the forest sector				
Wood fuel, coniferous (Mm^3)	37.62	33.76	32.80	[1]
Wood fuel, non-coniferous (Mm^3)	38.61	37.35	38.63	[1]
Wood fuel total (Mt)	53.36	49.78	50.00	c
Wood fuel, coniferous including net trade (Mm^3)	37.58	33.78	32.83	[1]
Wood fuel, non-coniferous including net trade (Mm^3)	38.66	37.44	38.66	[1]
Wood fuel including net trade total (Mt)	53.37	49.86	50.04	c
Briquettes and agglomerates production (Mt)	0.11	0.11	0.11	[1]
Charcoal production (Mt)	0.85	0.85	0.85	[1]
Wood pellet production (Mt)	9.54	8.45	8.59	[1]
Pellets, briquettes, charcoal total (Mt)	10.51	9.41	9.56	c
Briquettes and agglomerates including net trade (Mt)	0.26	0.27	0.25	[1]
Charcoal including net trade (Mt)	0.96	1.01	0.93	[1]
Wood pellets including net trade (Mt)	0.76	1.12	1.95	[1]
Pellets, briquettes, charcoal including net trade (Mt)	1.97	2.40	3.12	c
Biodiesel production (HDRD) (Ml)	5674.54	3259.70	1862.47	[5]
Feedstock required (HDRD) (Mt)	5.54	3.18	1.82	c
Sulphate pulp production (Mt)	42.79	44.41	45.26	[1]
Black liquor used for energy (Mt)	60.66	62.96	64.17	c
Black liquor surplus (Mt)	16.36	16.98	17.31	c
Hog fuel estimate (Mt)	14.31	23.87	61.96	e
Share of roundwood directly used for energy (%)	19.2%	17.8%	17.4%	c
Share of roundwood indirectly used for energy (%)	19.2%	20.2%	20.3%	c
Total roundwood used for energy (%)	38.4%	38.0%	37.6%	c
Role of bioenergy in the agricultural sector				
Ethanol production (cereal) (Ml)	58146.5	56840.7	59729.9	[5]
Biodiesel production (FAME, HVO) (Ml)	6140.0	6468.6	6528.0	[5]
Feedstock required (ethanol) (Mt)	161.52	157.89	165.92	c
Feedstock required (FAME, HVO) (Mt)	13.06	13.76	13.89	c
Total feedstock required (Mt)	174.58	171.65	179.81	c
Total agricultural production used for energy (%)	0.0%	26.2%	29.8%	c

Sources: [1] FAO, 2024; [2] Kaza et al., 2018; [3] IEA, 2024; [4] World Bank, 2023; [5] EIA, 2023

Note: c represents 'calculated value'; e represents 'estimated value'

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Appendices

Table A1: Joint Wood Energy Enquiry explanations on aggregated data

S1 Direct
Any wood fibre entering energy production without any further treatment or conversion. It comprises removals from forests and outside, and any wood defined by the FAO as coming from “Other Wooded Land” (OWL) and “Trees Outside Forests” but is wider than these two definitions. It comprises any woody biomass from any land use and covers amongst others infrastructure maintenance (roads, railway, power transmission lines, pipelines, etc.), hedgerows, agricultural residues from fruit tree orchards, wood from gardens and parks, etc. It comprises any form of woody biomass, such as green chips, roundwood or split, stacked or loose from any part of the trees such as roots, stemwood and branches, fruits, and shells.
S2 Indirect
Processed and unprocessed co-products (residues) from the wood processing industries are considered as indirect supply. These co-products can be solid (sawdust, chips, slabs, etc.) or liquid from the pulp industry (black liquor or tall oil). Includes processed wood fuels with improved energy content per bulk volume (compressed) – e.g. wood pellets, briquettes, charcoal.
S3 Recovered
The so-called post consumer recovered wood comprises any waste wood fibre after at least one life cycle. It comprises wood from construction, renovation, and demolition, but also packaging as well as old furniture. Countries often apply different classifications to distinguish between different wood waste categories (contaminated with colours, glue, etc.).
S4 Unspecified
Many countries know something about the amount of wood used but not its source. These households’ surveys are often conducted by the energy statistics and are hence not interested in detecting the different sources and origin of the wood fibres. This category represents a further step in making the JWEE more compatible with the energy statistics.

U1 Power & heat
The definition of U1 refers to "Main Activity Producers" (IEA definition), which refers to plants which are designed to produce electricity/combined heat and power (CHP) or Heat only. If one or more units of the plant is a CHP unit (and the inputs and outputs can not be distinguished on a unit basis) then the whole plant is designated as a CHP plant. However, a sawmill, for example, which produces heat for itself as well as selling it outside, would fall under the next (U2) category. Main activity supply undertakings generate electricity and/or heat for sale to third parties, as their primary activity. They may be privately or publicly owned.
U2 Industrial
This refers to "auto producer" (IEA definition) undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity. They may be privately or publicly owned. It includes mainly the forest-based industries, namely the (chemical) pulp producers who sell some of their energy to third parties (real or virtual sales are considered). Ideally the data should also include the process heat that is used for the production of the good at the specific plant.
U3 Residential
In the first version of the JWEE this user group was referred to as "Private households". For consistency reasons with energy statistics, it was renamed to "Residential". It is referred to by the IEA as all consumption by households, excluding fuels used for transport. It includes households with employed persons (ISIC Division 95) which is a small part of total residential consumption.
U4 Other
This definition comprises any other economic sector that is not included in the above mentioned (e.g., agriculture, forestry and fishing, commercial and public services, and transport).

Table A2: Forest biomass definitions

Type	Definition	Source
Coniferous (C)	All woods derived from trees classified botanically as Gymnospermae, e.g. *Abies* spp., *Araucaria* spp., *Cedrus* spp., *Chamaecyparis* spp., *Cupressus* spp., *Larix* spp., *Picea* spp., *Pinus* spp., *Thuja* spp., *Tsuga* spp., etc. These are generally referred to as softwoods.	[1]
Non-coniferous (NC)	All woods derived from trees classified botanically as Angiospermae, e.g. *Acer* spp., *Dipterocarpus* spp., *Entandrophragma* spp., *Eucalyptus* spp., *Fagus* spp., *Populus* spp., *Quercus* spp., *Shorea* spp., *Swietenia* spp., *Tectona* spp., etc. These are generally referred to as broadleaves or hardwoods.	[1]
Woody biomass	Organic woody material both above-ground and below-ground, and both living and dead, measured to a minimum diameter of 0 mm (diameter breast height). Includes stem, stump, branches, bark, seeds and foliage,	[2]

	roots, shrubs and bushes. Excludes: litter	
Above-ground (living) woody biomass	All living woody biomass above the soil, including stem, stump, branches, bark, seeds and foliage.	[2]
Below-ground (living) woody biomass	All living woody biomass of live roots and the below-ground part of the stump.	[2]
Forest	Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Explanatory notes: 1. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 meters in situ. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10 percent and a tree height of 5 m are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate. 2. Includes areas with bamboo and palms provided that height and canopy cover criteria are met. 3. Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest. 4. Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 ha and width of more than 20 m. 5. Includes plantations primarily used for forestry or protection purposes, such as rubberwood plantations and cork oak stands. 6. Excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens.	[3]
Woody Biomass Outside Forests	Any woody biomass outside areas defined as "Forest". It includes woody biomass form "Other wooded land" and "Trees outside forests".	[3]
Other Wooded Land	Land not classified as "Forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.	[2]

Sources: [1] UNECE/FAO 2024; [2] Forest Europe 2020; [3] FAO 2025; [4] FAO 2004; [5] IEA 2025; [6] UK 2025

Table A2: Forest biomass definitions (con't)

Type	Definition	Source
Trees outside forests	Includes all trees found outside forests and outside other wooded lands: - stands smaller than 0.5 ha; - tree cover in agricultural land, e.g. agro forestry systems, home gardens, orchards; - trees in urban environments; - along roads and scattered in the landscape.	[2]
Industrial Roundwood (C & NC)	Coniferous and non-coniferous Industrial Roundwood: All roundwood except wood fuel. It is an aggregate comprising sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood. It is reported in cubic metres solid volume under bark (i.e. excluding bark). The customs classification systems used by most countries do not allow the division of Industrial Roundwood trade statistics into the different end-use categories that have long been recognized in production statistics (i.e. sawlogs and veneer logs, pulpwood and other industrial roundwood). (...) It excludes: telephone poles.	[1]
Fuelwood (C & NC)	Coniferous and non-coniferous Fuelwood: Roundwood that will be used as fuel for purposes such as cooking, heating or power production. It includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that will be used for charcoal production (e.g. in pit kilns and portable ovens). The volume of roundwood used in charcoal production is estimated by using a factor of 6.0 to convert from the weight (t) of charcoal produced to the solid volume (m3) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. It excludes wood charcoal. It is reported in cubic metres solid volume underbark (i.e. excluding bark). It includes wood fibres from above-ground woody biomass and below-ground woody biomass (excluding bark).	[1]
Chips and particles	Wood that has been reduced to small pieces and is suitable for pulping, for particle board and/or fibreboard production, for use as a fuel, or for other purposes. It excludes wood chips made directly in the forest from roundwood (i.e. already counted as pulpwood, round and split). **It is reported in cubic metres solid volume excluding bark.**	[1]
Wood residues	The volume of roundwood that is left over after the production of forest products in the forest processing industry (i.e. forest processing residues) and that has not been reduced to chips or particles. It includes sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, residues from carpentry and joinery production, etc. It excludes wood chips made either directly in the forest from roundwood or made from residues (i.e. already counted as pulpwood, round and split or wood chips and particles). **It is reported in cubic metres solid volume excluding bark.**	[1]
Black liquor	Alkaline spent liquor obtained from digesters in the production of sulphate or soda pulp during the process of paper production, in which the energy content is mainly originating from the content of lignin removed from the	[4]

	wood in the pulping process.	
Post-consumer recovered wood	Used wood arising from construction of buildings or from civil engineering works. Recovered wood from transport (pallets), private households, as well as used wood arising from construction or demolition of buildings or from civil engineering works.	[4]
Municipal solid waste	Waste produced by households, industry, hospitals and the tertiary sector which contains biodegradable materials (…).	[5]

Sources: [1] UNECE/FAO 2024; [2] Forest Europe 2020; [3] FAO 2025; [4] FAO 2004; [5] IEA 2025; [6] UK 2025

Table A3: Wood energy definitions

Type	Definition	Source
Wood Charcoal	Wood carbonized by partial combustion or the application of heat from external sources. It includes charcoal used as a fuel or for other uses, e.g. as a reduction agent in metallurgy or as an absorption or filtration medium. It is reported in metric tonnes.	[1]
Wood Pellets	Wood pellets is a fuel product compressed from milled wood. Raw materials are cutter shavings and sawdust, which are by-products of the mechanical wood-processing industry. The expression 'pellets' means cylindrical products which have been agglomerated either directly by compression or by the addition of a small quantity of binder, having a diameter not exceeding 25 mm and a length not exceeding 45 mm.	[6]
Torrefied wood pellets	Torrefied wood pellets are produced in a controlled carbonization process in which biomass is heated with little or no oxygen at high temperatures to produce a black char-like substance. The usual process involves raw wood or other biomass being prepared and torrefied, and then pelletized or briquetted.	[6]
Wood Briquettes	Densified biofuel made with or without pressing aids in the form of cubiform or cylindrical units, produced by compressing pulverized biomass. The raw material for briquettes can be woody biomass (...) are usually manufactured in a piston press. The total moisture of the biofuel briquette is usually less than 15 % of mass. (The JWEE assumes water content of 8 %).	[4]
Biofuel	Any solid, liquid or gaseous fuel produced from biomass.	[7]
Second-generation biofuel	Fuels produced from cellulosic materials, crop residues and agricultural and municipal wastes, including cellulosic ethanol and certain renewable diesels	[7]
Pyrolysis	Pyrolysis is thermal degradation either in the complete absence of oxidizing agent, or with such a limited supply that gasification does not	[7]

	occur to an appreciable extent or may be described as partial gasification. Relatively low temperature are employed of 500 to 800 °C, compared to 800 to 1000 °C in gasification.	
Pyrolysis Oil	Bio-oil produced by fast pyrolysis of biomass. A dark brown, mobile liquid containing much of the energy content of the original biomass, with a heating value about half that of conventional fuel oil. Can be burned directly, either alone or co-fired with other fuels, gasified or otherwise upgraded. Conversion of raw biomass to pyrolysis oil represents a considerable increase in energy density and it can thus represent a more efficient form in which to transport it.	[6]
Renewable diesel	Includes biodiesel (a methyl-ester produced from woody biomass, of diesel quality), biodimethylether (dimethylether produced from biomass), Fischer Tropsch (Fischer Tropsch produced from biomass), (...) and all other liquid biofuels which are added to, blended with or used straight as transport diesel. Biodiesel includes the amounts that are blended into the diesel - it does not include the total volume of diesel into which the biodiesel is blended.	[5]
Synthesis Gas	A mixture of carbon monoxide (CO) and hydrogen (H2) which is the product of high temperature gasification of organic material such as biomass. Following clean-up to remove any impurities such as tars, synthesis gas (syngas) can be used to synthesize organic molecules such as synthetic natural gas (SNG - methane (CH4)) or liquid biofuels such as synthetic diesel (via Fischer-Tropsch synthesis).	[6]

Sources: [1] UNECE/FAO 2024; [2] Forest Europe 2020; [3] FAO 2025; [4] FAO 2004; [5] IEA 2025; [6] UK 2025

Table A4: Energy definitions

Type	Definition	Source
Energy Transformation Sector	The transformation sector comprises the conversion of primary forms of energy to secondary and further transformation (e.g. coking coal to coke, crude oil to petroleum products, heavy fuel oil to electricity).	[5]
Electricity	Wood (in tdm and m^3) consumed to produce electricity (in Table IV). Electricity is generated by thermal power plants separated to electricity and CHP plants.	[5]
Heat	Wood (in tdm and m^3) consumed to produce heat (in Table IV). Heat is generated by power plants separated into CHP plants and heat plants.	[5]
CHP	Wood (in tdm and m^3) consumed for combined Heat and Power generation (in Table IV). It refers to plants which are designed to produce both heat and electricity. UNIPEDE refers to these as co-generation power stations.	[5]

Main Activity Producer	Main Activity Plants refers to plants which are designed to produce electricity/CHP or Heat only. If one or more units of the plant is a CHP unit (and the inputs and outputs can not be distinguished on a unit basis) then the whole plant is designated as a CHP plant. Main activity supply undertakings generate electricity and/or heat for sale to third parties, as their primary activity. They may be privately or publicly owned. Note that the sale need not take place through the main activity grid. Note: This includes district heating by communities, and small producers. Note: Subsidiaries of wood industry companies that only sell power/heat should be included here. For example, a joint company (between sawmill and energy provider) would be a main activity producer.	[5]
Direct Consumer (Heat, CHP and Electricity)	Undertakings generating heat, CHP or electricity for their own use and/or for sale, as an activity which supports their primary activity (e.g. paper production). They may be privately or publicly owned.	[5]
Final consumption	The term final consumption (equal to the sum of end-use sectors' consumption) implies that energy used for transformation and for own use of the energy producing industries is excluded. Final consumption reflects for the most part deliveries to consumers (see note on stock changes). In final consumption, petrochemical feedstock are covered under industry as an of which item under chemical industry for those oil products that are principally used for energy purposes. Separated from these are the other oil products that are mainly used for non-energy purposes (see non-energy use), which are shown in the rows for non-energy uses and included only in total final consumption. Backflows from the petrochemical industry are not included in final consumption.	[5]
Residential	All consumption by households, excluding fuels used for transport. Includes households with employed persons (ISIC Division 95) which is a small part of total residential consumption.	[5]
Agriculture, Forestry and Fishing	Agriculture/Forestry includes deliveries to users classified as agriculture, hunting and forestry by the ISIC, and therefore includes energy consumed by such users whether for traction (excluding agricultural highway use), power or heating (agricultural and domestic) [ISIC Divisions 01 and 02]. Fishing includes fuels used for inland, coastal and deep-sea fishing. Fishing covers fuels delivered to ships of all flags that have refueled in the country (including international fishing) as well as energy used in the fishing industry [ISIC Division 05]. Previously fishing was included with agriculture/forestry and this may continue to be the case for some countries.	[5]
Transport Sector	Consumption in the Transport sector covers all transport activity (in mobile engines) regardless of the economic sector to which it is contributing [ISIC Divisions 60, 61 and 62].	[5]

Sources: [1] UNECE/FAO 2024; [2] Forest Europe 2020; [3] FAO 2025; [4] FAO 2004; [5] IEA 2025; [6] UK 2025

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