ISSN 1831-9424

European Commission

JRC SCIENCE FOR POLICY REPORT

Biomass production, supply, uses and flows in the European Union

Integrated assessment

Avitabile V, Baldoni E, Baruth B, Bausano G, Boysen-Urban K, Caldeira C, Camia A, Cazzaniga N, Ceccherini G, De Laurentiis V, Doerner H, Giuntoli J, Gras M, Guillen Garcia J, Gurria P, Hassegawa M, Jasinevičius G, Jonsson R, Konrad C, Kupschus S, La Notte A, M'barek R, Mannini A, Migliavacca M, Mubareka S, Patani S, Pilli R, Rebours C, Ronchetti G, Ronzon T, Rougieux P, Sala S, Sánchez López J, Sanye Mengual E, Sinkko T, Sturm V, Van Leeuwen M, Vasilakopoulos P, Verkerk PJ, Virtanen J, Winker H, Zulian G

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2023

Joint Research Centre

EUR 31566 EN

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JRC132358

EUR 31566 EN

PDF ISBN 978-92-68-04915-0 ISSN 1831-9424 doi:10.2760/811744 KJ-NA-31-566-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Avitabile V, Baldoni E, Baruth B, Bausano G, Boysen-Urban K, Caldeira C, Camia A, Cazzaniga N, Ceccherini G, De Laurentiis V, Doerner H, Giuntoli J, Gras M, Guillen Garcia J, Gurria P, Hassegawa M, Jasinevičius G, Jonsson R, Konrad C, Kupschus S, La Notte A, M'barek R, Mannini A, Migliavacca M, Mubareka S, Patani S, C Pilli R, Rebours C, Ronchetti G, Ronzon T, Rougieux P, Sala S, Sánchez López J, Sanye Mengual E, Sinkko T, Sturm V, Van Leeuwen M, Vasilakopoulos P, Verkerk PJ, Virtanen J, Winker H, Zulian G. *Biomass production, supply, uses and flows in the European Union. Integrated assessment.* Mubareka S, Migliavacca M, Sánchez López J (Editors). Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/811744, JRC132358.

***IMPORTANT NOTE**: this is a new version of the previous report (doi:10.2760/484748; EUR 31415), published on the 24 February 2023, in which chapter 4 on "European and global macroalgae production and uses" has been corrected due to an error in the data processing and to a subsequent update in the main data source (FAO, 2023). As a consequence, the previous version has been superseded.

Contents

Abstract

The European Union (EU) uses biomass to meet its needs for food and feed, energy, and materials. The demand and supply of biomass have environmental, social, and economic impacts. Understanding biomass supply, demand, costs, and their associated impacts is particularly important for relevant EU policy areas, to facilitate solid and evidence-based policymaking.

As the European Commission's (EC) in-house science service, the role of the European Commission’s Joint Research Centre (JRC) is to provide EU policies with independent, evidence-based, scientific and technical support throughout the whole policy cycle, thereby contributing to coherent policies. To provide a sound scientific basis for well-prepared EC policy making, the JRC was requested by Commission services to periodically provide data, processed information, models, and analysis on EU and global biomass supply and demand and its sustainability. This report is the 3rd public-facing report under this mandate.

Foreword

As we strive to find solutions to increasingly pressing and alarming direct and indirect impacts of the climate and biodiversity crises, we find great consensus for the bioeconomy. Over the past decade, the European Commission has adopted a number of initiatives that set goals aimed at decoupling economic growth from resource use. The European Green Deal accelerated the protection of biodiversity (Biodiversity Strategy), the mitigation of climate change (Stepping up Europe's 2030 climate ambition), a more sustainable food system (Farm to Fork Strategy) and, in general, the increasing sustainability of the economy and circular use of resources. In all these initiatives, biomass is a key resource.

We turn to biomass, and therefore the bioeconomy, as a means to transform our societies and economies so that we can live in harmony with the planet and achieve a sustainable balance in the socio-ecological system. This means relying on biomass that is sustainably sourced and transformed. The bioeconomy offers an opportunity to realign the economy with the biosphere, stimulating us to seek innovative alternatives to non-renewable sources, while also – and principally – inviting us to consume less.

As scientists at the Joint Research Centre (JRC), our role is to provide a high standard of scientific and technical support to EU policy by delivering evidence and by curating knowledge in a holistic way, such as required by the topic of the bioeconomy. The JRC provides the European Commission services, on a long-term basis, with data, models and analyses of EU and global biomass potential, supply, demand and related sustainability. This task requires integration across sectors and policies, and calls for state-of-the-art biomass-related data, knowledge and modelling tools.

This issue in the series of reports prepared under the JRC Biomass mandate, highlights our increasing dependency on biomass for material and energy over the past decade. Although we are getting better at recovering our bio-waste for material and energy, we still require an increasing amount of biomass from primary production systems. The report points out the potential to re-engineer biomass for high-value-added products, and examines the full life cycle of a representative basket of bio-based products in terms of their environmental impacts. It also highlights that, although we are doing better at replenishing our seas, they are still not fully healthy. The forest biomass embodied in our traded commodities is considerable, and our consumption of natural resources needs to be curbed.

Biomass is a sine qua non for a Green Transition. Biomass produced from ecosystems is being re-engineered while new uses for biomass are being invented to offset emissions. However, ecosystems are under great pressure. We expect forests, the seas, and freshwater and agro-ecological systems not only to generate goods, but also to mitigate climate change and maintain biodiversity at the same time.

Our economies and societies depend on a healthy planet. Therefore, we should stop asking "How much biomass is available for human use?", but rather ask ourselves "How can we live in harmony with our planet to foster a lasting equilibrium between humans and the natural world?"

Director Alessandra Zampieri

Directorate for Sustainable Resources

Joint Research Centre

Acknowledgements

The authors would like to acknowledge the support of the technical experts of the Interservice Group on Biomass Supply and Demand in the European Commission, chaired by the Directorate General for Research & Innovation, whose comments were essential during the execution of the work.

The authors of Chapter 4 would like to thank Sing Sing Ngai, Translator – Terminologist in the Directorate General for translation for her translation of data from China on macroalgae.

The authors of Chapter 6 would furthermore like to thank the European National Forest Inventory Network (ENFIN, http://enfin.info/) for their collaboration in efforts to harmonise forest parameters and Rene Colditz for his input on the new EU Forest Strategy and EU Forest Monitoring in that context. Finally, the authors of Chapter 7 would like to thank Udo Mantau for his continued support in the effort to harmonise statistics on woody biomass, allowing for a hamonised overview of woody biomass flows and the wood resource balance.

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Executive summary

The European Union (EU) uses biomass to meet its needs for food and feed, energy, and materials. The demand and supply of biomass, our technological innovation and push for resource efficiency, have economic, environmental, and social impacts. Understanding biomass supply, demand, costs, and their associated impacts is particularly important for relevant EU policy areas, to facilitate solid and evidence-based policymaking.

As the European Commission's (EC) in-house science service, the role of the European Commission's Joint Research Centre (JRC) is to provide EU policies with independent, evidence-based, scientific and technical support throughout the whole policy cycle, thereby contributing to coherent policies. To provide a sound scientific basis for well-prepared EC policy making, the JRC was requested by Commission services to periodically provide data, processed information, models, and analysis on EU and global biomass supply and demand and its sustainability. This report is the 3rd public-facing report under this mandate[1], but several outputs have resulted in the form of policy briefs, data sets, peer-reviewed papers and other communication tools, these are listed in the dedicated pages of the European Commission's Knowledge Centre for Bioeconomy[2].

Policy context

Biomass is very much centre stage in the European Green Deal. Forests, the seas, freshwater and agricultural systems, are expected to simultaneously mitigate climate change, house biodiversity and generate goods. As a result, the biomass produced from these sources is being re-engineered, and new uses for biomass are being invented to offset emissions. Meanwhile, the societal challenges we are all facing are being addressed at a global level and the EU's pledges to international commitments are resulting in a series of overarching EU-level strategies. These are engaging commitments towards the Sustainable Development Goals and more specifically, to mitigate climate change, enhance ecosystems and conserve and enhance biodiversity, as well as promote justice, equality, and competitiveness. Geopolitical events are, in turn, also impacting the EU and forcing us to re-think how our resources are managed, as well as the EU's food and energy sovereignty.

The powerhouse systems that we rely on to bring us through a green transition to a new way of living with lower impact are the terrestrial, marine and freshwater systems. Basic data and information about them and the services they provide which includes, but is not exclusively, biomass provision are a fundamental piece of policy making. Our own waste streams also provide an increasingly important source of biomass, alleviating direct impacts on primary production systems, yet re-engineering waste is also not without costs.

Monitoring is essential to identify areas in need of policy intervention as well as to assess the coherence and the impacts of existing legislation. The Action Plan of the 2018 EU Bioeconomy Strategy includes a specific action for the development of an EU-wide, internationally coherent monitoring system to track economic, social and environmental progress towards a circular and sustainable bioeconomy. The European Commission's Joint Research Centre is leading this action, in collaboration with several Commission Services, Member States and stakeholders. The monitoring system is publicly available through the European Commission's Knowledge Centre for Bioeconomy (KCB). The JRC Biomass Mandate is an important source of data for the EU Bioeconomy Monitoring System[3] for the biomass-related indicators. The following indicators are provided by the collective efforts related to this Mandate:

a) **Total biomass supply for food purposes[4].** This indicator is calculated by estimating food demand in all Member States and the European Union and converting this food demand into raw biomass dry matter equivalents. It includes all types of biomass (agricultural or aquatic) that is used to satisfy food requirements of the citizens of the EU. Food produced to be exported is excluded, as well as all waste that takes place before the food is available to consumers. Consumption waste is included in the estimated quantity; that is, some of this biomass will be wasted in the consumption phase.

[1] The others were:
https://publications.jrc.ec.europa.eu/repository/handle/JRC109869.
https://publications.jrc.ec.europa.eu/repository/handle/JRC122719.
[2] https://knowledge4policy.ec.europa.eu/projects-activities/jrc-biomass-mandate_en.
[3] https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring_en.
[4] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.4.

b) **Biomass directly consumed by EU citizens by source (animal, fish, plant-based, algae)[5].** This indicator estimates the quantity of food, in raw biomass dry matter equivalents, that is actually consumed by the citizens of the EU. Consumption waste is excluded from the total quantity.

c) **Biowaste[6]**. Data on waste generation is collected from EU member states in a framework set up by the Waste Statistics Regulation includes a mix of organic and inorganic wastes generated from various economic activities (including households).

d) **Food waste[7].** JRC developed a model to perform the estimation of food waste generated by EU MS across the supply chain (primary production, processing and manufacturing, retail and distribution, food services, and household consumption), at food group level (sugar beet, cereals, fruit, vegetables, potatoes, oilseeds, meat, fish, eggs, and dairy).

e) **Total biomass consumed for energy and materials[8]**. The total biomass consumed for energy and the total biomass consumed for materials are two separate indicators derived from the JRC Biomass Mandate. The values represent both primary and secondary sources of biomass (thus also by-products and waste), converted to tonnes of dry matter.

f) **Share of woody biomass used for energy[9]**. This indicator shows the total biomass of woody origin consumed annually in the production of energy as a share of total uses. The woody biomass flow diagrams are the data source for this indicator.

g) **Cascade uses of wood resources[10]**. This indicator is based on the wood resource balance data. The indicator is calculated as the share of by-products and post-consumer wood used for material production relative to the absolute woody biomass uses reported in the EU-27. Also reported is the share of secondary wood used for energy.

h) **Ratio of annual fellings (m3/ha/year) to net annual increment (m3/ha/year)[11].** Total fellings as a fraction of the net annual increment based on JRC's estimates using harmonised datasets developed in collaboration wit National Forest Inventories.

i) **Fishing mortality of commercially exploited fish and shellfish exceeding fishing mortality at maximum sustainable yield[12]**. This indicator is computed by JRC for the Scientific Technical and Economic Committee for Fisheries (STECF) but is reported in the EU Bioeconomy Monitoring System through the JRC Biomass channel. The indicator shows the model-based trend over time of fish stock biomass relative to 2003 in the EU waters of the North-East Atlantic and adjacent seas (FAO area 27) and the Mediterranean and Black seas (FAO area 37).

Main findings

In this report, we describe the biomass sources and uses for the agricultural, forestry, algae, and fisheries and aquaculture sectors with the latest available data both in comparative terms (using the same units) in Chapter 1, as well as with deep dives into the sectors themselves, highlighting the most salient issues in the respective sectors (Chapters 2-7). We also examine the contribution of food, wood and other biowaste to the biomass supply (Chapters 7 & 9). Each of these sectors are assessed by experts whose methods and models differ from one another. The basis upon which the approaches are selected by the experts will vary for any number of reasons, and each approach has its limitations and caveats. In this report, we endeavor to make clear what the main limitations of the approaches are, where relevant.

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[5] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.5.

[6] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.5 & https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.6.

[7] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.1 & https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.2.

[8] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.2 & https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.3.

[9] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.4.a.4.

[10] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.1.

[11] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=2.2.a.1.

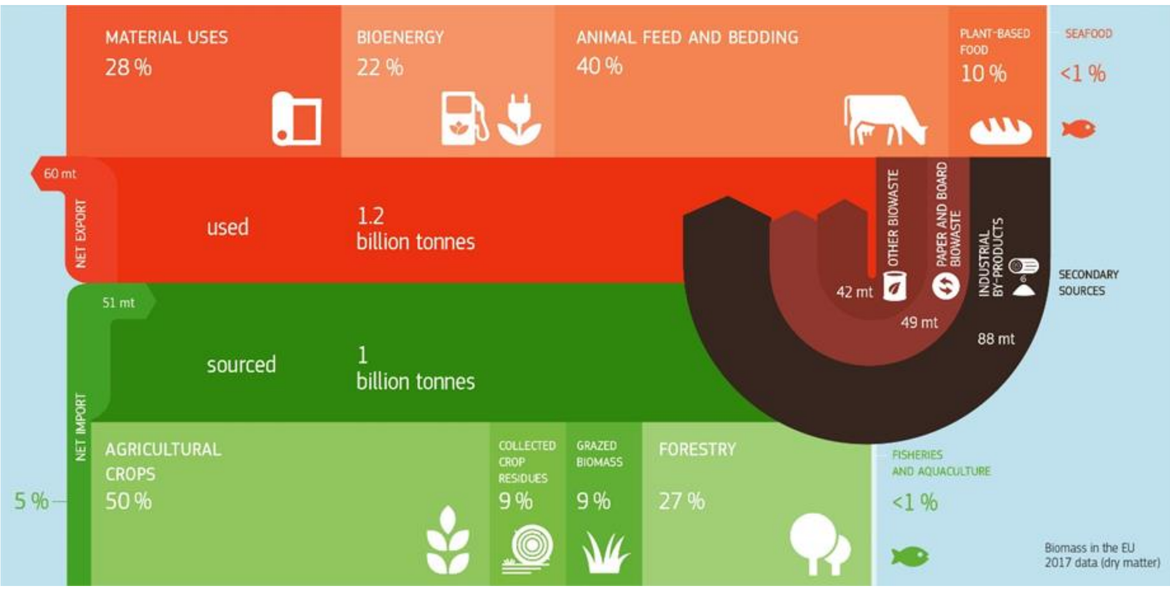
[12] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=2.2.b.2.

A description of the trends in biomass supply and uses of these sectors indicates the direction in which the EU-27 is heading. Much of the data in this and previous reports are reported in the EU Bioeconomy Monitoring System[13] or elsewhere in the Knowledge Centre for Bioeconomy (KCB)[14]. This ensures a curated and long-lasting legacy of the JRC Biomass Mandate. The data is also reported in the relevant portals and reports to the topics treated here. They are cited in the individual chapters if this is the case.

Several specific topics were selected for in-depth studies for the JRC Biomass Mandate in 2022. These include a specific study on the prices of timber (Chapter 8); the outlook of the agricultural biomass flows (Chapter 3); a detailed analysis of the algae sector (Chapter 4: Seaweed); a special look at trade of bio-commodities (Chapter 13); and an overview of land use in the EU, with focus on so-called marginal lands (Chapter 14).

Biomass supply and uses in the EU-27

The total sources of biomass, which includes domestic production and net imports, in the EU-27 amounts to approximately 1 billion tonnes of dry matter (tdm), whereas the uses amount to 1.2 billion tdm (Chapter 1). The additional biomass in uses with respect to sources, which is domestic production plus net-imports, is due to the recovery of waste from industry and households (Chapter 9):



Almost 70% of the biomass supply is from the agricultural sector, which includes food, residues collected and grazed biomass (Chapter 1). The crops and residues are grown on roughly 37% of the total EU-27 (2018 EEA extent accounts[15]) (Chapter 14). The biomass produced in the EU for food purposes (including inputs), amounts to roughly 500 million tonnes dry matter (Mtdm) in a year[16] (Chapter1), of which roughly 100 Mtdm is plant-based food.[17]

To achieve the cross sectoral view presented in Chapter 1 and in the figure above, the native units for the individual sectors were converted to tonnes dry weight. This involves the use of correction coefficients to estimate the quantities in tonnes of dry matter, which entails a loss in precision. However, the purpose of the presentation is to

[13] https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring_en.
[14] The KCB develops a robust and comprehensive knowledge base that is needed to drive the bioeconomy towards circularity and sustainability (https://knowledge4policy.ec.europa.eu/bioeconomy_en). The bioeconomy encompasses all sectors and associated services and investments that produce, use, process, distribute or consume biological resources, including ecosystem services. As such it is a natural enabler and result of the European Green Deal transformation. It takes a holistic, cross-sectoral perspective to biological resources. This allows to identify win-win solutions (COM(2022) 283 final).
[15] https://www.eea.europa.eu/data-and-maps/data/data-viewers/ecosystem-extent-accounts.
[16] *Total biomass supply for food purposes, including inputs* indicator, EU Bioeconomy Monitoring System, https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.4.
[17] *Biomass directly consumed by EU citizens as food* indicator, EU Bioeconomy Monitoring System, https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=1.1.a.5.

show relative trends and shares of biomass consumption and flows for the sectors, and this is achieved through the constancy in the conversion approaches over the years for each of the sectors.

Much of the remaining biomass sources (27%), are from forestry. Based on the specific assessment carried out by JRC within the present study, we estimated that 551 Mm^3 were removed from forests in 2017 (including bark) (Chapters 6&7). Secondary wood (wood chips and particles; black liquor), amounted to 179.6 Mm^3 in the same year (Chapter 7).

The supply of fish from aquaculture reached 1.1 million tonnes. Spain, France, Greece, and Italy represent 66% in weight and 61% in value of the total EU aquaculture production in 2020, according to FAO data. Marine fish represent 21% of the weight and 40% of the value of the EU aquaculture production. Molluscs represent 49% of the weight and 27% of the value. Diadromous fish represent 20% of the weight and 24% of the value. Freshwater fish represent 10% of the weight and 7% of the value. As to marine fishing, roughly 3.9 million tonnes of seafood (including fish) were landed from EU waters in 2020. There has been a reduction in the EU seafood supply and economic performance from marine fishing since 2016-17. This reduction in the supply is largely driven by the efforts to reduce overexploitation and external factors that have undermined the performance of the EU fishing fleet, such as Brexit, the impact of the COVID-19 pandemic and more recently, high fuel prices. These aspects are further discussed in Chapter 5.

In addition to the other sources of biomass shown in the figure above, seaweed is an increasingly important source of biomass, with its direct and indirect climate change mitigation potential, Macroalgae contribute to the transformation of large amounts of CO_2 into O_2 , play an important role in marine ecosystems contributing to the global primary production and supporting complex food webs in coastal zones and are a valuable resource in the European Bioeconomy, mainly by the food and chemical industry. Regarding the supply of macroalgae biomass, according to 2022 FAO data, the EU-27 Member States imported in total 157.3 thousand tonnes of seaweed products in 2019 (measured in net product weight) and exported a total of 89.5 thousand tonnes. In 2020, the traded products, both imports and exports, increased with the imports amounting to 173.4 thousand tonnes and the exports to 98.3 thousand tonnes. In 2020, the Member state that recorded the largest traded seaweed products was Ireland with a total of 64.8 thousand tonnes imported and 77.9 thousand tonnes exported, followed by France (71.8 thousand tonnes of net product weight imported, and 9.5 thousand tonnes exported), including intra and extra EU trade.

Waste is also an important source of biomass in the EU. Biowaste from agriculture, industry and households amounted roughly to 147 Mtdm in 2018 based on Eurostat data[18]. Of this, 90.4% was recovered[19]. When using more detailed data, using a mass-balance approach for food, the food waste generated in 2019 is computed at 84.7 Mtdm alone (Chapter 9), and the wood waste, when computed with more detailed data, is computed at 137.5 Mtdm (in 2017, Chapter 7).

The trend in biomass supply is increasing from both primary domestic production and secondary sources.

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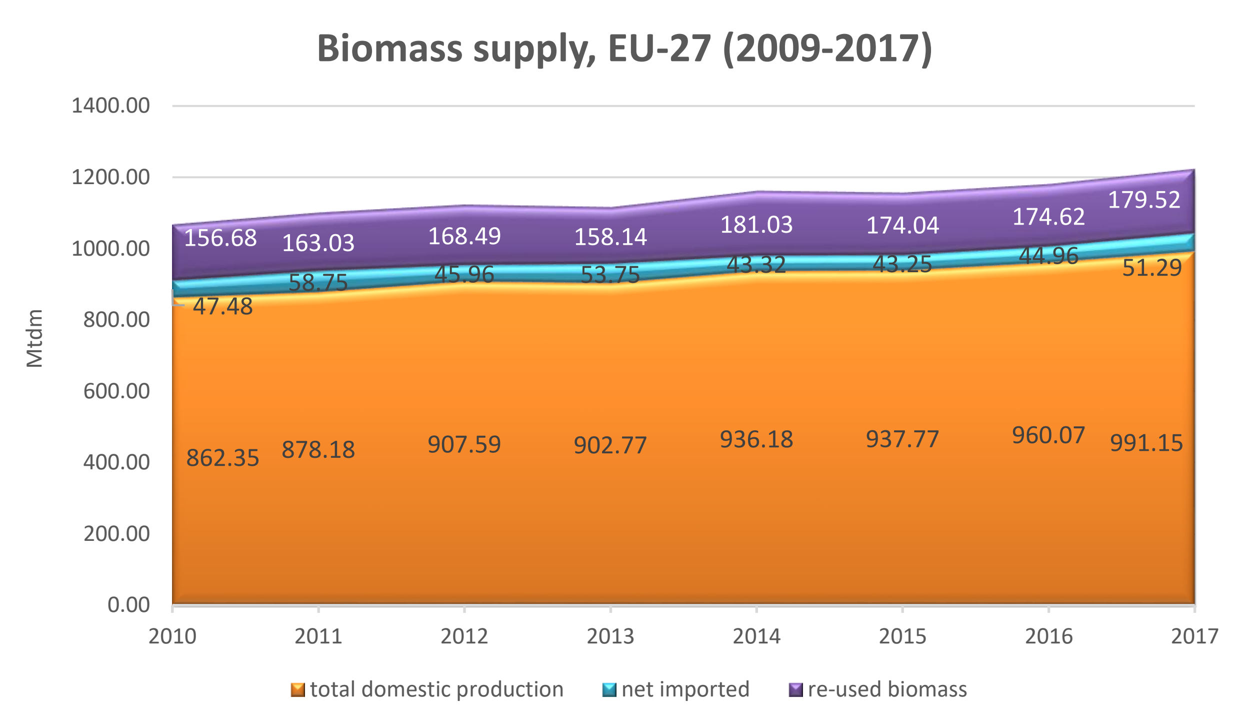
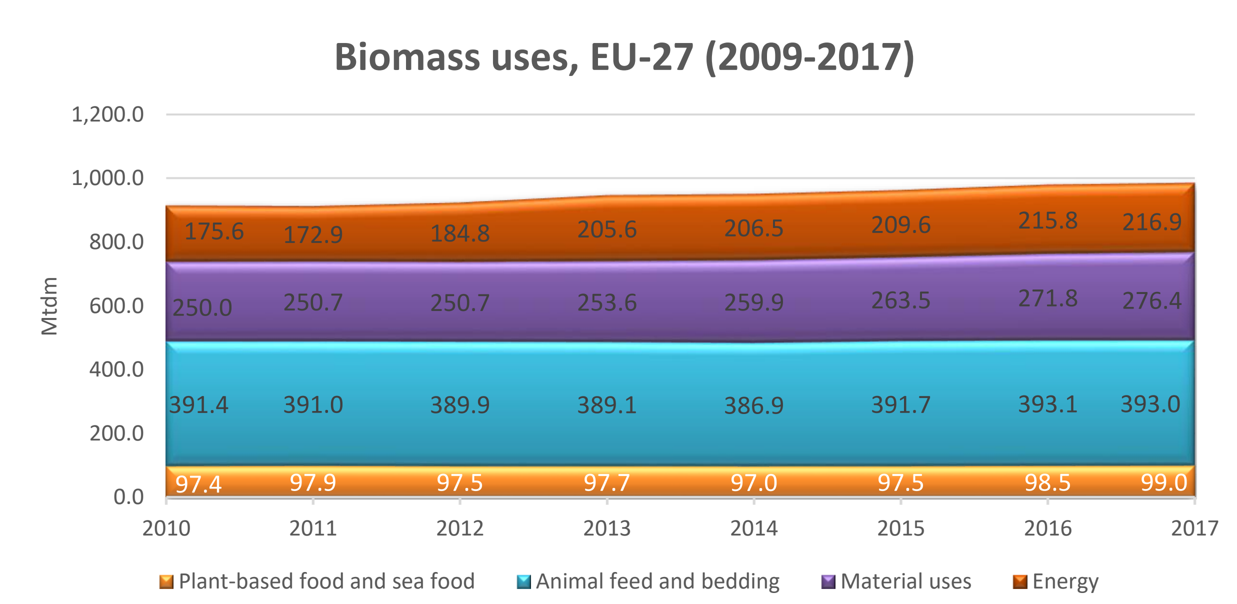
[18] *Biowaste generated by source* indicator, https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.5.

[19] *Biowaste recovered by source* indicator, https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.6.



Turning to the uses of biomass, most of the uses of biomass are for food production. Animal feed and bedding accounts for almost 40% (393.0 Mtdm, net of exports of animal-based food products) and plant-based food accounts for 9.7% (95.7 Mtdm). With respect to non-food products, materials account for 28% (276.4 Mtdm) and energy for 22% (216.9 Mtdm) (Chapter 1).

The trend in the biomass used in the EU-27 is increasing from both primary domestic production and secondary sources. The trend is most pronounced for biomass uses for bioenergy, followed by material uses, while food uses remain largely constant:



Biomass production and impacts

Biomass is foreseen to become increasingly important as a resource in the EU and depending on where the biomass will be produced, either direct or indirect impacts will occur.

One clear example is the deforestation and forest degradation in the tropical areas, which is known to be driven by the production of cropland areas to produce commodities. The EU-27 has been identified as an important contributor to tropical deforestation through the consumption and trade of products and commodities. The proposal for a regulation on deforestation-free products (COM(2021) 706) focused on six commodities (cattle, cocoa, soy, coffee, palm oil, and wood). On December 2022 the European Parliament, the Council, and the European Commission reached the provisional political agreement on the text of the EU Regulation on deforestation-free supply chains, which contains one additional commodity: rubber. Here we report on the crop commodities (cocoa, soy, coffee and palm oil) and cattle. The EU-27 plays a major role in the import of coffee and cocoa beans, palm oil, and soybean products, the latter mostly used to feed animals.

Between 2014-2019, the imports of the EU-27 contributed to deforestation,with a large variability depending on the commodity.

In a separate analysis, the Bioeconomy Footprint was quantified taking74 representative end-use products and 59 primary products into account. The Bioeconomy Footprint is based on the consumption intensity and the environmental impact intensity of a set of representative products, following the rationale of the Consumption Footprint indicator extensively published elsewhere, and referenced in Chapter 12. The total environmental impact of the EU Bioeconomy was shown to have increased over time between 2010 and 2020 with, as expected, the size of the footprint being proportional to population. However, the Bioeconomy Footprint per capita has also increased in almost all EU-27 countries between 2010 and 2020 (Chapter 12). Although this indicator should be interpreted with caution because it is not contextualised within a counterfactual situation and the environmental impacts of the non-bio counterparts (where possible, e.g. non-food) are not measured, it is still providing a valuable indication of the impact of an increased consumption of bio-based products. The pressure on land to produce biomass, whether it is within the EU or outside of our borders, should therefore be closely monitored with the perspective that the capacity of the land to produce biomass it is not limited to the biomass we take directly, but also what we take indirectly (i.e. water to produce biomass), as well as to what we put back into the land (i.e. fertiliser and pesticides) and these are pressures that lead to important impacts on ecosystem services. Ecosystem services range from the biomass provision (e.g. crop, timber and fisheries) to the filtration of pollutants (from air, water and soil) to the protection from natural hazards (e.g. flooding and landslides) and maintenance of habitats directly and indirectly used and valued by people (e.g. pollination, pest control and carbon sequestration). Ecosystems with appropriate extent and in good condition are able to provide higher flows and more services than fragmented and degraded ecosystems. Thus, the management of biomass-producing ecosystems will impact not only the biomass production itself, but a range of ecosystem services. This also has implications when considering bringing abandoned or marginal lands back into production (Chapter 14).

Forest production systems

The EU forest biomass stock is equal to 18.4 billion tdm (referred to the total above ground biomass in 2020), corresponding to a density of roughly 117 t per hectare. About 89% of the EU-27 forest area, and 92% of this biomass stock, are considered as "available for wood supply".

The biomass stock in EU forests has continuously increased since 1990, by about 1-2% per year, but its growth has slowed down during the last 5 years, due to different concomitant factors, including ageing processes, an increasing impact of natural disturbances and other climatic drivers.

Due to the strong relationship with climate, the growth rate of forests, estimated through the net annual increment (NAI), varies considerably between Member States. Central European countries present the largest NAI with a growth rate of >8 $m^3ha^{-1}yr^{-1}$, and Mediterranean and Scandinavian countries present the lowest NAI of <4 $m^3ha^{-1}yr^{-1}$ (Chapter 6).

In Europe, National Forest Inventories (NFI) provide valuable reference statistics, but they refer to different definitions, spatial scales, monitoring periods and temporal frequency. For this reason, data harmonisation, based on a wide collaboration with NFI experts, is essential to perform any meaningful pan-European assessment. The harmonised statistics presented in this report provide unbiased estimates, which partially overcome the limits of official statistics, but they remain limited in their temporal and spatial resolution. Such harmonisation can only be achieved with a long-term acquisition and integration of ground and remote sensing data that are designed and acquired in a way to be highly compatible between EU Member States.

Agri production systems

The total annual agricultural biomass production potential in the European Union for the reference period (2016 – 2020) is estimated at 924 Mtdm per year in EU-27, where 54% of the agricultural biomass produced is economic production while the remaining 46% is residues. Cereals and plants harvested green dominate the economic production, jointly accounting for about 80% of total biomass production. The residue production comes predominantly from cereals (73.2%) and in a lesser extent from oil-bearing crops (16.9%). Looking at the crop level, wheat is the crop that contributes the most to the total biomass production followed by green maize, maize and barley. In the production of agricultural residues, the other major contributors are maize, rapeseed and barley.

Regarding the geographical distribution of the agricultural biomass, six Member States dominate both the economic production and residue production: France, Germany, Italy, Poland, Spain and Romania (358 Mt/y and 295 Mt/y respectively). France and Germany are, respectively, the first and second largest producers, for both economic and residue production.

The availability of biomass from residue production is expected to be rather stable in the next few years. On the other hand, given the improvement in agro-management practices, there is a projection of higher yields of the economic production for the future in all Member States except in France and Germany, but climate change will have a major impact on crop yields perspectives (Chapter 2).

Marine production systems

The state of European fish stocks is monitored through the Common Fisheries Policy (CFP). Indicators estimated for two main areas of European waters, the East Atlantic, North Sea, and Baltic Sea regions; and the Mediterranean and Black Sea region, indicate that while there is a decrease in the indicator of fishing pressure (F/F_{MSY}) in the NE Atlantic EU waters in the period 2003-2020. This indicator for fishing pressure computed for stocks from the Mediterranean & Black Seas through modelling, has remained high during the same period. While there appears to be a slight downward trend in the median value for the fishing pressures indicator since 2013, it is still not in line with the objective of the CFP (Chapter 5). The model-based indicators for the trend in biomass show a general increase over time since 2007 in the NE Atlantic (EU waters only), both for assessed stocks and for data-limited stocks for which only a relative biomass index is available from scientific survey data. On average, in 2020, biomass was around 35% (for assessed stocks) and 50% (for data limited stocks) higher than in 2003. In the Mediterranean and the Black Sea, the median biomass was higher at the beginning of the time-series, but declined and remained stable from 2006–2015, after which it showed a gradual increase. The Scientific, Technical and Economic Committee for Fisheries (STECF) noted a large uncertainty around the indicator of median values for biomass over time, however it still remains the best available data.

Focus on supply chain

We focus on specific issues at the various stages of the supply chain in this 2022 report. We analysed the prices of timber throughout the pandemic and current crisis; assess innovative uses of wood; and look into the biomass uses in biorefineries.

Timber price volatility

The drivers of price volatility in the forest sector following the COVID pandemic in the period 2020-2022 are assessed in this report. The interactions between different stages of the global forest products markets are put into evidence. The study on the effect of the lock-down and stimulus measures related to the COVID-pandemic was initiated in early 2022 for the JRC Biomass Study. The effects were an increased demand for wood for construction and renovation, while at the same time, a constraint in the supply of wood products. The result was an increase in the prices of wood products. These were more pronounced for processed products than for primary forest products. Furthermore, we detected that an apparent imperfect transmission of price signals from processed wood products markets to roundwood markets could increase price volatility. A few months after the study was initiated, the geopolitical issues were the cause of a continuation in the price volatility events, which are still ongoing at the end of 2022.

The strong demand for processed wood products led to price hikes. For example, comparing pine logs with pine lumber prices illustrates how raw material prices remained unchanged in real value terms during the pandemic, while the price of processed products increased (although time will tell: past contracts still in vigour are slower to react to price changes). The price of secondary processed products has increased more than that of primary forest products. Although market participants normally tend to adapt their behaviour in anticipation of future developments, a lack of price transmission between secondary and primary products most likely led forest owners to delay fellings in expectation of higher prices, which restricted the supply of roundwood and the production of processed wood products.

As the pandemic was ending, the prices would have normally reverted to a lower long-term level, however the Ukraine crisis and the associated sanctions on the Russian Federation erupted. This has led to rapidly increasing energy prices in Europe and Worldwide, exacerbating inflation and causing reduced economic activity due to reduced household income and increased production costs in most manufacturing industries. Decreased demand led lumber prices to decrease towards the end of 2022, although prices remain at a higher level compared to before the pandemic (Chapter 8).

Innovative uses of biomass

Spatially explicit data on biomass processing facilities help understand their role in the EU and global bioeconomies and, with additional data and tools, assess their direct and indirect impacts on local economies. Although data on production activities and territorial distribution of biomass processing facilities are still scarce, the JRC publishes data on biomass processing facilities in the EU and in selected non-EU countries with different focus. When looking at chemical and material biorefineries, a subset of biomass processing facilities (which also co-produce food and feed as well as bioenergy), forestry and agriculture are the main feedstock sources, where agricultural feedstock used is mostly (91%) of primary origin while forestry feedstock for a relatively large share is of secondary origin (43%). The share of secondary biomass used by the chemical and material biorefineries is lower outside the EU (16%) than in the EU (23%) (Chapter 13).

An assessment of the innovative wood products in the EU shows that although there is little quantitative data available, an increase in wood biomass use for innovative products was detected. A deeper look at four semi-finished products is looked at in this report (Chapter 15).

Key conclusions

The main findings listed above stem from a broad range of topics related to biomass, from all production systems and waste. This report aims to provide an assessment of the latest available knowledge on the EU-27 biomass production, supply and demand from the agriculture, macroalgae, fisheries and forestry primary production sectors, as well as bio-waste. The assessment of the environmental impacts of our biomass consumption, including the impacts in regions outside of the EU, were made using a life-cycle assessment approach that was generalised and does not necessarily reflect the supply chains we describe in the detailed chapters, but on the other hand provide an overview of the general trends in impacts of our overall consumption.

When assessing all biomass production, supply, uses, demand, flows and impact at once, we find that in many cases we are making progress in terms of resource efficiency (e.g. increased wood, food and other bio-waste re-use and recycling), however we are also producing and consuming more overall. This Jevon's Paradox[20] (Jevon's 1865), is the result of efficiency goals, however, a too-narrow focus on efficiency generates lock-in, and low adaptability to change. Whereas efficiency is important in the short term, adaptability is important in the long term, such as for the sake of resilience (Holling and Gunderson, 2002[21]). Furthermore, when combined with a rebound effect whereby there is an overall increased use of biological resources because they are in fact more efficiently produced, less expensive, and their diversification in uses are encouraged, we conclude that our impact on biomass-producing systems is increasing.

[20] During the transition to coal as an energy carrier in the economy in the mid-to-late 1800s, economist (Jevons, 1865) observed a certain paradox where, as the efficiency of coal use increased, the overall magnitude of coal use also increased. Jevons, W.S., The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines, 2nd Rev. e., Macmillan and Co, 1865.

[21] Holling, C.S., and L.H. Gunderson, 'Resilience and Adaptive Cycles', Panarchy: Understanding Transformations in Human and Natural Systems, Island Press, 2002, pp. 25–62.

Thus in our quest to produce and use biomass more efficiently, there is an apparent unintentional side effect of consuming more overall. This is well illustrated with the example of cascade use in wood. While we are re-using wood fibres more and more, we are also generating more new wood fibres.

Many gaps remain in reporting on the topic, namely the system's perspective. While more detail on each specific sector can be found in literature, including JRC's own, a generalised gap is in understanding the sustainability of the whole socio-ecological system and the implications of biomass production, supply and uses really implies. While the reporting here aims to be comprehensive, it still follows a reductionist approach where the various relevant sectors are treated separately and represented by siloed chapters. The societal metabolism perspective and the use of the MuSIASEM approach, as described in Mubareka et al., forthcoming[22], can complement the perspective by integrating several of the data sets used to present results here, into a holistic picture of the socio-ecological system related to biomass production and uses in the EU-27. A holistic perspective would capitalise on the results presented here, available after nearly 10 years of activity of the JRC Biomass Mandate[23] into meaningful time series and published datasets, within a context that takes our society and economy into consideration. In this way, we aim to achieve a more balanced view of the real implications of sourcing and using biomass, and a better understanding of the boundaries thereof.

Quick guide

This report is a compilation of chapters written by the respective experts whose names are listed at the beginning of each chapter. Since each topic has its own specificities, including logic in units, geographical coverage and level of depth, the chapters may seem disconnected, however the common thread between them is biomass. The authors do not believe in distorting the data too much for the sake of a harmonised overview, for example in expressing the data in common units throughout because often these common units, such as tonnes of oil equivalent, carbon equivalent or tonnes of dry matter, require additional conversions and therefore decreases precision. The approach to convert data adds to the uncertainty of the data and it is very difficult for readers to work backwards to recreate the native units of measure.

The report is set-up according to the following broad categories:

1) Overview of biomass production and uses (Chapter 1)
2) Production, supply uses and flows by sector (Chapters 2-9)
3) Novel uses of biomass (Chapters 10 & 11)
4) Assessments of impacts of biomass production and uses (Chapters 12-15)

[22] Mubareka, S., Giuntoli, J., Sanchez-Lopez, J., Lasarte-Lopez, J., M'barek, R., Ronzon, T., Renner, A, Avraamides, M. Trends in Bioeconomy, Monitoring and assessment in the EU-27. JRC Science to Policy report, forthcoming in 2023.

[23] https://knowledge4policy.ec.europa.eu/projects-activities/jrc-biomass-mandate_en.

1 European Biomass supply and use from a cross-sectorial perspective

Patricia Gurría & Robert M'barek

Key messages

- The total supply of biomass in the EU-27 adds up to approximately 1 billion tonnes of dry matter of which 90% is produced in the EU[24].
- In 2016, the share of biomass used from agricultural sources is overall higher (61.9%) than the share of woody biomass used (37.8%) in the EU, however, shares vary greatly between Member States.
- Harmonisation of biomass flows to common units provides a cross-sectorial perspective, allowing trends in shares of biomass uses to emerge.

In the last few years, the EC has adopted multiple initiatives that set goals towards decoupling economic growth from resource use (The European Green Deal (European Commission, 2019)), protecting biodiversity (The Biodiversity Strategy (European Commission, 2020)), mitigating climate change (Stepping up Europe's 2030 climate ambition (European Commission, 2020b)) and, in general, increasing the economy's sustainability and circular use of resources (Bioeconomy Strategy (European Commission, 2012, updated in 2018), Farm to Fork Strategy (European Commission, 2020c), Circular Economy Action Plan (European Commission, 2020d)). In all these initiatives, biomass is a key resource.

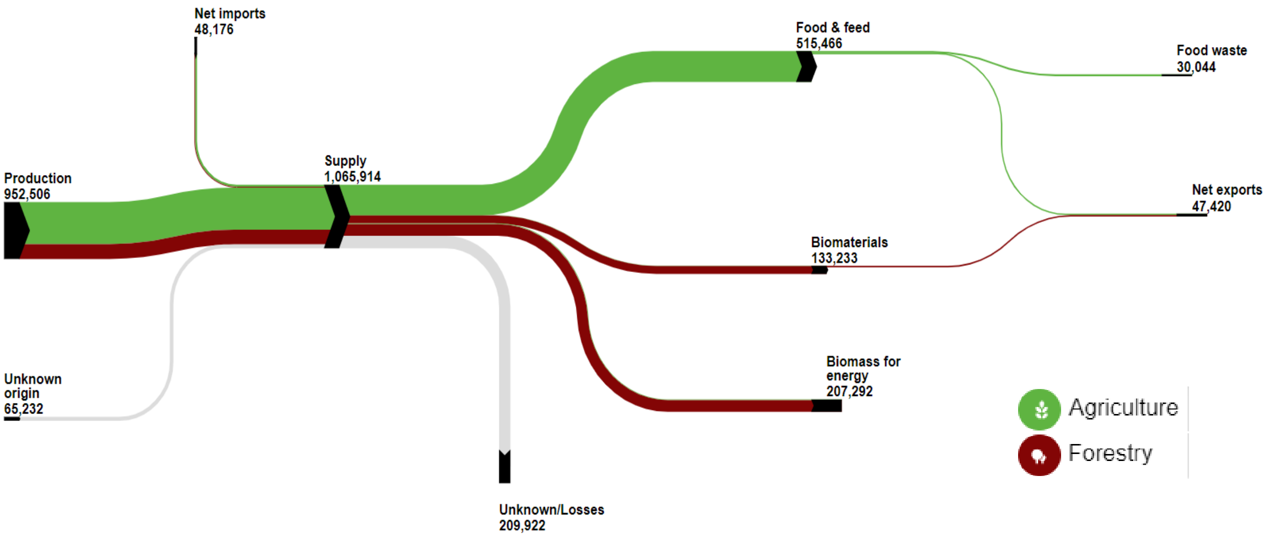
The quantification of the flows of biomass is an essential component to assess the sustainability of a bioeconomy. It provides necessary data to understand how the available biomass is used, where there are trade-offs, and how dependent we are on international markets. While it is the purpose of the whole report to provide numbers on biomass sources and uses in the native units that make the most sense for each sector, this chapter is dedicated to describing the biomass sources and uses from a cross-sectoral perspective through the added value of converting all biomass to a common unit: tonnes of dry matter (tdm). This approach was developed within the framework of the Biomass Assessment Study, initially published in 2017 (Gurria et al., 2017) to show the flows of biomass for three sectors of the bioeconomy, from supply to uses, including trade. The cross-sectoral biomass flow diagrams can be visualised in the EU Biomass Flows[25] tool in the form of Sankey diagrams (Gurria et al., 2017, 2020, 2022) and are the result of the teamwork of multiple experts, whose work is discussed in detail in other chapters of this report. The trade-off of presenting data in this way is a loss of sector-specific data, for example we do not capture all waste streams here. For example, whereas the by-products streams for the forest sector are documented (see Chapter 7), they are not for agricultural biomass, thus these streams are not represented at all in the overall cross sector representation.

1.1 Biomass supply & uses in dry matter

The total supply of biomass from primary productions systems (i.e. not including waste or by-products streams) in the EU-27 adds up to approximately 1 billion tdm. Almost 90% of this biomass is produced in the EU-27, while 5% of the biomass supply is imported from extra-EU countries (the origin of the remaining 5% is unknown). Of the total biomass available for further processing or consumption, approximately 70% is of agricultural origin, making agriculture the largest source of harvested biomass in the EU-27. Woody biomass accounts for 25% of the total (Figure 1). The relative weight of the fisheries and aquaculture sector is quantitatively quite small (<1%). Nevertheless, it still is an important source of biomass when considering economic or nutritional values.

[24] This figure is complemented by secondary flows of biomass (e.g. reuse of biowaste), which is estimated to be around 180 million tonnes of dry matter but is not discussed in this chapter.
[25] https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/.

Figure 1. Biomass flows by sector, EU-27, net trade, 2017 (1000 tdm).



Note: Data for 2017 is shown for cross-sectoral comparison. The width of the flows is proportional to the quantity of biomass of each origin and the flows may not be visible in the figures (e.g. agriculture to bioenergy). Please refer to the online version (https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/).

Source: EU Biomass Flows (DataM, 2022).

The agricultural sector is also the biggest producer of domestic biomass with 74% of the total, followed by forestry with 26% of the dry matter content. The distribution of biomass origin for each Member State is shown in Table 1.

Table 1. Domestic biomass production, 2017 (million tonnes of dry matter (Mtdm)).

Member State	**Agriculture**	**Forestry**	**TOTAL**	**% Agriculture**	**% Forestry**
France	158.59	26.41	184.99	86%	14%
Germany	113.78	34.44	148.21	77%	23%
Poland	62.30	23.70	86.00	72%	28%
Italy	59.48	6.88	66.36	90%	10%
Spain	55.16	8.85	64.01	86%	14%
Romania	50.59	7.60	58.19	87%	13%
Sweden	14.19	38.80	52.98	27%	73%
Finland	7.20	33.10	40.31	18%	82%
Czechia	17.11	10.14	27.25	63%	37%
Hungary	24.13	2.99	27.12	89%	11%
Denmark	24.89	2.01	26.90	93%	7%
Bulgaria	17.64	3.36	21.00	84%	16%
Austria	11.34	9.24	20.57	55%	45%
Greece	13.91	0.86	14.77	94%	6%
Portugal	7.60	7.10	14.70	52%	48%
Lithuania	10.84	3.56	14.40	75%	25%

Member State	Agriculture	Forestry	TOTAL	% Agriculture	% Forestry
The Netherlands	12.57	1.66	14.23	88%	12%
Belgium	9.68	2.83	12.51	77%	23%
Slovakia	7.24	4.90	12.14	60%	40%
Latvia	5.11	6.75	11.87	43%	57%
Ireland	10.15	1.54	11.69	87%	13%
Estonia	2.46	6.01	8.47	29%	71%
Croatia	5.54	2.79	8.32	67%	33%
Slovenia	1.96	2.36	4.32	45%	55%
Luxembourg	0.66	0.19	0.85	77%	23%
Cyprus	0.32	0.01	0.33	98%	2%
Malta	0.01	0.00	0.01	100%	0%
EU-27	**704.45**	**248.06**	**952.51**	**74%**	**26%**

Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

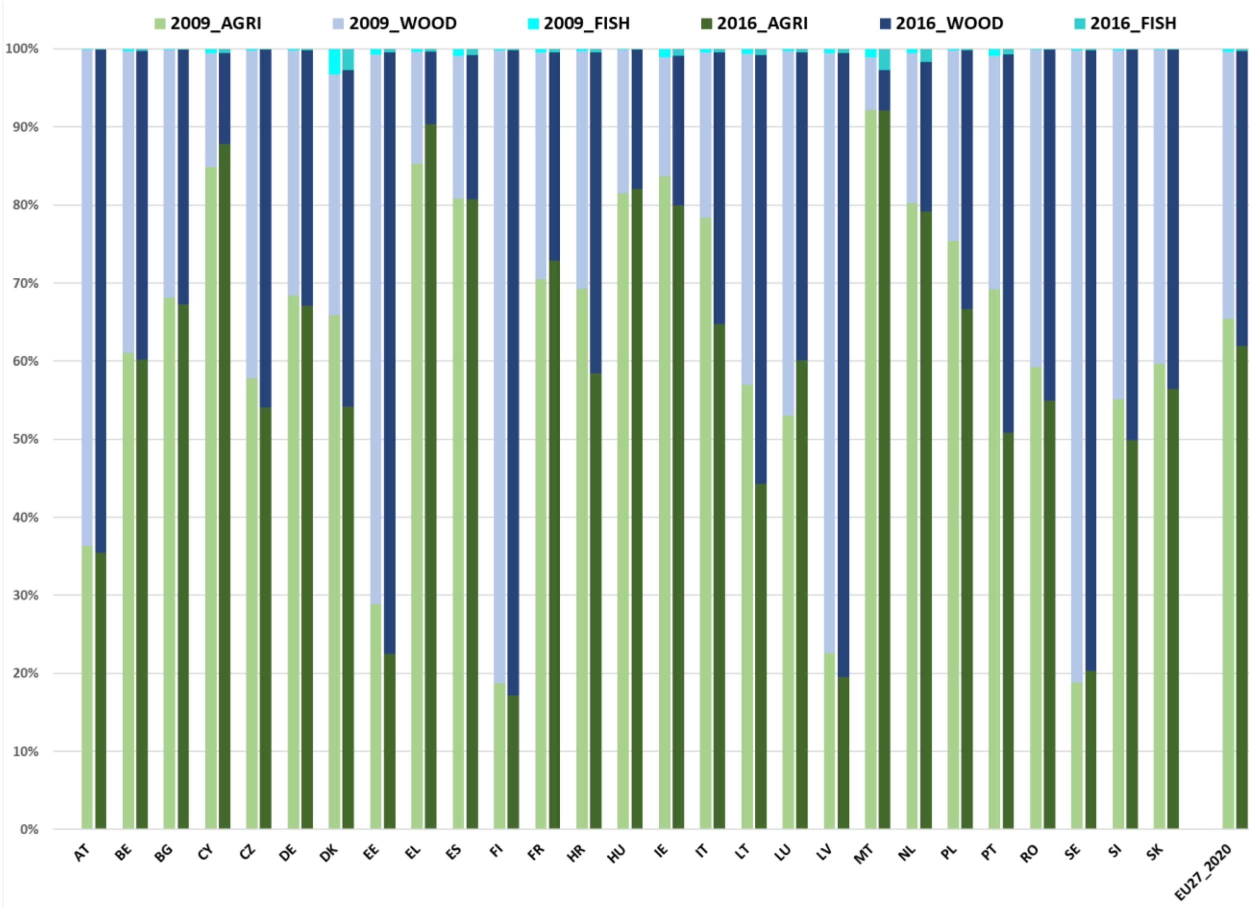
Most of the agricultural biomass (70%) is produced in the form of harvested crops. Although much smaller in quantity, grazing and harvested residues (each 13% of the total agricultural biomass) are also important sources. Only 6% of the biomass of agricultural origin is imported into the EU-27. Domestic roundwood is the largest source of woody biomass in the EU-27. Only 13% of the total available roundwood is imported or of unreported origin. As for fisheries and aquaculture[26], the biggest source of biomass is imported fish and seafood (44%), followed by captured fisheries (35%). "Domestically" produced biomass from the fisheries industry (captured fish landings and aquaculture) amounts to 43% of the total fisheries biomass supply.

Food and feed are the most important category in terms of biomass use. Due to large data gaps in terms of biomaterial and bioenergy uses of agricultural biomass those two categories of uses are under-estimated, although they are fairly well documented for forest biomass (see Chapter 7). The imbalance in known uses for waste streams results in a deficiency in the overall cross-sectorial biomass flows, because the biomass supply that cannot be assigned to a specific use or is lost or wasted (for agricultural biomass), cannot be represented. Furthermore, there is little data to comprehensively represent the cascading use of materials in the agricultural sector (e.g. from biomaterials to energy production from biomass). Advanced biofuels (i.e. straw, wood and other lignocellulosic biomass for liquid biofuels) and the agricultural biomass for heating (i.e. agripellets) are also not included here.

An important indicator in the EU Bioeconomy Monitoring System is the share of biomass used by source[27]. This gives an indication of the trends in biomass sources. The distribution of biomass shares by origin (agricultural, forestry or fisheries and aquaculture) varies across the EU-27, although in most MSs the share of agricultural biomass is higher than the share of other types of biomass. The share of agricultural biomass has declined in the last period where data from all sectors was available.

[26] 2016 data; it is the latest complete detailed available dataset.
[27] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.6.b.1.

Figure 2. Biomass share by origin, in 2009 and 2016 for each Member State and EU-27 average.

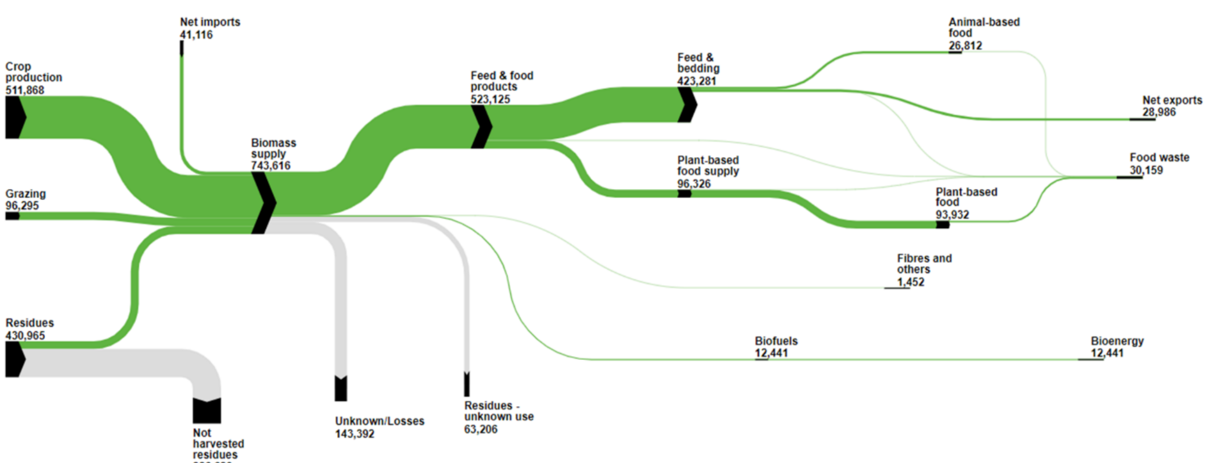


Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

1.1.1 Agriculture

In 2019, the EU-27 agricultural biomass total supply (in net trade) added up to approximately 744 Mt of dry vegetal biomass equivalents (Figure 3).

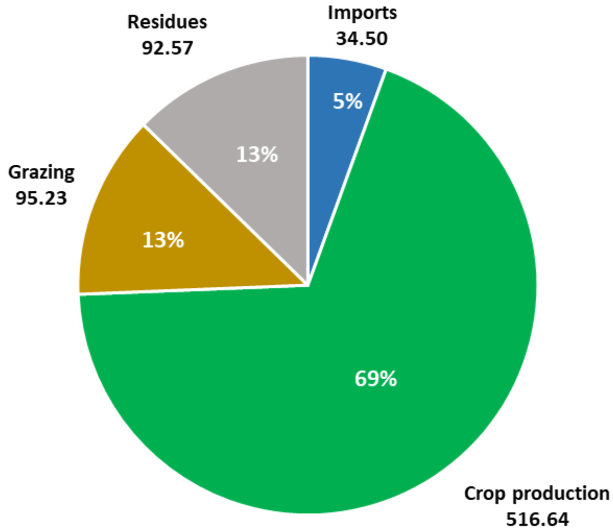
Figure 3. Biomass flows for agriculture, EU-27, net trade, 2019 (1000 tdm).



Source: EU Biomass Flows (DataM, 2022).

Most of this biomass is sourced in the form of domestic crop production (69% of the total, Figure 4), which, in 2019, is estimated at 512 Mtdm in the EU-27. Harvested crop residues provide an additional 94 Mtdm of biomass. It should be noted that of these harvested residues, only an estimated 33% (31 Mtdm) are used for feed. The remaining two thirds are used for other purposes (biomaterials or energy), lost or discarded, but the quantity of biomass that is used for each purpose cannot be estimated at this point. 96 Mtdm of biomass are grazed in pastures and meadows.

Figure 4. Sources of agricultural biomass, EU-27, net trade, 2019 (Mtdm).



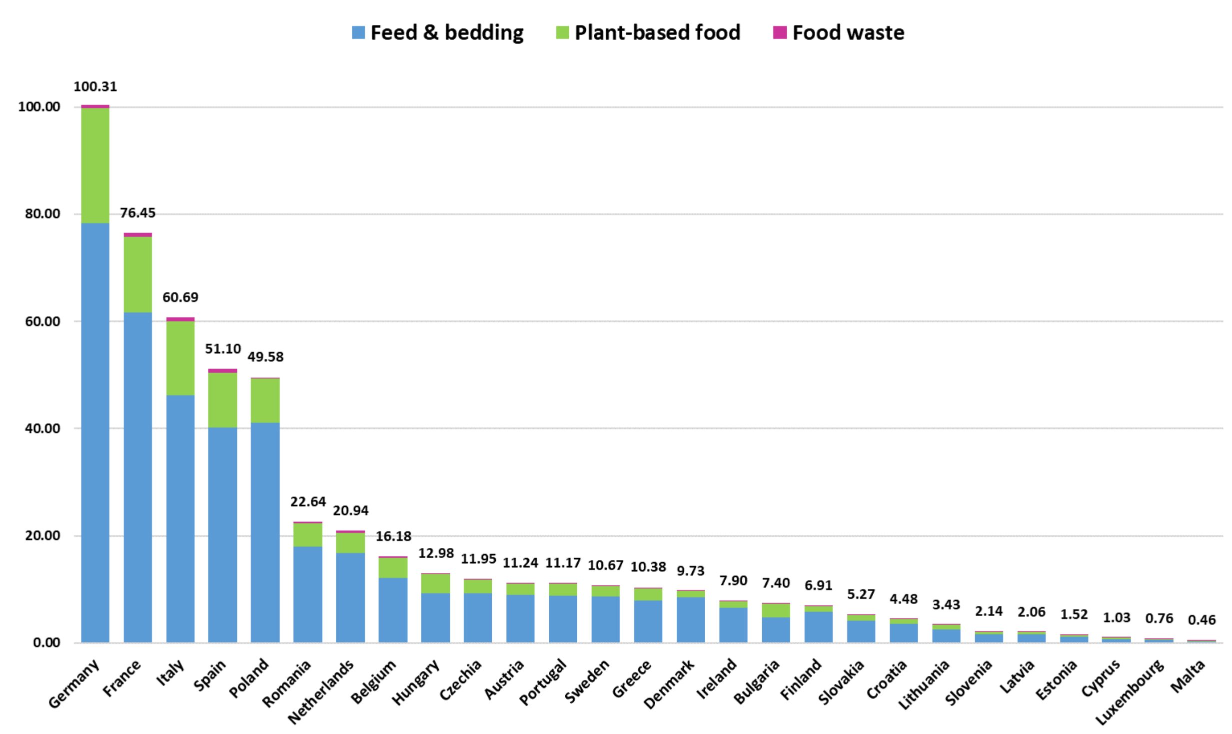
Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

Half of the crop dry matter produced in the EU-27 in 2019 were cereals, followed by fodder crops (31%) and root crops (8%). The remaining crop types account for only 11% of the biomass dry matter produced in the EU-27.

The biomass used for food and feed products is almost entirely of agricultural origin. 70% of the total agricultural biomass supply (net trade, expressed in dry matter) was used as food and feed in 2019. However, due to large data gaps in terms of biomaterial and bioenergy uses of agricultural biomass, those two categories of uses are clearly under-estimated. Approximately 80% of the total biomass for food and feed uses is used as animal feed & bedding for the production of animal-based food (either for domestic consumption or for export), while the rest is directly consumed as plant-based food or is food wasted before consumption (vegetal biomass at the processing and manufacturing stage). One third of the collected crop residues is used for feed and bedding and horticulture purposes. The remaining two thirds are discarded or used in downstream sectors. How these two thirds are split into biomaterials and bioenergy uses cannot be quantified at this point.

Within the EU-27, Germany (100 Mtdm) and France (76 Mtdm) were the biggest producers of food and feed. Figure 5 shows how much biomass is dedicated to producing animal- or plant-based food in each Member State.

Figure 5. Food and feed uses, net trade, 2019 (Mtdm).

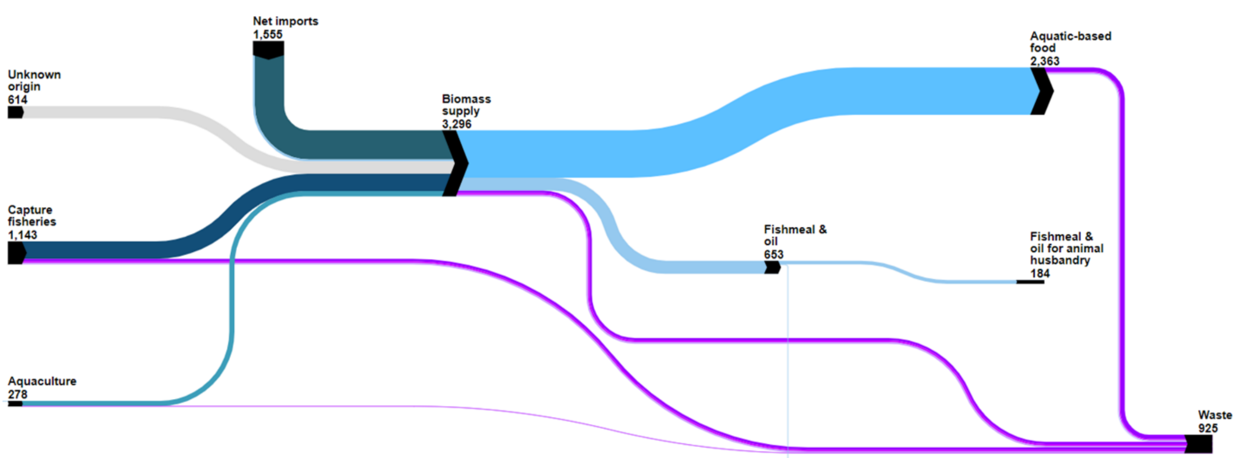


Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

1.1.2 Fisheries and aquaculture

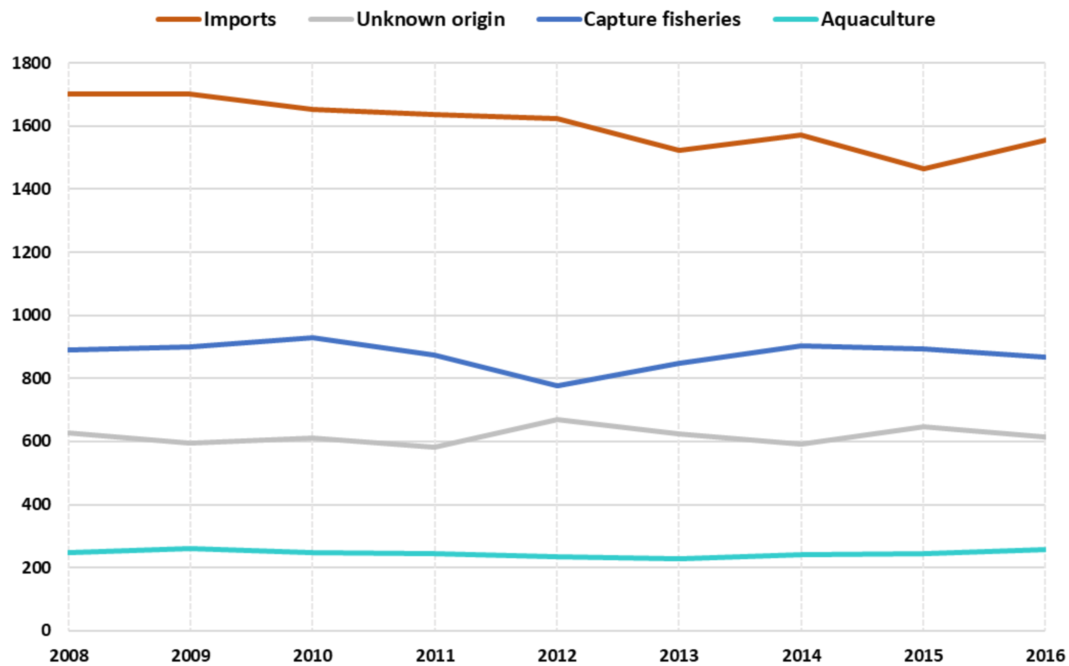
EU-27 production of seafood by capture fisheries and aquaculture was approximately 1.4 Mtdm in 2016 with 1.1 Mtdm originating from capture fisheries and 0.3 Mtdm from aquaculture. EU-27 net imports of fish & seafood and fishmeal & oil amounted to approximately 1.6 Mtdm (52% of the total biomass of known origin, slightly higher than the domestic sources of fisheries and aquaculture biomass at 48%) (Figure 6, Figure 7).

Figure 6. Biomass flows for fisheries and aquaculture, EU-27, net trade, 2016 (1000 tdm).



Source: EU Biomass Flows (DataM, 2022).

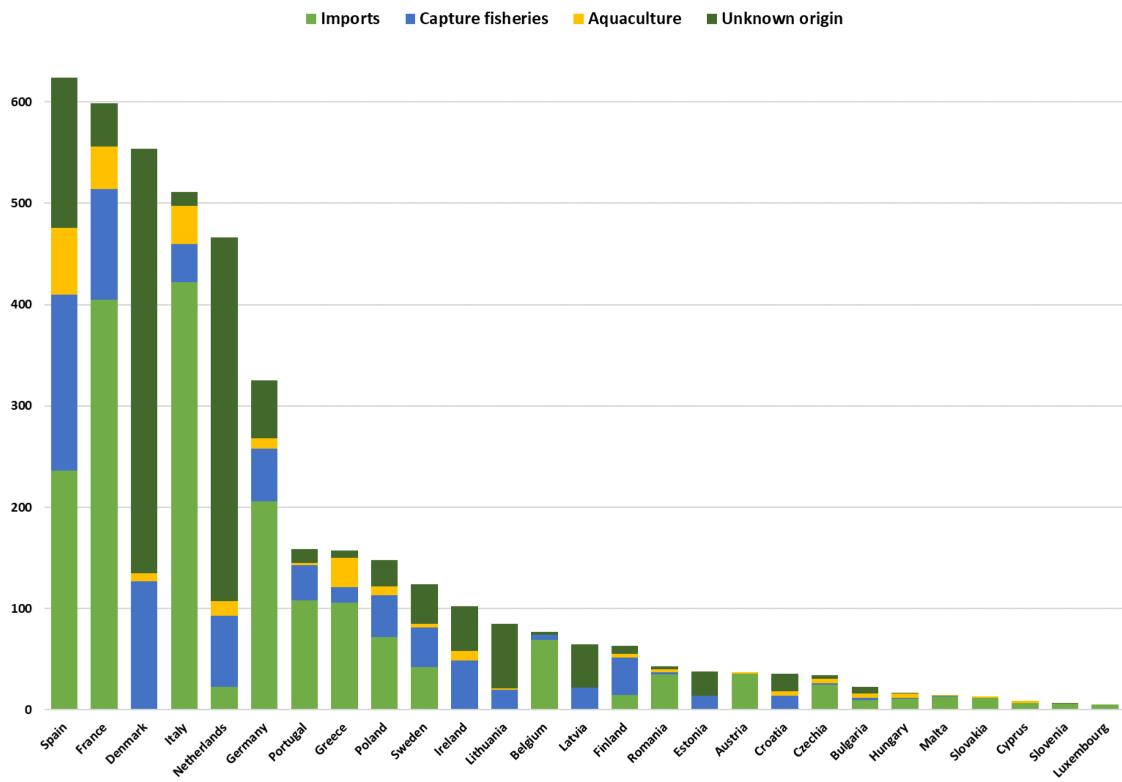
Figure 7. Evolution of the fisheries and aquaculture biomass sources, EU-27, net trade, 2016 (1000 tdm).



Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

Spain, France and Denmark report the largest supply of fisheries and aquaculture biomass in the EU-27. Spain is also the largest producer of farmed fish and seafood (Figure 8).

Figure 8. Biomass supply from fisheries and aquaculture, net trade, 2016 (1000 tdm).



Source: JRC 2022 (based on data from the JRC EU Biomass Flows).

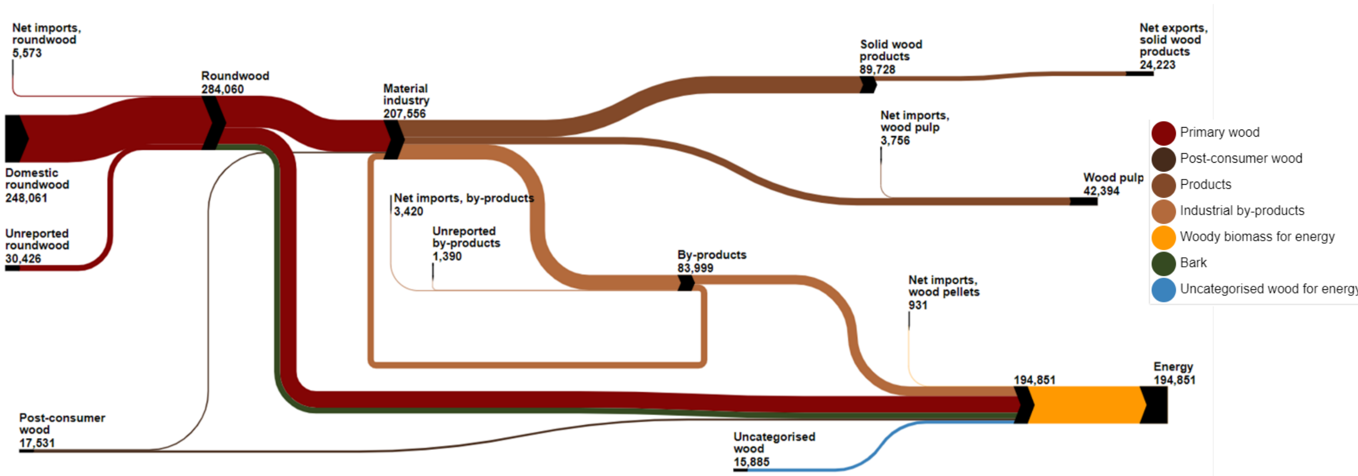
Roughly 1% of the biomass in dry matter that is used for food and feed is of aquatic origin. This accounts for 80% of the biomass supply of fisheries and aquaculture, with only 20% being used in the production of fishmeal and oil. Spain and France are the largest producers of aquatic-based food in the EU-27. Denmark, on the other hand, is the biggest manufacturer of fishmeal and oil.

1.1.3 Forestry

Woody biomass from forests and other wooded land is used and re-used across complex and interlinked value chains. Circular flows of biomass are key for woody biomass products, with wood often undergoing several cycles of reuse until it is disposed of (usually to produce energy). Woody biomass supply chains include the provision of primary wood from forests and other wooded land, industrial by-products, post-consumer wood and production of wood-based products and energy. The most important source of woody biomass is roundwood, which includes primary wood of any quality. EU-27 supply of roundwood was estimated at approximately 284 Mtdm in 2017, of which at least 87% was sourced domestically.

This supply was complemented with 17 Mtdm of post-consumer wood, 8 Mtdm net imports of by-products, wood pulp and pellets, 15 Mtdm uncategorised wood and 1 Mtdm of by-products of unreported origin. The total net imports of all woody biomass types are estimated to be approximately 13 Mtdm.

Figure 9. Woody biomass flows in the-forest based sector, EU-27, net trade, 2017 (1000 tdm).



Source: EU Biomass Flows (DataM, 2022).

In 2017, 195 Mtdm of directly or indirectly[28] gathered woody biomass were estimated to have been used for energy. It is important to note that, due to lack of data that can be integrated with the sources used for this analysis, many bioenergy pathways are missing (e.g. biogas production from biowaste). Almost all of the biomaterials also have an origin in forestry activities with the biggest component being solid wood products. In 2017, approximately 133 Mtdm of biomass were used for bio-materials. Although a net importer of roundwood, the EU-27 is a net exporter (24 Mtdm) of solid wood products. Roundwood is used for the production of solid wood products and wood pulp, but also for energy (part of it is transformed into wood pellets and other agglomerates before being burnt). The two main sectors for woody biomass uses are industries of wood-based products and energy production, but they are not parallel processes. Indeed, industrial transformation of wood generates by-products that are again used as inputs for the production of other wood-based products or for energy generation. Both the material and energy sectors use not only primary wood, but also industrial by-products, that are directly output from manufacturing, and post-consumer wood that has been recovered after at least one life cycle.

1.2 Conclusions for Chapter 1

Converting the main sources of biomass sourced and used in the EU-27 is a useful means to compare trends in shares of biomass uses by source. The EU-27 sources 1 billion tonnes of biomass in dry matter per year, of which only 5% are imported (this figure could be slightly higher due to the unknown origin of 5% of the biomass supply). Over two thirds of this biomass is of agricultural origin. Woody biomass is the second most important source of biomass in dry matter. Fisheries and aquaculture, while an important sector for nutrition that shows great potential for growth, is still a minor source of biomass when measured in dry weight.

The historical, cultural, geographical and climatic conditions of each Member State generally determine which type of biomass it produced. In addition, the production of biomass from agriculture is much more dynamic than woody biomass. Agriculture can be heavily influenced by policy and changes in weather and can adapt quicker to changes in demand. Most of the EU-27 countries specialise in agriculture, with some producing agricultural biomass almost exclusively with respect to forest biomass. However, a few countries, mostly in the northern regions, have a significantly higher share of woody biomass production (Estonia, Finland and Sweden), with some other Member States producing a balanced mix of both woody and agricultural biomass (Latvia, Slovenia, Portugal and Austria). France and Germany are the largest biomass producers in absolute terms, followed by Poland.

Half of all the biomass available in the EU-27, which includes biomass produced from primary production systems (this includes logging and crop residues), secondary sources such as waste recovery and industrial by-products in

[28] From processed wood or as by- or co-product of industrial roundwood processing.

the case of the forest industries, as shown in the first figure of the Executive Summary, is used to produce food and feed; 22% is used in energy production, and 28% is used to produce materials. Energy and biomaterials (in particular, agricultural biomass for material use and biomass for energy production) are the areas where data quality can be significantly improved, enabling better analysis of biomass usage.

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2 Agricultural biomass production

Giulia Ronchetti & Bettina Baruth

Key messages

- Agriculture is the primary source of biomass in EU and the total biomass is shared almost equally between economic and residue production.
- Approximately 70% of the agricultural biomass is produced in six Member States, namely France, Germany, Italy, Poland, Spain and Romania.
- Wheat and maize are the major contributors to agricultural biomass. For both crops, residual biomass is higher than the economic part.
- During the last 20 years, the biomass available from agriculture has increased thanks to, depending on the crop and country, changes in the cultivated areas or improvements in agro-management practices which impacted crop yields.
- In the next years, an increase in biomass availability may be expected, but it is influenced by the impacts of climate change on agriculture.

The bioeconomy policies play a key role in the green and fair transition in Europe by, inter alia, taking a cross-sectoral perspective to improve policy coherence and by identifying and resolving trade-offs, for example on land and biomass demands. However, an increased focus on how to better manage land and biomass demands to meet environmental and economic requirements in a climate neutral Europe is needed (European Commission, 2022).

Since the main source of biomass is agriculture for food and feed purposes, quantifying the available agricultural biomass is key to ensure adequate and nutritious food, as well as other biomass-demanding sectors for bio-based products. This assessment may also help maximise co-benefits, such as production of biomass, mitigation of climate change, fair living and working conditions for primary producers, and enhancing biodiversity while safeguarding and benefiting from ecosystem services.

The work presented in this study aims to assess the available biomass from agriculture following the blueprint established with the work published in García-Condado et al. (2019).

In this study, the quantification of agricultural biomass and residue production for the complete time series (2000-2020) with updated statistics is conducted. Furthermore, the impact of the different drivers determining the variability in production and yield, based on the new time series, are estimated and a detailed analysis of the most cultivated crops, with a view on their future availability in EU, is provided.

The agricultural biomass database covers the years from 2000 to 2020, but the main results are given as an average over the reference period of the last five years 2016-2020. Results and analysis are provided by crop, both at Member State and at EU level, and in a spatially explicit grid of 25 by 25 km[29]. In this report, results are presented only for EU-27.

[29] available here: [https://agri4cast.jrc.ec.europa.eu/DataPortal/Resource_Files/SupportFiles/grid25.zip]

2.1 Agricultural biomass production – statistical based assessment

The assessment of agricultural biomass includes the major crops cultivated in Europe, grouped in 9 main categories: cereals, sugar and starchy crops, oil-bearing crops, plants harvested green, permanent crops, vegetables, pulses, industrial crops and energy crops[30].

Total agricultural biomass production is estimated by differentiating two main components:

- Economic production: primary products, i.e. grains, fruits, roots, tubers, etc.;
- Residue production: secondary products, i.e. leaves, stems and husks.

Economic production is assessed by processing crop production statistics compiled by Eurostat and the National Statistics Offices to generate a consistent archive of all commodities for the Member States across all administrative levels (NUTS 0-3). The main steps of the processing algorithm consist in homogenising, filtering, filling gaps and merging crop statistics from the different data sources. In this update, figures for economic production normalised at standard values of moisture content (*m*) are considered[31].

On the other hand, there are no systematic agricultural statistics for residue production. Therefore, the estimates are deduced from crop production figures using empirical models, established from an extensive dataset of observations for each individual crop (as described in García-Condado et al., 2019) based on the relationship between crop economic yield (*Y*), provided by crop statistics, and residue yield (*R*), through a parameter named *Harvest Index* (*HI*): $R = \frac{Y}{HI} - Y$. Residue production is then calculated by multiplying the derived residue yields by crop area, and aggregating values to provide results at different administrative levels.

No estimation of crop residues has been done for plants harvested green, vegetables and energy crops, because all aboveground biomass is considered as economic production.

Finally, for the spatial representation and analysis, all the biomass-related quantities reported at NUTS 3-level have been disaggregated to 25 km grid cells, using several land cover classes from the CORINE land cover map 2018.

2.2 Agricultural biomass production in the EU

2.2.1 Contribution of crop groups

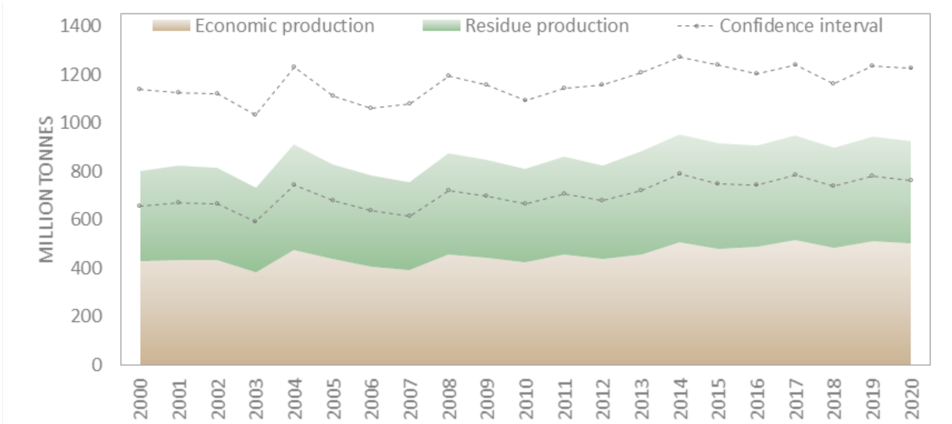
The total annual agricultural biomass production in the European Union for the reference period (2016 – 2020) is estimated at 924 million tonnes dry matter (Mtdm) per year in EU, where 54% are economic production, and 46% are residues. As reported in Figure 10, the production has slightly increased over the years, as the 2000-2004 average of agricultural biomass was around 817 Mtdm per year.

Considering the last five years, a significant decrease is observed for the years 2016 and 2018 because of adverse weather conditions. As a matter of fact, in 2016 a notable reduction of cereals production was registered in France (Ben-Ari et al., 2018), while in 2018 a more wide-ranging drought affected yields in central and eastern Europe (JRC MARS Bulletin, June 2018).

[30] Crops grown exclusively for energy production, not included in any of the other crop groups

[31] https://ec.europa.eu/eurostat/estat-navtree-portlet-prod/BulkDownloadListing?sort=1&dir=data tables apro_cpsh1 and apro_cpshr, update 29/07/2022

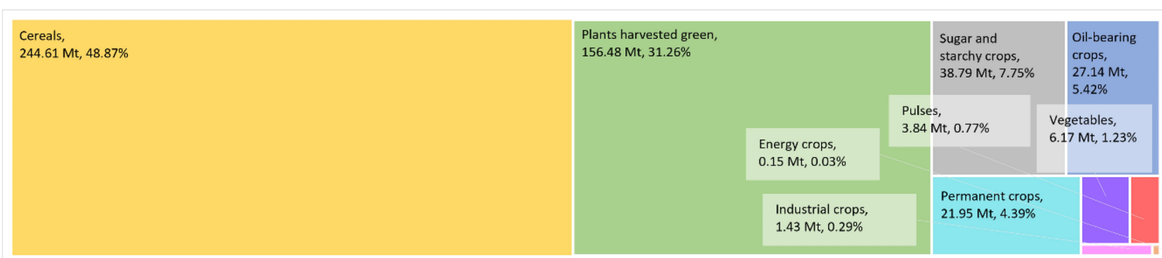
Figure 10. Evolution of agricultural biomass production (economic production and residues in Mt dry matter per year) in the EU from 2000 to 2020.



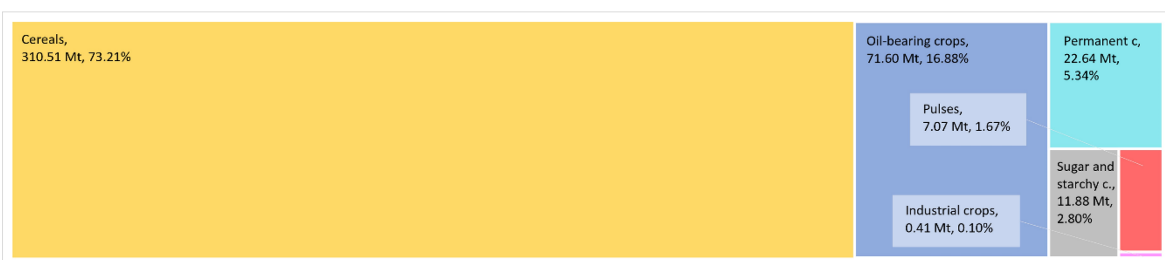
Source: Eurostat[32], JRC 2022 (own calculations).

The last 5-year average shows that cereals (245 Mtdm/y) and plants harvested green (156 Mtdm/y) dominate economic production, jointly accounting for about 80% of total biomass production, followed by sugar and starchy crops (39 Mtdm/y), and oil-bearing crops (27 Mtdm/y). Cereals (311 Mtdm/y) rank first also for residue production, second place for oil-bearing crops (72 Mtdm/y). In both of these crop groups, the biomass of residues is higher than economic production (Figure 11).

Figure 11. Economic production (above) and residue production (below) in the EU-27 (expressed in Mt dry matter per year) and the shares for each crop group. Average values over the reference period 2016-2020.



Economic production



Residue production

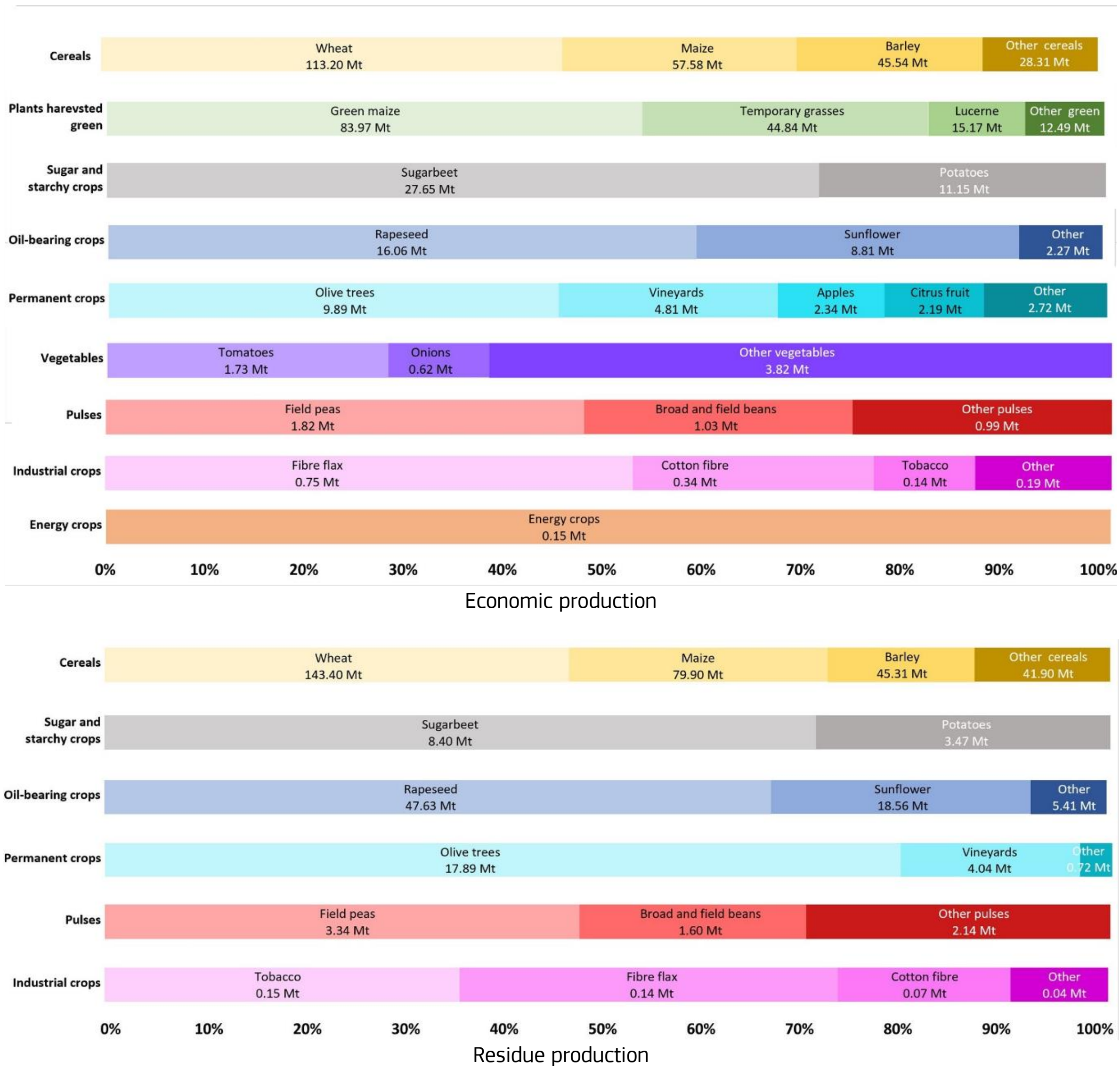
Source: JRC 2022 (own calculations).

When investigating the distribution of each crop in detail, it is noted that the greatest contribution in terms of biomass is provided by wheat (whose average production exceeds 100 Mtdm for both economic and residue), followed by green maize (84 Mtdm/y), maize (58 Mtdm/y) and barley (46 Mtdm/y) for economic production. Maize

[32] Eurostat, 2020. Annual crop statistics handbook. Crop statistics working group.

(80 Mtdm/y), rapeseed (48 Mtdm/y) and barley (45 Mtdm/y), on the other hand, rank second, third and fourth respectively for residue production (Figure 12).

Figure 12. Economic production (above) and residue production (below) in the EU-27 (expressed in Mt dry matter per year) and the shares for each crop within the respective crop groups. Average values over the reference period 2016-2020.



Source: JRC 2022 (own calculations).

2.2.2 Distribution by EU Member States

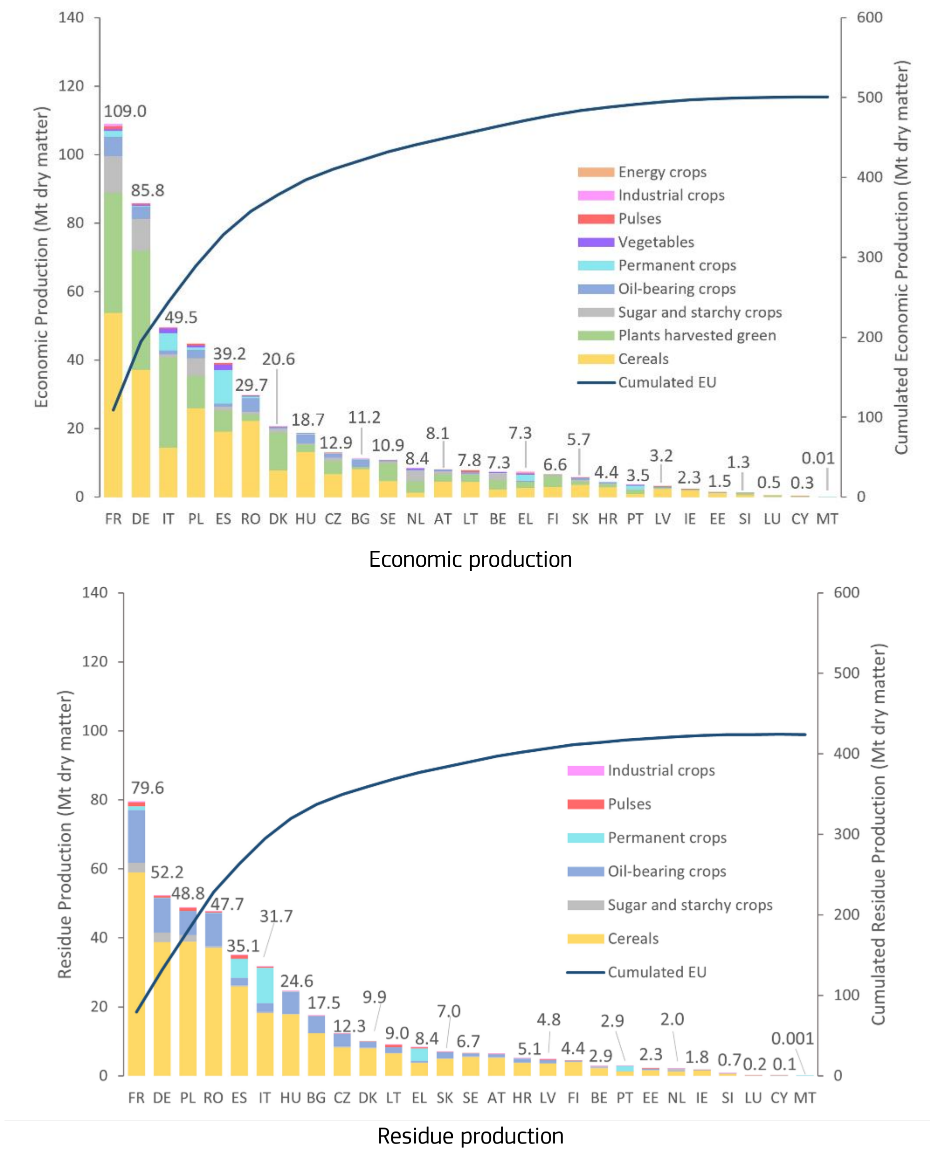
About 70% of both the economic produce and their residues (358 Mtdm/y and 295 Mtdm/y respectively) is produced in six Member States: France, Germany, Italy, Poland, Spain and Romania.

France and Germany are, respectively, the first and second largest producers, for both economic and residue production. Poland ranks fourth and third for economic and residue production, respectively. Romania is the fourth contributor to EU residues production whereas it only occupies the sixth place in terms of economic production. As a matter of fact, Romania is a large producer of maize that can produce large amounts of biomass in leaves and stems, even when grain yields are average or low. On the contrary, Italy is the third contributor to EU economic production but the sixth contributor to residue production, since the major production derives from plants harvested green that account only for the economic part (Figure 13).

As regards residue production, after cereals the contribution of oil-bearing crops is relevant in most Member States, except for Spain, Italy, Greece and Portugal where pruning residue derived from permanent crops prevail due to the extended cultivation of olive trees and vineyards that can be found in these countries.

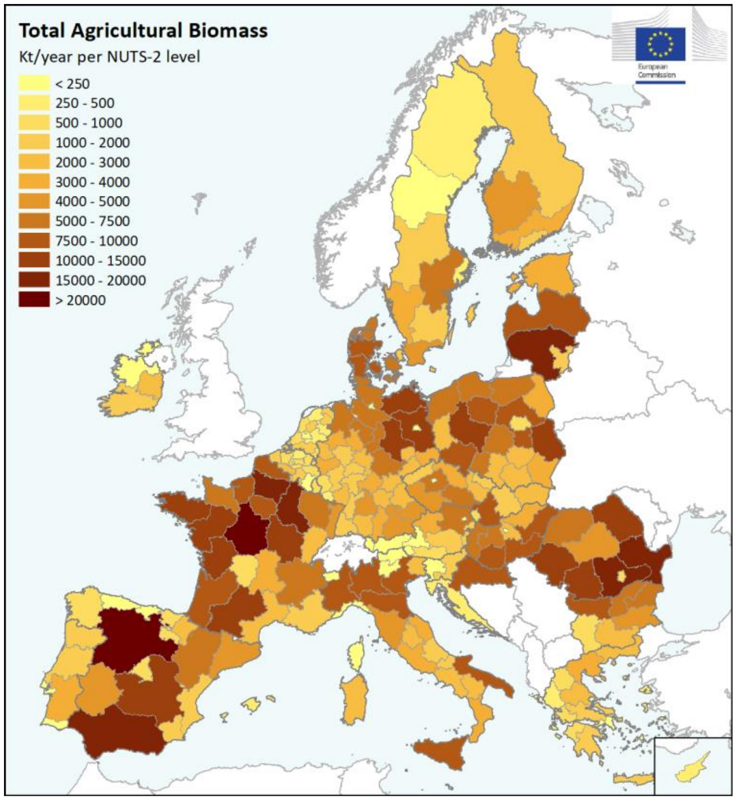
Moreover, the most productive regions in each Member State can be seen in Figure 14, which represents the distribution across EU NUTS-2 regions of the total aboveground biomass available from the agricultural sector.

Figure 13. Economic production and residue production from the main crop groups per Member State, expressed in Mt of dry matter per year. Average values over the reference period 2016-2020.



Source: JRC 2022 (own calculations).

Figure 14. Distribution of agricultural biomass production (in Kt dry matter per year) across the EU (NUTS-2 regions) for the reference period 2016-2020.



Source: JRC 2022 (own calculations).

2.2.3 Inter-annual variability in crop residue production

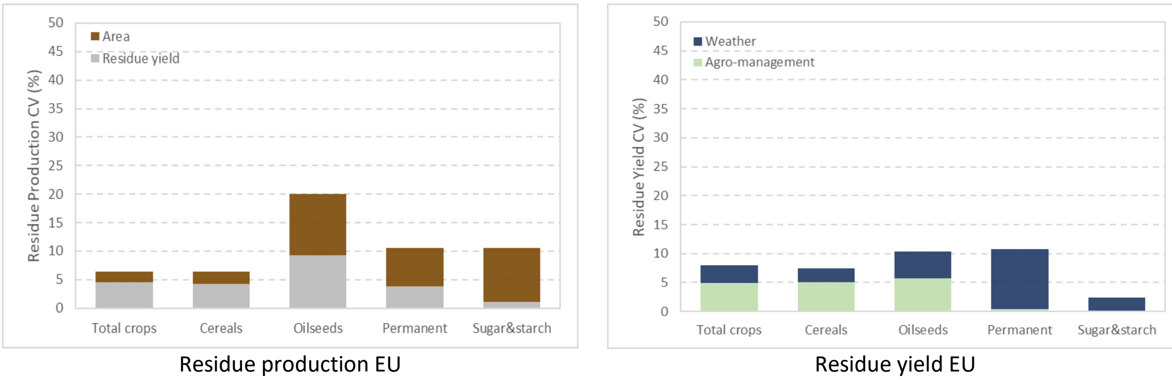
The inter-annual variability of crop residue production has been quantified using the coefficient of variation CV: $CV_i(\%) = \frac{\sigma_i}{\mu_i} \text{ x } 100$. The explanatory factors to this variability are identified in changes in area (A), weather (W) and agro-management drivers (T), the latter together contributing in inter-annual variability of residue yields (R).

The computation of these factors has been performed by reproducing the approach described in García-Condado et al. (2019). First, the fraction of the variance in residue production that is attributable to changes in area and residue yields (R) is quantified by conducting a multiple linear regression analysis. Then, the variance of R is decomposed in the factors T and W, with a linear trend model over the considered period (2000-2020). The resulting coefficient of determination r^2 and its complement to unit $1\text{-}r^2$ are interpreted as the proportion of the variance of R that is explained by T and W, respectively.

Coefficient of variation in percentage, CV%, of residue production and residue yield have been computed for the main crop groups, namely cereals, oil-bearing crops, permanent crops and sugar and starchy crops, at EU level.

The inter-annual variability for residue production (Figure 15, left panel) considering all crops is around 7%, and would be primarily driven by changes in residue yield, with a minor influence of changes in area. Being the most important contributors to total production, cereals present similar values. Conversely, the inter-annual variability of residues from oilseeds, permanent crops, sugar and starchy crops is much higher and mostly affected by area changes, compared to cereals. This means that in the last 21 years, residue production for cereals has maintained rather stable and the low variability within the years has to be attributed almost entirely to changes in yield values. On the contrary, residue production for oilseeds has changed over the years due to variations in both area and yield. As regards permanent and sugar crops, the variability over the years is lower than the one observed for oil crops, but it is highly dependent on changes in the production areas.

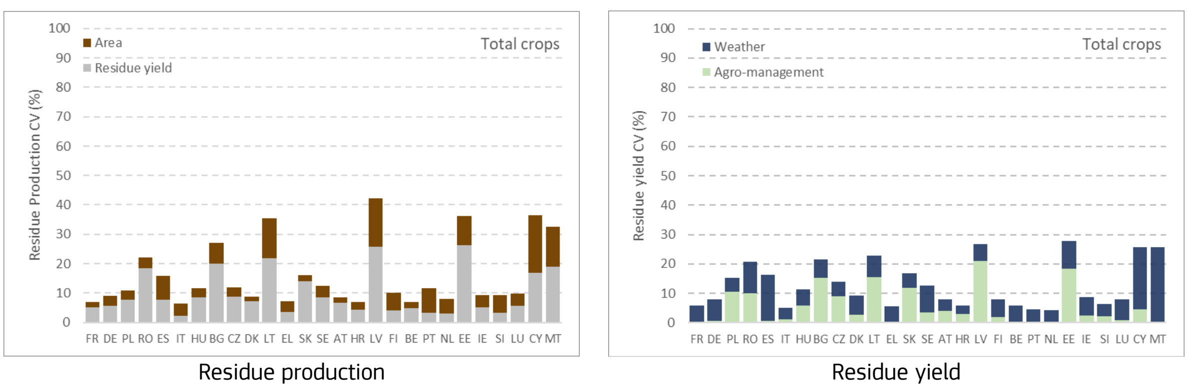
Figure 15. Inter-annual variability – expressed as coefficient of variation in percentage, CV% – of residue production (Mtdm/y; left panel) and residue yield (tdm/ha·y); right panel) at EU level from 2000 to 2020, calculated for the complete set of crops evaluated (Total crops) as well as for each crop group separately: cereals, oilseeds, permanent, sugar and starch crops.



Source: JRC 2022 (own calculations).

The variability of residue yield is largely due to agro-management factors for cereals and oilseed crops (Figure 16, right panel), whereas the effect of weather conditions explains the variance in residue yield for permanent, sugar and starchy crops. In the last 20 years, research and innovation, including improved machinery, new cultivars and new agro-practices have played a major role in changes of residue yields for cereals and oilseeds in EU. Nevertheless, the actual impact of these factors on yield varies within each Member State and depends on the considered crop.

Figure 16. Inter-annual variability – expressed as coefficient of variation in percentage, CV% – of residue production (Mtdm/y; left panel) and residue yield (tdm/ha·y); right panel) for each Member State from 2000 to 2020, calculated for the complete set of crops evaluated (Total crops).

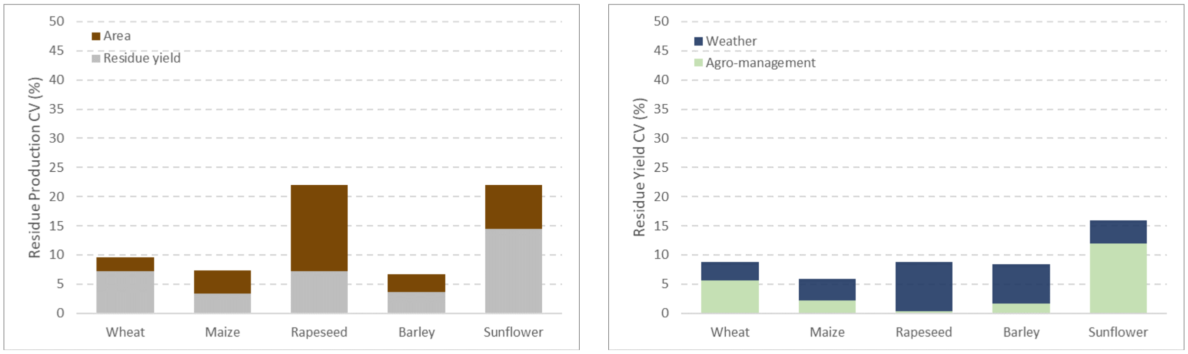


Source: JRC 2022 (own calculations).

The estimated inter-annual variability of biomass production from crop residues in most of the EU countries is quite low (below 10%), while in the Baltics (i.e. Lithuania, Latvia and Estonia), Romania and Bulgaria the variability exceeds 20%. The variability of residue production is primarily driven by variations in residue yield, rather than changes in area. Among the top producers, only in Italy the relevance of crop area changes is higher than the residue yield, as well as in Spain, where there is an equal contribution of area and yield changes.

The inter-annual variability of residue yield estimations differs substantially among countries. Central and western countries –e.g. France, Germany, Italy, Austria, Belgium, the Netherlands– are characterised by high and stable residue yields over the years (CV < 10%). In North-eastern EU countries (e.g. Poland, the Czech Republic, Slovakia, Latvia, Lithuania, Estonia) the residue yield variability is higher (i.e. exceeding 20% in the Baltics) and mostly linked to technical and agro-management factors, resulting in a positive trend in total crop biomass yield during the last 20 years. In south-eastern countries (e.g. Romania and Bulgaria) the residue yield inter-annual variability can also reach 20%, due to a high relevance of agro-management practices, whereas in Spain similar CV is estimated but almost totally driven by weather conditions, specifically rainfall regimes (Figure 17).

Figure 17. Inter-annual variability – expressed as coefficient of variation in percentage, CV% – of residue production (Mtdm/y; left panel) and residue yield (tdm/ha·y); right panel) at EU level from 2000 to 2020, calculated for the five crops with the highest residue production: wheat, maize, barley, rapeseed, sunflower.



Residue production EU

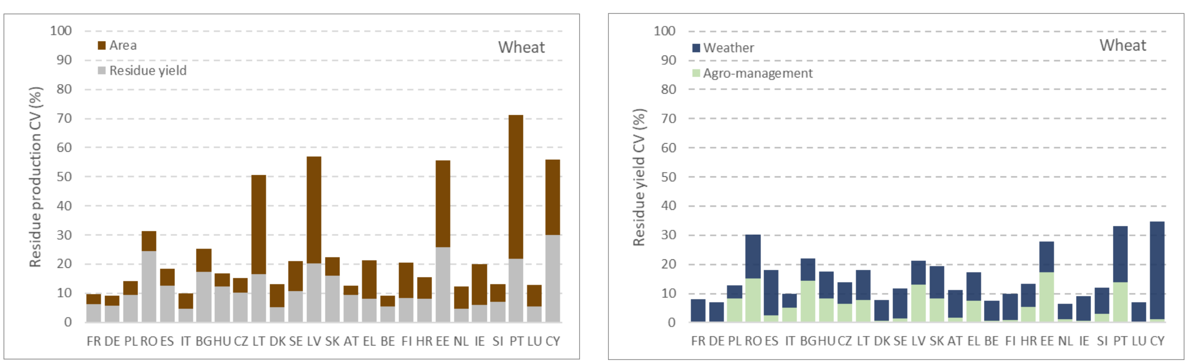
Residue yield EU

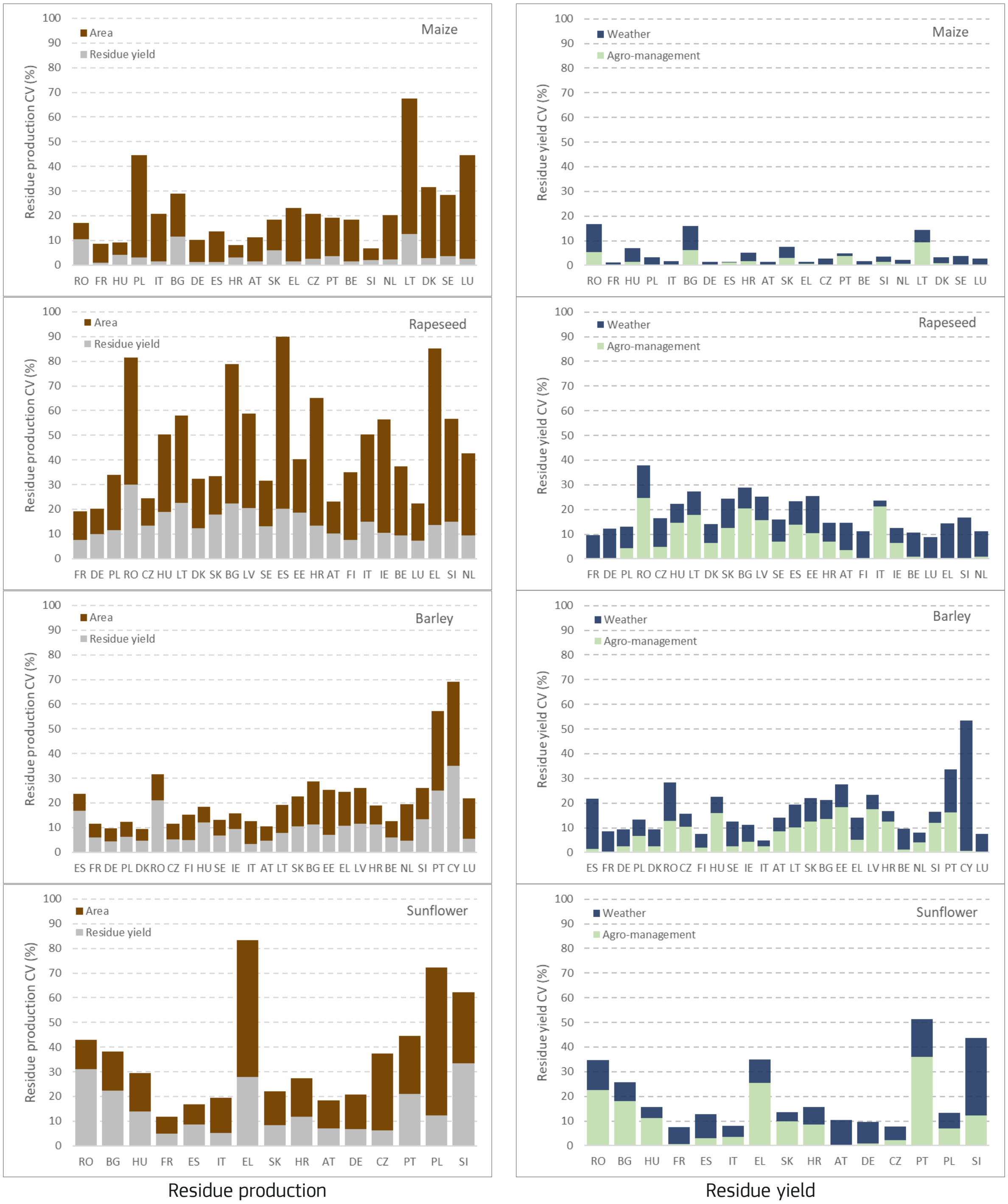
Source: JRC 2022 (own calculations).

Differences in the variability of crop residue production do exist among crops. The inter-annual variability of residue production for wheat, maize and barley is low (CV < 10%) while for both rapeseed and sunflower it exceeds 20%. Among cereals, wheat has higher variability than maize and barley, as wheat production is relevant in North-eastern EU where we estimated less stable production with respect to southern and western countries (mostly contributing to maize and barley production). However, the variability for wheat is mostly driven by changes in residue yield; for maize and barley the impact of crop area changes is more relevant and contributes half of the inter-annual variability of residue production.

Among oilseeds, crop residue production have doubled over the last 20 years: rapeseed and sunflower have similar CV%, but resulting from different factors. For rapeseed, production variability is mostly explained by changes in area: the estimated area in 2000 was around 3.75 Mha but already in 2010 it reached 6.45 Mha, and the last 5-year average, the rapeseed growing area has maintained close to 6 Mha. Regarding sunflower, the major driver is residue yield: the estimated area in the last 20 years has remained stable around 4Mha, while yield was calculated close to 2.8 t/ha in 2000 and in 2018 increased to 4.7 t/ha. This is the result of technical improvements in the main producer countries, namely Romania, Bulgaria and Hungary (Figure 18).

Figure 18. Inter-annual variability – expressed as coefficient of variation in percentage, CV% – of residue production (Mtdm/y; left panel) and residue yield (tdm/ha·y); right panel) for each Member State from 2000 to 2020, calculated for the five crops with the highest residue production: wheat, maize, barley, rapeseed, sunflower. Member States are ranked in decreasing order of their residue production.





Source: JRC 2022 (own calculations).

The inter-annual variability of residue production estimated for each Member State for the five major crops confirmed the general behaviour already highlighted at EU level. The variability for wheat, maize and barley is low and rarely exceeds 20%, apart from in the northern and south-eastern countries. In the case of maize, the highest variability is calculated for Poland and Lithuania and it is mostly explained by area changes: in Poland, the area in 2020 is six times as large as in 2000, in Lithuania almost multiplied by nine. This can be attributed to the global warming that is slowly contributing to cultivate new crops in historically unsuitable environments (Hristov et al., 2020). However, the variability of yield for maize is the lowest of all crops, as in many countries maize is irrigated (Zajac et al., 2022) and therefore yields are less subject to high variations. Only in Romania, Bulgaria and Hungary the variability of residue yield reaches 10%, where maize can be exposed to droughts that reduce crop yields drastically, as in the case of 2007 and 2012 (MARS Bulletin July 2007; JRC MARS Bulletin July 2012).

The highest inter-annual variability for residue production, as already mentioned, is estimated for rapeseed. In all Member States, with the exception of the top two producers (France and Germany), the production variability is greater than 20%; and in all countries, the area change is the most relevant driver that contributed to the increase in productivity.

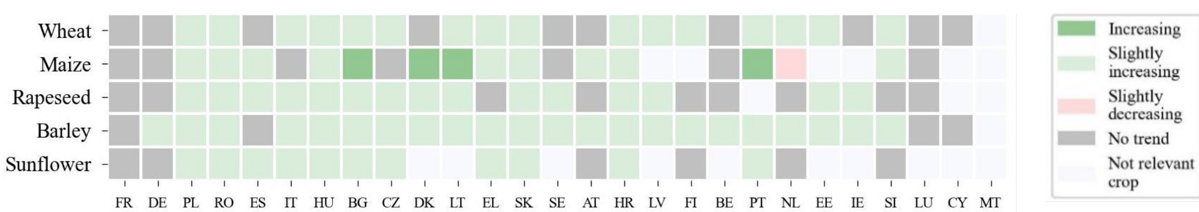
From these analyses, it is shown that the availability of biomass from residue production is expected to be rather stable in the next few years. If we assume no changes in crop area in a medium-term scenario, weather will be the primary factor driving residue production, as research and innovation on agricultural practices can contribute little to yield variability and particularly have a minor role in the variability of yield in the top producer countries.

2.2.4 Crop economic yield: future perspectives

Given that in this assessment the residue yield is derived from the economic yield, the future availability of residual biomass is highly dependent on the economic part itself. Therefore, a short trend analysis on crop economic yield to estimate yield expectations of the major crops in all Member States was conducted and is presented hereafter. The five crops with the highest residue production have been selected: wheat, maize, rapeseed, barley and sunflower. For each crop, a trend analysis with a significance level (α) equal to 5% was computed based on yield values in the last 20 years.

Overall, a slightly (<10%) increasing trend prevails for all crops in EU, with the exception of the top EU producer, France, - where no trend has been highlighted for any crop. Similarly, in Germany only barley yields show a slightly increasing trend. This translates in the projection of higher yields for the future in all Member States, with the exception of the two top producers. Particularly, a slight rise in yields of all crops is expected in northern and eastern countries, including Poland, Romania, Hungary, Bulgaria, Slovakia and Croatia. Regarding specific crops, barley shows increasing trends in a much higher number of countries with respect to wheat and maize. Nonetheless, the highest increase (>10%) is foreseen for maize yields (in Bulgaria, Denmark, Lithuania and Portugal), but a decreasing trend is calculated in the Netherlands (Figure 19).

Figure 19. Trend analysis on economic yield for each Member State, calculated for the five crops with the highest residue production: wheat, maize, barley, rapeseed, sunflower. Member States are ranked in decreasing order of their production.



Source: JRC 2022 (own calculations).

In conclusion, the results of this trend analysis are quite optimistic, leading to a slowly growth of crop economic yield in the next years. However, this is a simple analysis that is conducted taking into account only statistical yield values of the last 20 years, without considering any other influencing factor. More reliable estimates can be obtained from scenario analyses, which include also environmental variables as climate. In Hristov et al. (2020), an analysis of the impacts of climate change on European agriculture by 2050 is presented. In this study, authors combine the results of different simulation models to estimate crop yield changes in EU in 2050 under global warming conditions (+1.5°C and +2°C). Simulations show yield increase for wheat in northern Europe, driven by increasing amounts of precipitation and a shortening of the crop growing cycle, while few reductions are expected around 2050 in southern Europe. From the simulation results, maize is projected to be the most affected crop by climate change in the EU. Maize yield reductions are estimated for most producing countries and particularly in southern Europe. Water availability is the most relevant factor to guarantee irrigation; otherwise, in rainfed conditions maize production will be lost in most countries.

2.3 Conclusions for Chapter 2

The total annual agricultural biomass production in the European Union for the reference period (2016 – 2020) is estimated at 924 million tonnes (Mtdm) per year in the EU. Up to 54% of the agricultural biomass produced is economic production while the remaining 46% is residues. While the agricultural production has slightly increased in the overall analysed period (2000-2020), a significant decrease is observed for the years 2016 and 2018 because of adverse weather conditions.

In the last 5 years, cereals (e.g. wheat) and plants harvested green (e.g. green maize) dominate the economic production, jointly accounting for about 80% of total biomass production. The residue production comes predominantly from cereals (73.2%) and in a lesser extent from oil-bearing crops (16.9%). Wheat is the crop that contributes the most to the total biomass production. In the economic production it is followed by green maize, maize and barley. In the production of agricultural residues, the other major contributors are maize, rapeseed and barley.

About 70% of both the economic production and residues (358 Mtdm/y and 295 Mtdm/y respectively) is produced in six Member States: France, Germany, Italy, Poland, Spain and Romania. France and Germany are, respectively, the first and second largest producers, for both economic and residue production. The availability of biomass from residue production is expected to be rather stable in the next few years. On the other hand, given the improvement in agro-management practices, there is a projection of higher yields of the economic production for the future in all Member States except in France and Germany, the two top producers, but climate change will have a major impact on crop yields perspectives.

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3 Agricultural biomass uses

Patricia Gurría & Robert M'barek

Key messages

- Understanding the main agricultural markets is important to assess the level of trade dependency as well as current and future needs of agricultural biomass in the EU.
- The main use of the cereals consumed (not exported or added to stocks) in the EU-27 is feed, 40% higher than the quantity used for plant-based food and industrial products.
- The EU is highly dependent on oilseeds and oilseed product imports. Most of the imports of vegetable oil are of seed types not cultivated in the EU, such as palm or coconut. The total available vegetable oil was mainly used for food and feed (50%) but also for bioenergy (38%).
- Over half of the production of the main fruits and vegetables is consumed or exported fresh.
- The EU is a net exporter of meat and dairy products.
- Almost 60% of the milk delivered to dairies is processed into manufactured dairy products.

The agricultural sector is the largest producer of biomass in the EU-27 (almost 70% of domestic biomass production is of agricultural origin). Once sourced, most of the agricultural biomass available in the EU-27 is used to produce food and feed. In 2019, the EU-27's supply of agricultural biomass was approximately 744 million tonnes of dry matter, of which 68% were sourced in the form of crops. As shown in Chapter 2, cereals and plants harvested green account for about 80% of economic biomass production in the EU-27, followed by sugar and starchy crops (7.7%) and oil-bearing crops (5.4%). Regarding residue production, cereals are the main contributors (73.2%) followed by oil-bearing crops (16.9%).

Visualising the flows of biomass in the bio-based value chains of the EU-27 is essential to understand the EU-27 overall biomass flows and the agricultural markets. It helps to analyse the level of dependency of the EU-27 in agricultural biomass imports, as well as the biomass needs to produce and meet the demand of food and other bio-based products in the future. The quantification of flows of biomass can provide valuable information for potential assessments of food security risks and the shifting of biomass from food and feed, or energy production to other uses and vice versa.

In this chapter, an overview of the main food value chains in EU-27 markets (cereals, oilseeds and products, meat, selected fruits and vegetables, and dairy) is provided, with an estimation of their performance in the coming years (until 2030). All data used to create the flows for these commodities have been extracted from the EU agricultural outlook[33] published annually by the European Commission (European Commission, 2021).

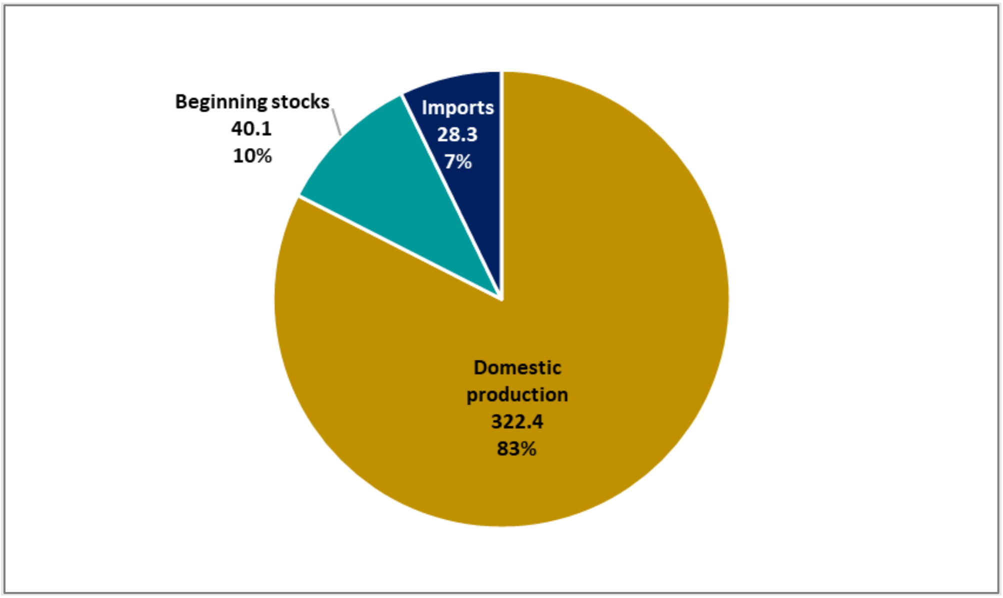
3.1 Agricultural biomass flows in detail – from the past to the future

3.1.1 Cereals

The total supply of cereals in the EU-27 is approximately 391 million tonnes of fresh matter (Figure 20), most of which are produced domestically. Only 7% of the cereals supply is imported annually, mainly maize (65% of the imported cereals) and wheat (18%).

[33] https://agriculture.ec.europa.eu/data-and-analysis/markets/outlook/medium-term_en.

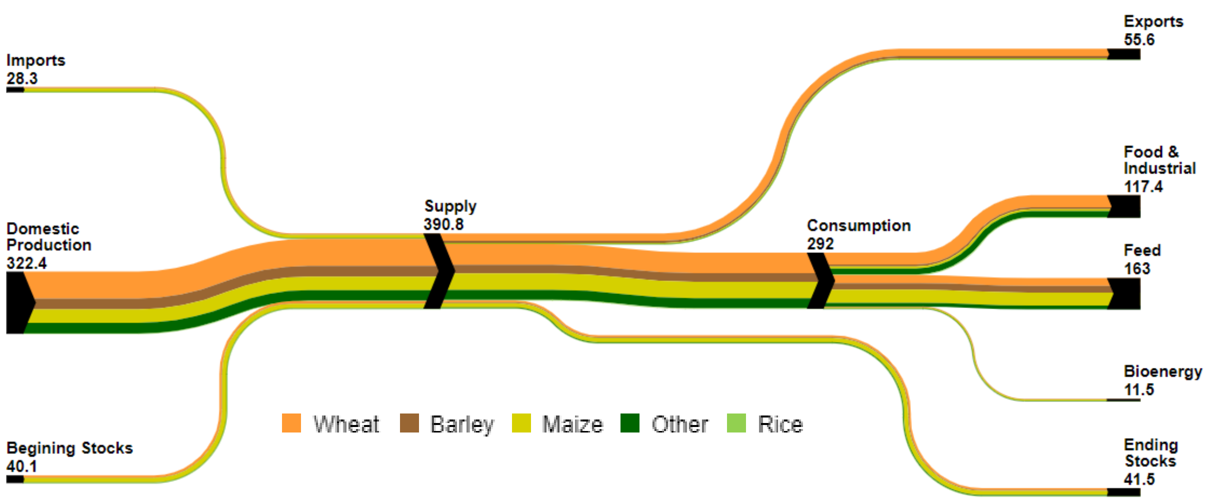
Figure 20. Cereals supply in the EU-27 in 2019 (absolute values in million tonnes of fresh matter).



Source: JRC 2022 (based on data from the *Medium-term Outlook commodity flows).*

The available cereal supply is exported (almost 14%), added to existing stocks for later use (11%) or consumed domestically (Figure 21). Of the cereals consumed domestically, most are used to produce food, feed and industrial products. The quantity of cereals used in the production of animal-based food -as feed for domestic animals- (56% of the total supply of cereals) is almost 40% higher than the quantity used to produce plant-based food and industrial products (40% of the total). Only 4% of the consumed cereals are used for biofuel production.

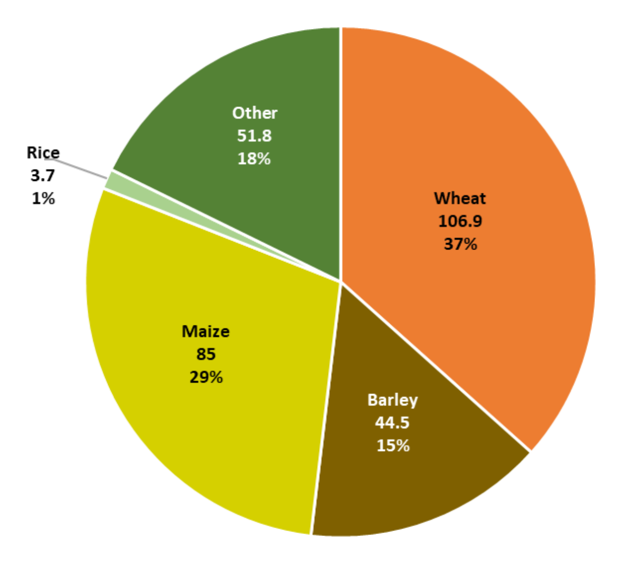
Figure 21. Cereal flows in the EU-27 in 2019 (million tonnes of fresh matter).



Source: Medium-term Outlook commodity flows (DataM, 2022).

Wheat and maize account for almost 66% of the cereals consumed annually in the EU-27 (cereals not exported or moved to stocks). Barley is the third most consumed cereal (c.a. 15%) (Figure 22).

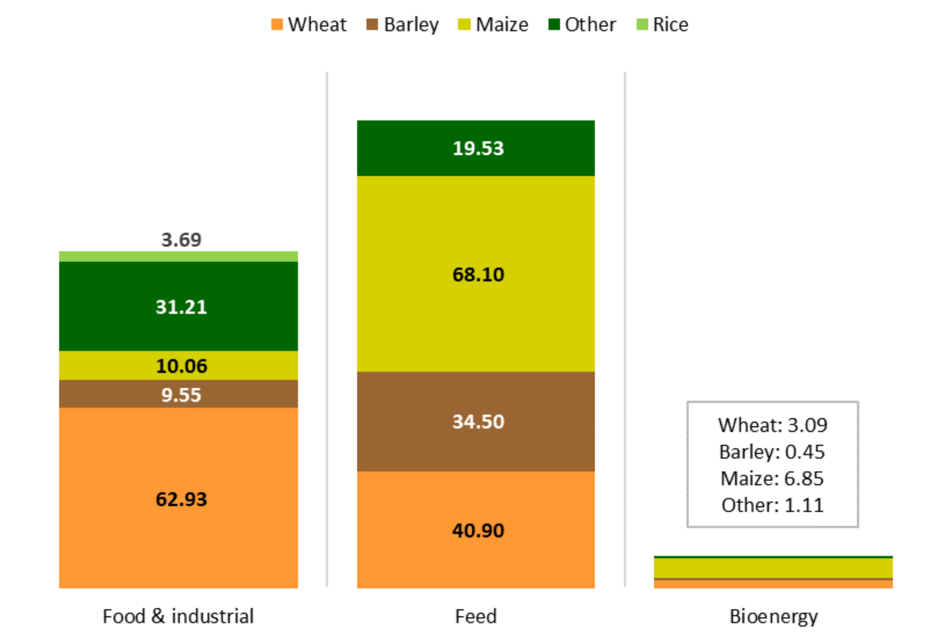
Figure 22. Cereal consumption in the EU-27 in 2019 (absolute values in million tonnes of fresh matter).



Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows).

However, the uses of each type of cereal show differences. The main use of wheat and other minor cereals is the production of food and industrial products (59% of the wheat, 60% of other cereals and all of the rice consumption), while barley and maize are being primarily used for feed (80% of the maize and 78% of the barley) (Figure 23).

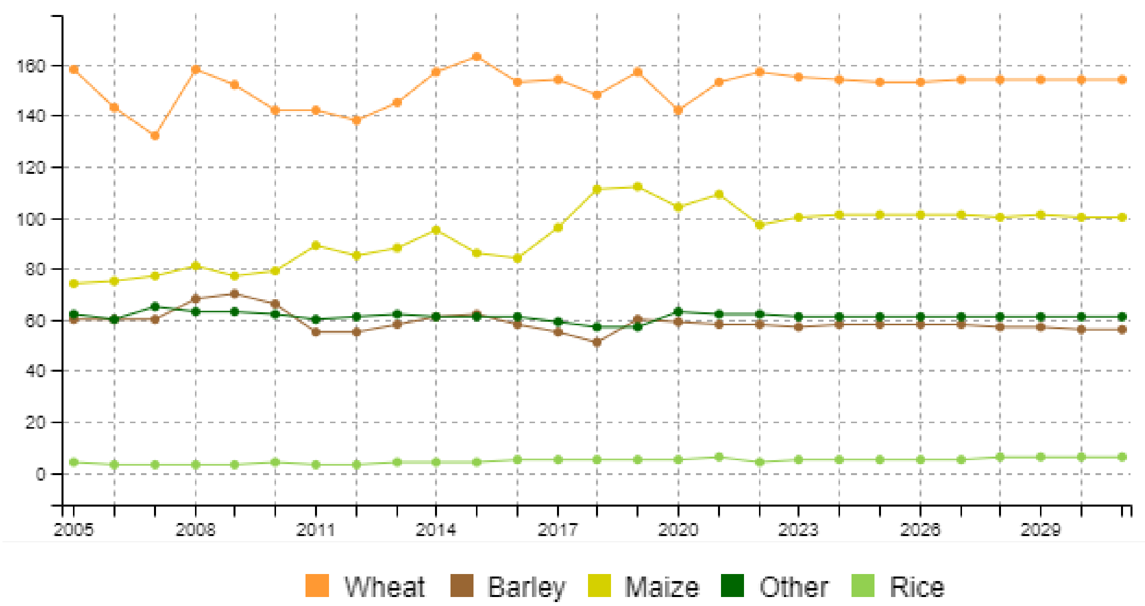
Figure 23. Cereal quantity by use type in the EU-27 in 2019 (values in million tonnes of fresh matter).



Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows).

The supply of cereals is expected to remain relatively constant until 2031, with wheat being approximately 40% of the total. However, future major disruptive events such as the ones that took place in 2022 (the invasion of Ukraine by the Russian Federation, increasing energy and fertiliser prices, rising inflation, etc.) could obviously have a considerable impact on the quantity of cereals produced in the EU-27, as well as on the origin and quantity of cereal imports (Figure 24).

Figure 24. Cereals supply in the EU-27 (values in million tonnes of fresh matter) from 2005 to 2031.

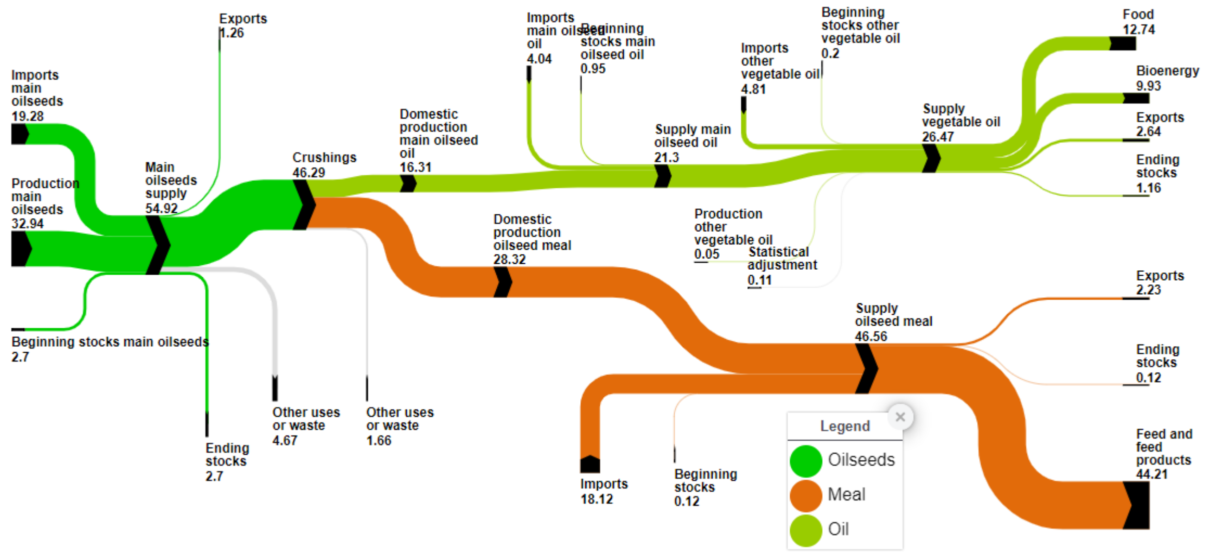


Source: Medium-term Outlook commodity flows (DataM, 2022).

3.1.2 Oilseeds and products

Oilseeds have a more complex value chain, as they are used to produce both meal and vegetable oil. The EU-27 is more dependent on imports of oilseeds and their derived products than any other of the main agricultural commodities. 60% of the total supply of oilseeds (approximately 56 million tonnes) is either produced domestically or extracted from existing stocks (Figure 25). Rapeseed, sunflower and soy are also imported for crushing, with these imports accounting for 40% of the total seed supply.

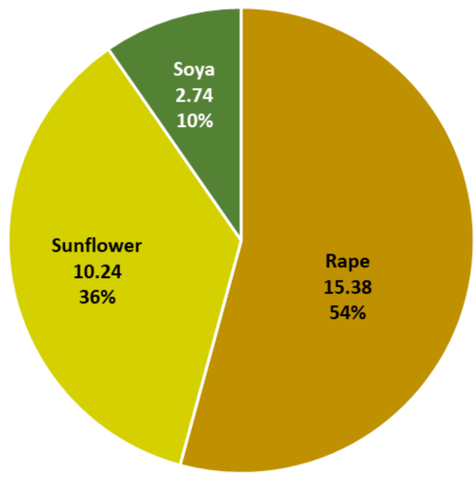
Figure 25. Oilseed and product flows in the EU-27 in 2019 (values in million tonnes).



Source: Medium-term Outlook commodity flows (DataM, 2022).

In 2019, the EU-27 produced 28 million tonnes of oilseeds, mainly rapeseed, sunflower, soya and groundnuts. Rapeseed is the most significant crop, at over half (54%) of the total production (Figure 26).

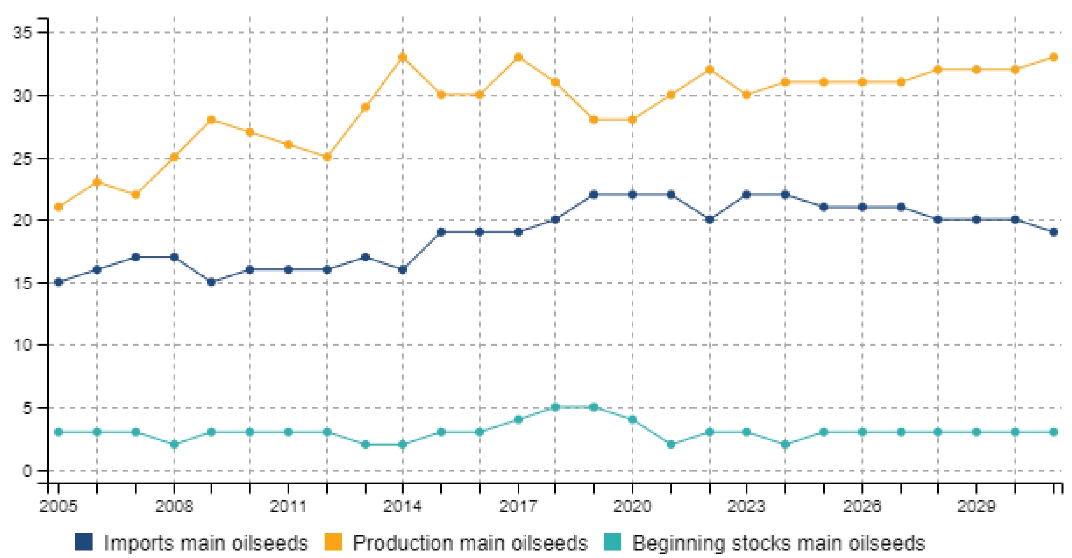
Figure 26. Oilseed domestic production in the EU-27 in 2019 (absolute values in million tonnes).



Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows*).*

The supply of oilseeds has suffered some shifts in recent years (Figure 27). Furthermore, the previously mentioned events that took place in 2022 might have a major impact on the imports of oilseeds into the EU-27 in the coming years. The long-term effects are difficult to assess at this point, but future studies should provide a better picture and improve the current projections.

Figure 27. Oilseeds supply in the EU-27 (values in million tonnes) from 2005 to 2031.

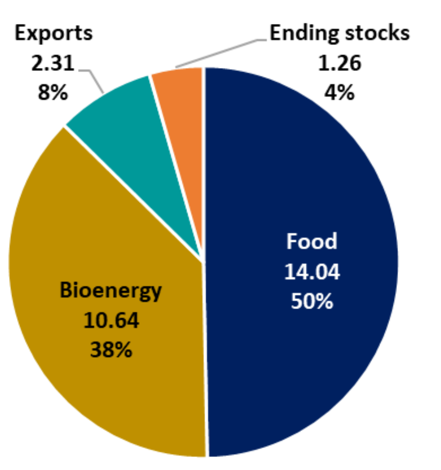


Source: Medium-term Outlook commodity flows (DataM, 2022).

Approximately 90% of the total supply of oilseeds is crushed or used to increase the existing stocks; 8% is either used for undefined purposes or wasted, and only 2% is exported. After crushing, 63 % of the biomass is turned into oilseed meal and 35% is extracted as oil, while 2% is used for other purposes or wasted.

Imports are an important contribution to the supply of oilseed meal in the EU-27 (oilseed meal is represented by the orange flows in Figure 25). In 2019, more than 20 million tonnes (41% of the total supply) of oilseed meal were imported, complementing the domestic production and some extraction from existing stocks to reach a total of almost 50 million tonnes of meal available for consumption, of which only a very minor quantity is exported. Imports are equally important for the supply of vegetable oil (oil is represented by the light green flows in Figure 25. Most of the oil imported into the EU-27 comes from seeds not traditionally crushed in the domestic market (palm, cottonseed, coconut and others). Adding up the production, imports and extraction from stocks of oil from the main oilseeds (rapeseed, sunflower, soya and groundnuts) to that of oil from other types of seeds, the available supply of vegetable oil in the EU-27 in 2019 was over 28 million tonnes. This available supply was almost entirely used for food (50%), bioenergy (38%) or was added to domestic stocks (4%), with exports accounting for only 8% of the uses (Figure 28).

Figure 28. Oil uses in the EU-27 in 2019 (absolute values in million tonnes).

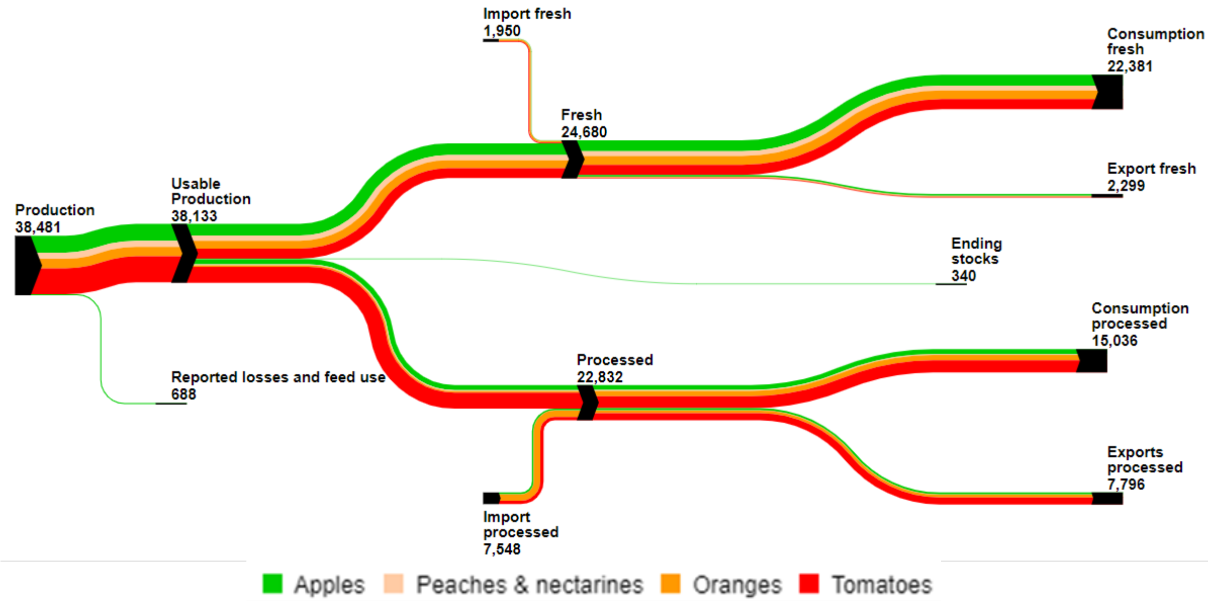


Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows*).*

3.1.3 Fruits and vegetables

The EU-27 produced 38 million tonnes (fresh equivalent) of tomatoes, apples, oranges, peaches and nectarines, which are the main commodities in the domestic markets (Figure 29). Approximately 60% of the total production is consumed fresh, while 40% is further processed. In addition, over 9 million tonnes (in fresh equivalent) of these commodities are imported, mostly in the form of processed products. The high share of imports of processed products results in an almost even split between available supply of fresh products and that of processed. However, as a larger share of processed fruit and vegetables is exported, the final domestic consumption of fresh products exceeds that of processed fruits and vegetables.

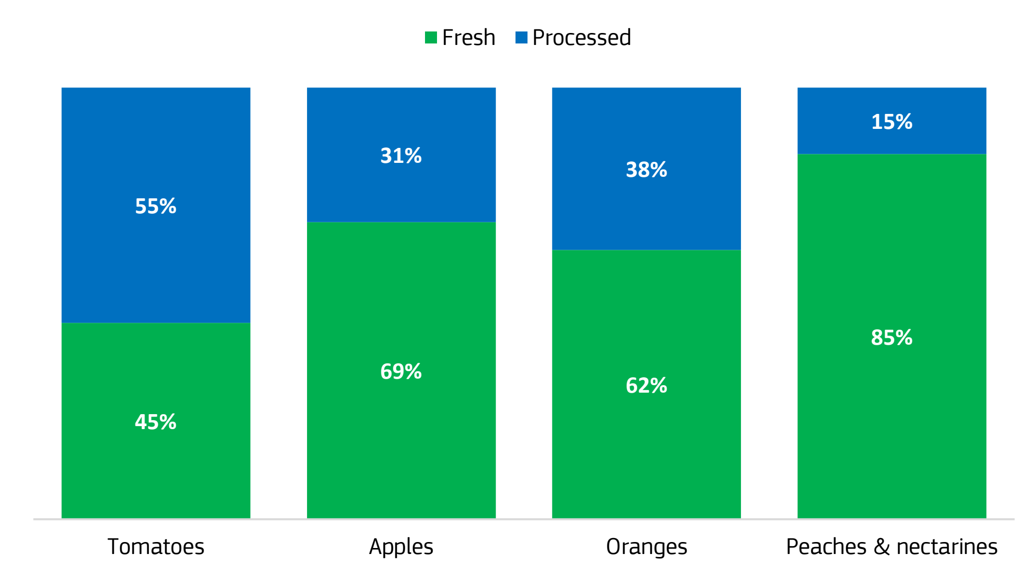
Figure 29. Main fruits and vegetable flows in the EU-27 in 2019 (values in million tonnes of fresh equivalent).



Source: Medium-term Outlook commodity flows (DataM, 2022).

Peaches and nectarines, apples and oranges are mostly consumed fresh in the EU-27, while tomatoes are consumed as processed products in a higher share (Figure 30).

Figure 30. Consumption form shares of main fruits and vegetables in the EU-27 in 2019.

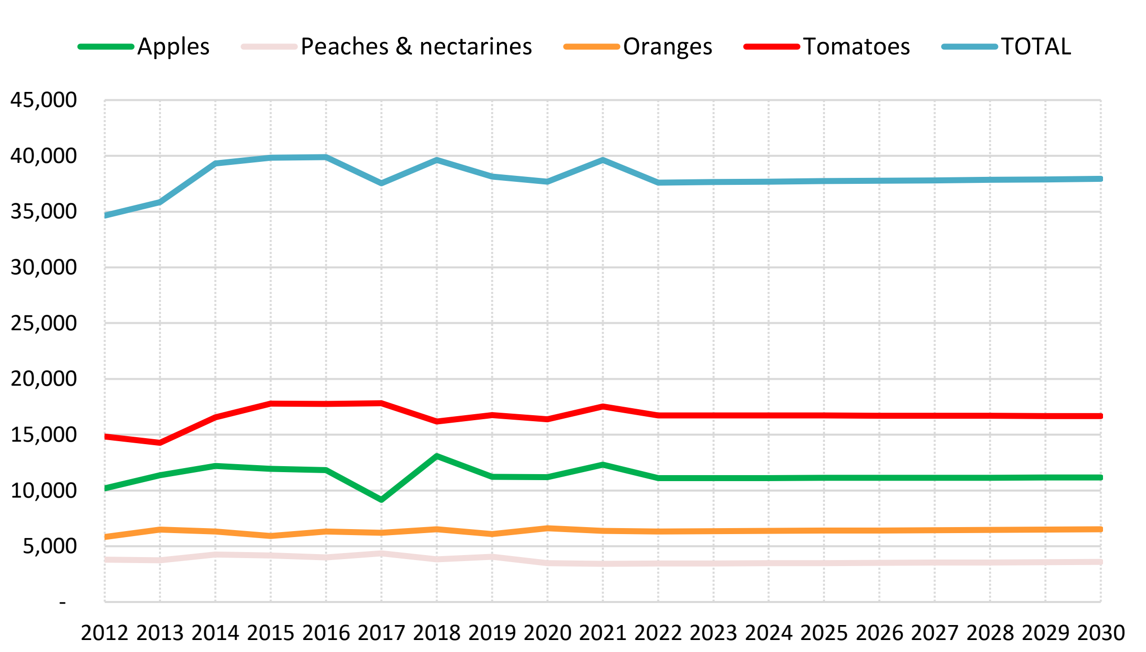


Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows*).*

Approximately 9% of the available fresh supply and 34% of the processed products are exported. The population in the EU-27 consumes approximately 37 million tonnes of fresh equivalent of these 4 commodities (fresh and processed).

It is difficult to estimate the future performance of these crops, as frequent fluctuations in production have occurred in the past years. However, the outlook projections show a baseline between 37.5 and 38 million tonnes of fresh equivalent in the coming decade (Figure 31).

Figure 31. Production of main fruits and vegetables in the EU-27 (million tonnes of fresh equivalent) from 2012 to 2030.

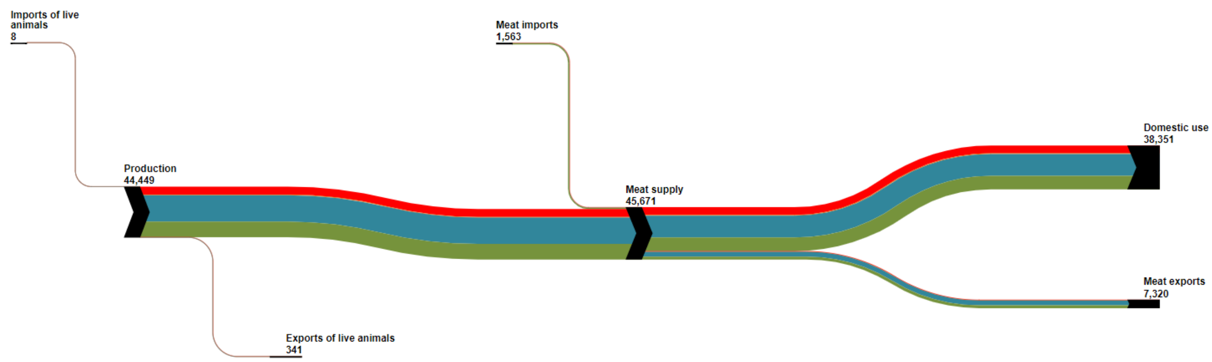


Source: JRC 2022 (based on data from the Medium-term Outlook commodity flows*).*

3.1.4 Meat

The value chains of meat are very simple, as almost the entire quantity of meat produced or imported in the EU-27 is destined for human consumption. The EU-27 is currently almost self-sufficient in meat consumption and produces an excess of meat that is exported. In carcass weight equivalents, half of the meat produced domestically is from pigs. Pig meat is also the source of 57% of the exports, followed by 34% of poultry. Beef and veal exports account for 8% of the total exports of meat. In contrast, over half of the imported meat is poultry, followed by almost 25% of beef and veal imports (Figure 32).

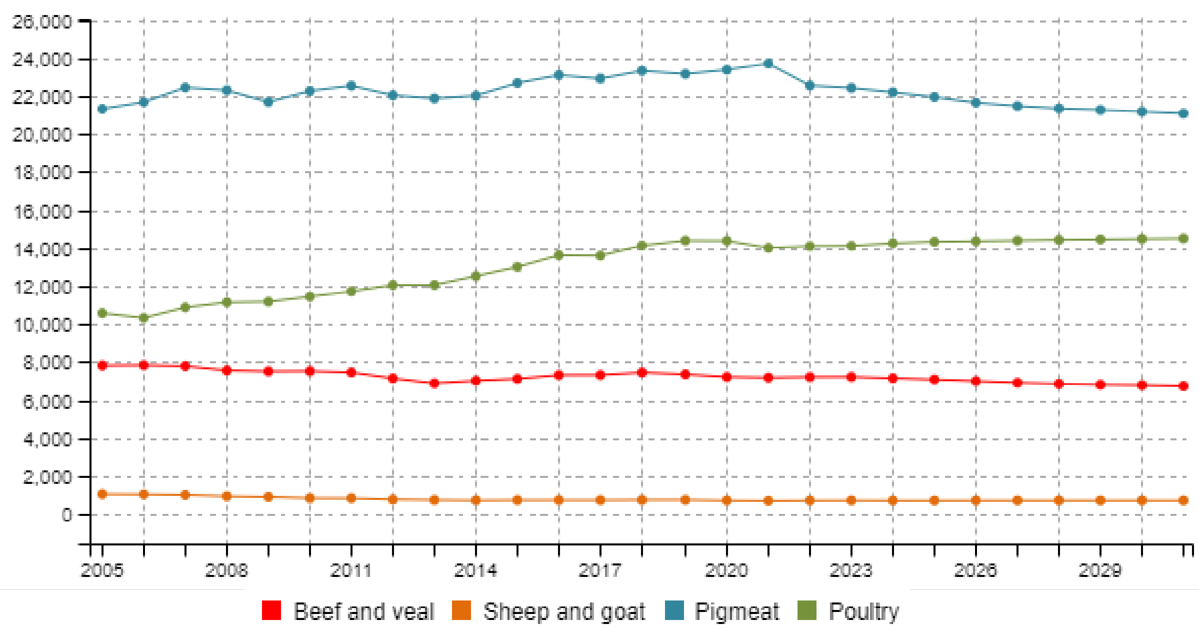
Figure 32. Meat flows in the EU-27 in 2019 (million tonnes of carcass weight equivalents).



Source: Medium-term Outlook commodity flows (DataM, 2022).

Meat production is not expected to experience major changes in the coming decade, although a decline of pig meat and beef and veal, and a slight increase of poultry are projected (Figure 33).

Figure 33. Meat production in the EU-27 (million tonnes of carcass weight equivalents) from 2005 to 2030.

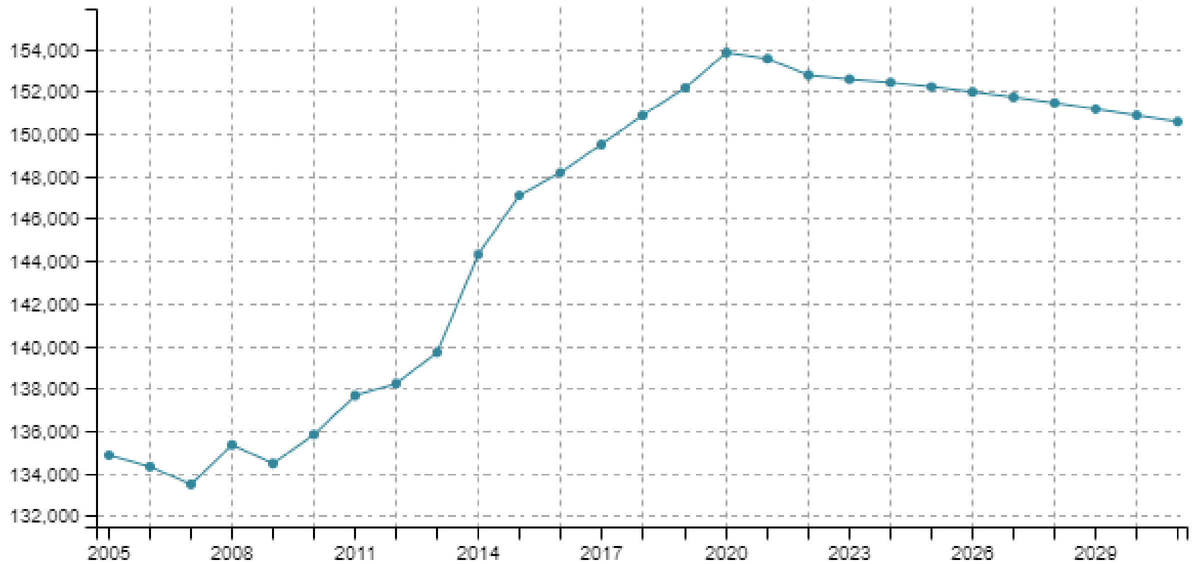


Source: Medium-term Outlook commodity flows (DataM, 2022).

3.1.5 Dairy

In 2019, the EU-27 produced over 150 million tonnes of cow milk. This quantity has been steadily rising during the past decades, but 2020 shows a change in the trend (Figure 34).

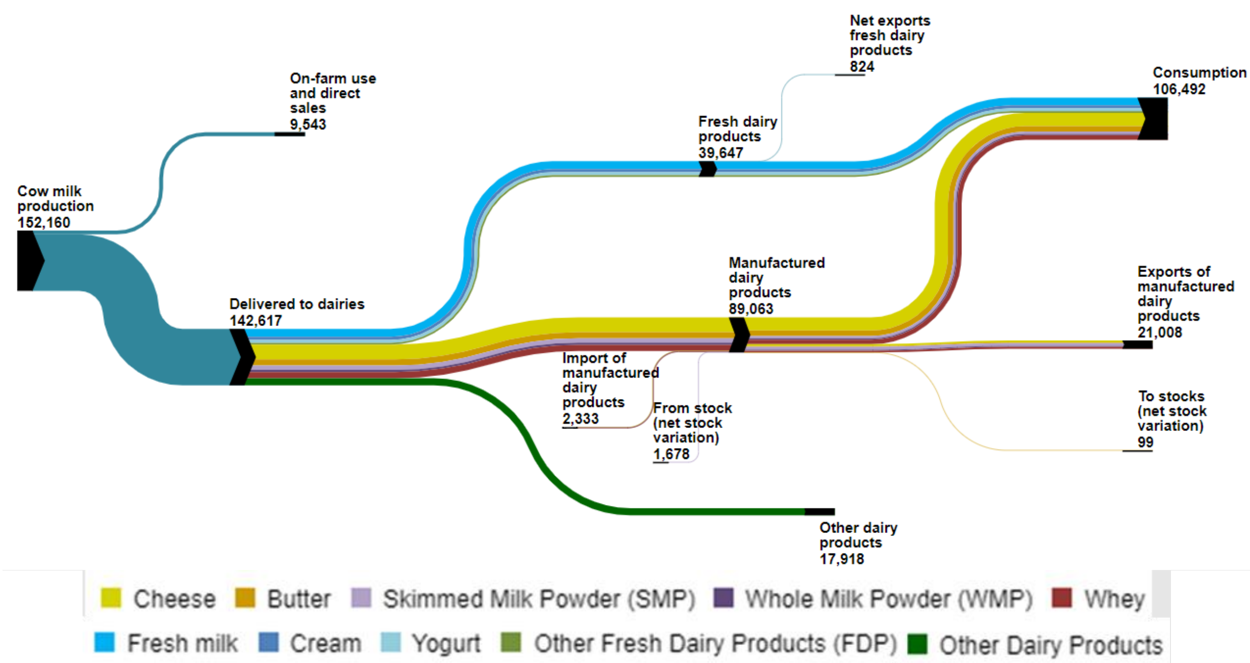
Figure 34. Cow milk production in the EU-27 (million tonnes) from 2005 to 2031. Note: for visualisation purposes, Y-axes starts at 132,000 Mt.



Source: Medium-term Outlook commodity flows (DataM, 2022).

A small portion of the milk production is used on-farm and for direct sales, but the majority of the milk is delivered to dairies, where it is processed in different ways. 60% of the milk delivered is further processed into manufactured dairy products (cheese, butter, skim and whole milk powders and whey). Approximately 28% is sold as fresh dairy products (fresh milk, cream, yogurt and other fresh dairy products), while the remaining 12% is used in other ways (Figure 35). The EU-27 is currently self-sufficient in dairy products, as less than 2% of the total supply (measured in milk equivalents) is imported. These imports are in the form of manufactured products. In contrast, almost 15% of the available supply of dairy products is exported, almost exclusively in the form of manufactured dairy products.

Figure 35. Dairy product flows in the EU-27 in 2019 (million tonnes of milk equivalent).

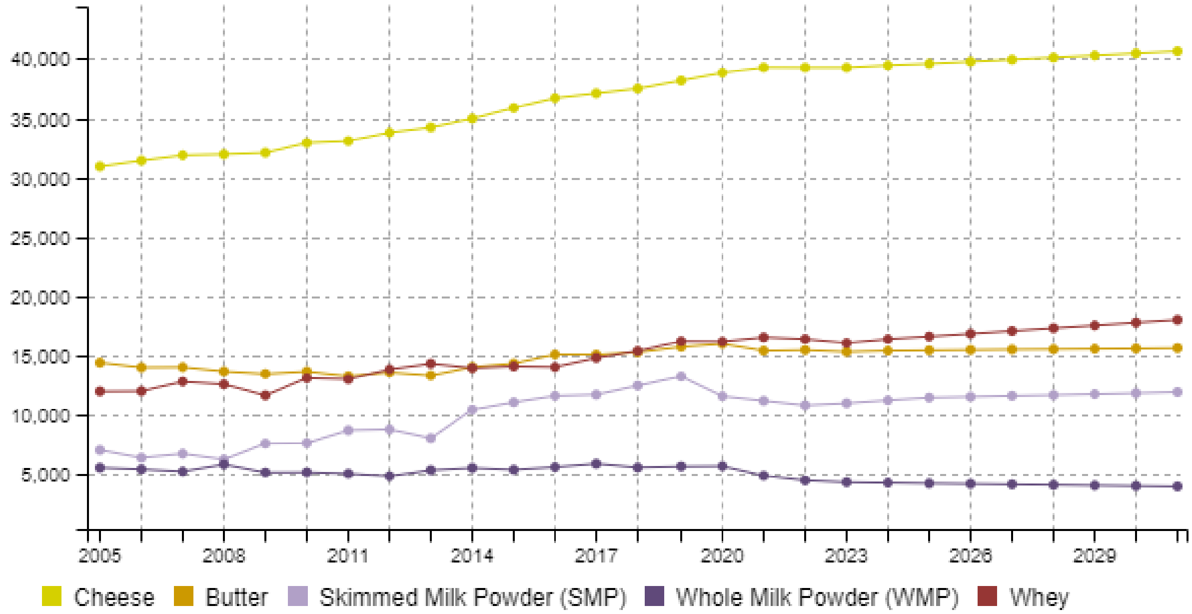


Source: Medium-term Outlook commodity flows (DataM, 2022).

Half of the fresh dairy products are consumed as fresh milk, although the consumption of fresh milk has been decreasing steadily since 2005, with only slight increases in the years 2015 and 2020. This trend is expected to continue. The consumption of cream and fresh dairy products is expected to increase in the coming decade, while yogurt is projected to remain stable or even slightly decrease.

Cheese is the most consumed commodity in the manufactured dairy products, amounting to approximately 43% of the total, followed by whey and butter with 18% each, and skimmed milk powder at 15%. The consumption of manufactured milk products has increased by 22% in the decade 2009-2019 (Figure 36), but the projections of the following decade indicate more moderate growth at approximately 4%.

Figure 36. Manufactured dairy products production in the EU-27, (million tonnes of milk equivalent) from 2005 to 2031.



Source: Medium-term Outlook commodity flows (DataM, 2022).

3.2 Conclusions for Chapter 3

The biomass flows of the main agricultural commodities show the current needs of biomass to ensure food security in the EU. These value chains show that the EU is largely self-sufficient in agricultural biomass, with the exception of oilseeds and their related products (oil and meal). This is largely due to the imports of oilseeds, meal and oil of varieties that are not native and cannot be produced in large quantities in the EU climates.

The projections for the next decade show fairly stable markets for all commodities, with slight increases in oilseed, poultry meat and dairy products supply. These projections, however, do not take into account major climatic or other events that might have an impact on production or trade markets.

A large portion of the agricultural biomass produced or imported into the EU is used for feed. Therefore, the performance of the animal-based product markets has a major impact on all other agricultural commodities. The EU is a net exporter of the major groups of animal products (dairy and meat products). Efficiency gains will be required to accommodate any export increases (such as those expected in milk production) in light of the stable trend in EU agricultural produce.

3.3 References for Chapter 3

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European Commission (2021), EU agricultural outlook for markets, income and environment, 2021-2031. European Commission, DG Agriculture and Rural Development, Brussels. Available at: https://agriculture.ec.europa.eu/data-and-analysis/markets/outlook/medium-term_en.

European Commission, Directorate-General for Research and Innovation, European bioeconomy policy: stocktaking and future developments: report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/997651.

4 European and Global Macroalgae production and uses

Céline Rebours & Javier Sánchez López

Key messages
— Algae play an important role in marine ecosystems contributing to the global primary production and supporting complex food webs in coastal zones. Algae resources have been explored for centuries by coastal communities as a source of fertilizers, cattle feed, and human food. Algae biomass is a valuable resource in the European bio-based economy currently used mainly by the food and chemical industry. Over the last decade, the demand for algae biomass has increased because of the development of new algae biomass-based applications (feed and food supplements, nutraceuticals, pharmaceuticals, third-generation biofuel, and bioremediation).   — In Europe, the EU environmental and maritime policies related to the Blue Bioeconomy, Blue Growth, and Circular Economy aim to foster the development of sustainable algae biomass production and use. At the European level, macroalgae production methods include harvesting from wild stocks and cultivation in land-based systems or offshore facilities. Management guidelines are therefore needed to ensure the sustainable exploitation of algae resources considering climatic and anthropogenic pressures on the marine environment and the ecological and economic viability of the biomass production sector.   — Global seaweed biomass production has increased exponentially in the last decades as a result of market demands. Globally, the production is mainly based on aquaculture cultivation, while in Europe harvesting from wild stocks still supplies most of the macroalgae biomass. The European aquaculture sector is currently seen as an alternative to meet the increase in the market demand for high quality sustainably produced algae biomass and has developed over the last decade. For Europe to find its place in the global seaweed market, there are still many knowledge gaps regarding the algae sector mainly related to biology, technology, as well as understanding and access to the market.   — The low quality and availability of production data, flows, and uses prevent an overarching approach to assess the potential use and value of this biomass source in the bio-based European economy. The improvement of the quality and quantity of the available information is critical to support policy and the algae sector in Europe.

The term "Algae" is defined as "*the population of unicellular/pluricellular organisms of a single algae species, all descended from the entirety/or a part of an organism or several organisms, being synonymous with a monoclonal culture and a genetic representative of a single algae species. This standard defines the terms related to functions, products, and properties of algae and algae products. Thus, this definition includes microalgae, macroalgae, cyanobacteria and Labyrinthulomycetes. Macroalgae are macroscopic eukaryotic pluricellular organisms composed of single differentiated cells able to obtain energy using chromophores*" (CEN, 2020).

Algae are currently the basis of the food chain in oceans and lakes, also contributing to the transformation of large amounts of CO_2 into O_2 (e.g. Raven and Giordano, 2014). However, their growth and overall performance are limited by different factors such as nutrients, light availability, temperature, and dissolved oxygen concentration. To enlarge the contribution of algae to the sustainability of mankind, the development of technologies allowing to enlarge the production of algae is envisioned (Fabris et al., 2020). In this sense, large efforts in Europe have been devoted in the last decades to understand what determines the performance of algae and how to bring its production to the industrial scale. For example, in the policy arena, the Commission has recently adopted the Communication 'Towards a strong and sustainable EU algae sector' (COM/2022/592)[34], an initiative comprising 23 actions to unlock the potential of algae in the European Union.

[34] https://oceans-and-fisheries.ec.europa.eu/publications/communication-commission-towards-strong-and-sustainable-eu-algae-sector_en.

Worldwide, the production of macroalgae is predicted to reach a market value of EUR 9.3 billion with 30% produced in Europe by 2030 (Vincent et al., 2020). In this context, large efforts in Europe have been devoted in the last decades to understand the phenomena determining the performance of macroalgae and how to overpass it at an industrial scale (Araújo et al., 2021). Besides, data on the algae sector, including production values and socio-economic data are not available or not harmonised. For example, according to Vázquez Calderón and Sánchez López (2022), the enterprises in the EU-27 with algae as the main business stream employ 1,852 people and generate EUR 161.4 million of turnover. These authors estimated that enterprises dealing only with macroalgae, employ 1,068 people and generate EUR 129.5 million of turnover. On the other hand, the European Algae Biomass Association estimates the EU's algae sector employed in 2018 approximately 14,000 people and generated an economic value of EUR 1.7 billion of which EUR 700 million specifically from the macroalgae sector[35].

Macroalgae are mainly harvested from the sea where they grow naturally (wild harvest) or in specific production systems (aquaculture). Harvest of the wild seaweed resources can be done mechanically or by hand (on foot or diving). Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (FAO, 2022). In Europe, cultivation of larger species (e.g., *Saccharina latissima*) typically takes place at sea on long lines, whereas smaller algae (e.g. *Ulva spp*) are cultivated both at sea as on inland systems such as earthen or concrete ponds, or even in raceway systems like microalgae. The inland production is thus mainly reserved for niche applications or nursery facilities.

However, the European production capacity can still be much more enlarged, for that, it is mandatory to identify major bottlenecks limiting it, including both biological and technological aspects but also regulatory and market-related framework (Barbier et al., 2018).

In the present chapter, the latest and best available data on macroalgae biomass production are presented, including trade of algae products, as well as the main uses of the biomass produced. Moreover, the main gaps, uncertainties, future developments and recommendations for the development of the algae sector in Europe are detailed.

4.1 Methods

The FishStatJ workspace of the FAO Global Fishery and Aquaculture Statistics[36] was downloaded and analysed, including the datasets on global production by production source (species, country, production area, production source, and year (1950-2021)) (FAO, 2023), value source (species, country, production area, and year (1984-2021)) (FAO, 2023), global commodities production and trade referring to quantity (commodity, country, trade flow and year (2019-2020)) (FAO, 2022). Data on economic value are available only for macroalgae aquaculture production. For the data and analysis provided in this chapter, the production values (harvest and farmed) for the macroalgae species coded in the FAO database were selected, thus filtering out the categories of microalgae species (e.g. *Dunaliella salina*, *Chlorella vulgaris*), the cyanobacteria *Arthrospira* spp. (also coded as Spirulina) as well as the generic category "Plantae aquaticae" that, according to the FAO database, are farmed in freshwater or are captured from inland waters. Thus, the "Plantae aquaticae" produced in marine and brackish environments and captured in marine areas were included, as they were considered to most likely include macroalgae species. Data on trade only consider macroalgae biomass and derived products. In the last version of the FishStatJ FAO database (v4.03.00), *Saccharina japonica* is coded with its correct name, while in previous version it was mentioned under the name *Laminaria japonica.*

For statistical purposes, those aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period are considered as aquaculture production. In contrast, aquatic organisms exploitable by the public as a common property resource, with or without appropriate licenses, are considered as the harvest of fisheries. The production of aquatic plants is given in wet weight. Quantities are given in tonnes (=1000 kg). The value of aquaculture, converted from local currencies, is reported by FAO in thousands of US dollars using appropriate exchange rates and is expressed in nominal terms. For the present report, economic

[35] European Algae Biomass Association, 2021. What are algae? Position paper#1. Version 2.0. https://www.what-are-algae.com/download.pdf.
[36] FishStatJ v4.03.00 (March 2023). https://www.fao.org/fishery/en/topic/166235. Accessed 3 May 2023

values are expressed in EUR using a 0.96 EUR/USD conversion rate. In this chapter, the price of the macroalgae biomass (EUR per tonne) is estimated by dividing the value of aquaculture by the amount of macroalgae biomass farmed. More detailed market prices (business to business and business to consumer) of macroalgae specific species in Europe were provided by Araujo et al. (2021).

The data used for the analysis of the algae biomass production, trade, and flows presented in this report were based on the information published in scientific and grey literature and on the use of the available datasets on algae biomass production and trade. These datasets are the official statistics made available by Eurostat and the FAO that include the reporting by national authorities. All European countries (including non-EU countries) with available statistical data were considered relevant and included in the analysis, as some of the main European producers are not part of the EU-27. Thus, the results present a comprehensive overview of the sector at the European level. Analyses at the global level were also conducted for comparative purposes.

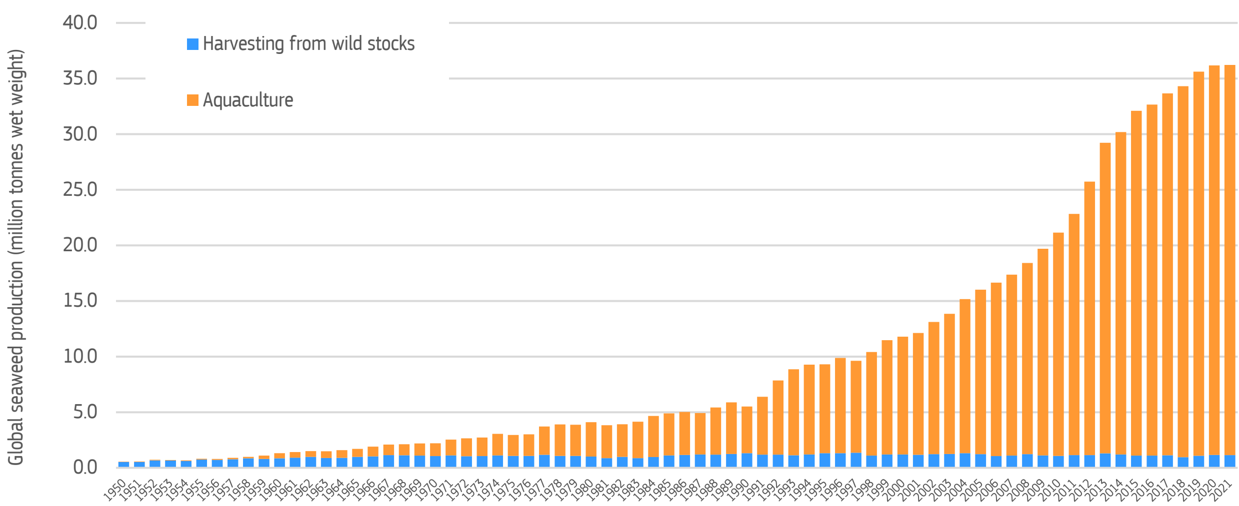
For reporting purposes, when data are not shown at national level in this study, they are aggregated and presented for the EU-27 and /or for other European countries[37]. For comparison purposes between biomass production (2021 data available) and trade (2020 data available), 2020 will be taken as a reference year.

Countries that are known to be producers of seaweed but are not covered in the databases used for this study (e.g. Israel) were not included.

4.2 Macroalgae biomass production

The annual global macroalgae production reported an increase worldwide since 1950 (Figure 37). Until 1970, the biomass was mainly harvested (wild catch). In 2020, the reported seaweed biomass harvested from wild stocks in 28 countries, as shown in Figure 37 (see Table A4.1 in Annexes to Chapter 4), amounted to a total of 1,160,818 tonnes (wet weight, hereafter referred as w.w.). The top 5 countries harvesting seaweed from their wild stocks are Chile, China, Norway, Indonesia and Japan, which account for over 78.1% of the world's seaweed harvest (Figure 38). The biomass harvested from wild stocks in the EU-27 in 2020 represented 7.0% of the global harvest while other European countries represented 14.5 % (Figure 41).

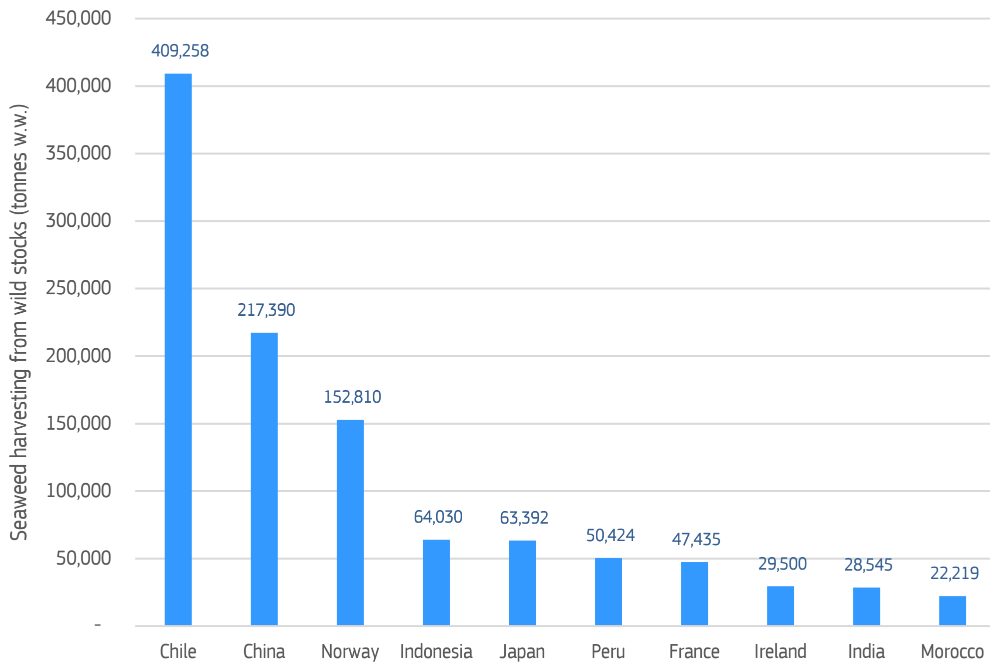
Figure 37. Global seaweed production in million tonnes wet weight. Quantity farmed and harvested from wild stocks from 1950 to 2021.



Data source: FAO, 2023.

[37] The EU-27 comprises the EU Member States as in 2020 (i.e. AT, BE. BG, HR, CY, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES, and SE) while other European countries refers to Faroe Islands (FO), Iceland (IS), Norway (NO), and the United Kingdom (UK).

Figure 38. Top 10 countries in wild stock seaweed harvesting in 2020.



Data source: FAO 2023.

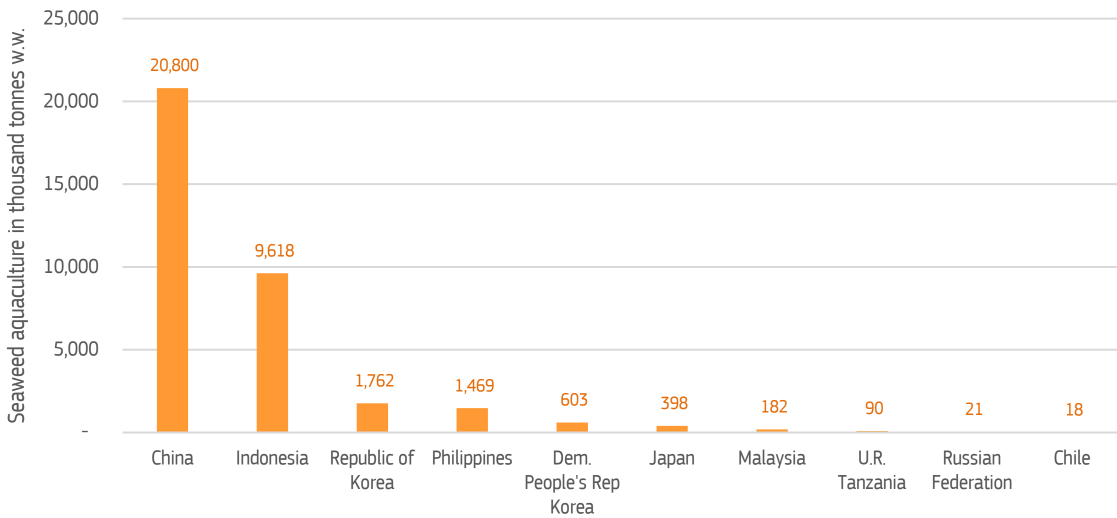
It must be noted that all the biomass reported by China as harvested from wild stocks (Figure 38) refers to the generic category “Aquatic Plants”, and that part of it (2,390 t.w.w) was excluded as they were being harvested in inland waters, according to FAO 2023.

The class Phaeophyceae is the dominating group reported with *Lessonia nigrescens* and *Lessonia trabeculata* in Chile, *Laminaria hyperborea* in Norway, which is also the species the most harvested in Europe with 149,853 t.w.w. (2020 data) and *Sargassum muticum* in Indonesia. In Europe, a variety of seaweed are reported to be harvested in 2020 and the brown seaweeds, *L. hyperborea*, *Ascophyllum nodosum* (58,868 t.w.w.) and *L. digitata* (35,152 t.w.w.) represent the largest volume (almost 98% of all seaweed harvested). Other red seaweed species are collected in Europe: *Himanthalia elongate*, *Undaria pinnatifida* (invasive), *Gelidium corneum* or *Gelidium* sp., *Furcellaria lumbricalis*, *Porphyra linearis, Alaria esculenta*. The green seaweeds are solely reported as Chlorophyceae with no mention of species.

Aquaculture of seaweed started over a century ago and developed to an industrial scale since the 1950´s in Asia. The aquaculture production increased steadily until the year 1999 to reach over 10,000,000 t.w.w. (Figure 37). In the following 20 years, the production worldwide was reported to more than triple and reached 35,015,081 t.w.w. for a value of almost EUR 14 million in 2020 (Figure 37, Table 2).

The main countries producing farmed seaweed in 2020 are China, Indonesia, Republic of Korea, Philippines, Democratic People's Republic of Korea, and Japan. These countries account for almost 98% of the world's aquaculture production (Figure 39 and Table 2). The red and brown seaweeds are estimated to be over 99.8% of the total production, in which almost 52% of the total production are Rhodophytes. These results are to be taken with precaution as large production quantities are not reported under a species name (Table 2). The highest price seems to be obtained by the red algae *Gigartina skottsbergii*.

Figure 39. Top 10 countries in seaweed aquaculture in 2020.



Data source: FAO 2023.

Table 2. Quantity (tonnes wet weight) and value (thousands EUR) of seaweed species produced worldwide by aquaculture. Biomass from non-identified species highlighted in bold.

ASFIS species (Scientific name)	2020 Production (t.w.w)	2020 Value (*000 EUR)	Price (EUR per t.w.w)
Saccharina japonica	12,470,011	4,273,613	342.7
Eucheuma spp.	8,129,404	1,542,736	189.8
Gracilaria spp.	5,180,417	2,174,437	419.7
Undaria pinnatifida	2,811,420	1,941,330	690.5
Porphyra spp.	2,220,180	1,245,965	561.2
Kappaphycus alvarezii	1,604,389	204,545	127.5
Pyropia tenera	828,538	1,352,874	1,632.8
Sargassum fusiforme	292,905	215,667	736.3
Eucheuma denticulatum	154,108	9,924	64.4
Sargassum spp.	80,936	25,133	310.5
Monostroma nitidum	8,242	4,249	515.6
Codium fragile	7,108	3,121	439.1
Ulva spp.	3,715	1,038	279.5
Capsosiphon fulvescens	2,062	4,938	2,394.9
Gracilaria verrucosa	1,695	77	45.6
Caulerpa spp.	1,021	573	561.5
Saccharina latissima	345	967	2,807.9
Enteromorpha prolifera	200	147	736.0
Gracilaria gracilis	190	18	96.9
Alaria esculenta	108	297	2,740.2
Cladosiphon okamuranus	105	21	200.0

Eucheuma isiforme	15	53	3,566.5
Laminaria digitata	10	35	3,515.3
Gigartina skottsbergii	1	5	4,618.4
Algae	24,935	48,025	1,926.1
Phaeophyceae	1,186,754	807,865	680.7
Chlorophyceae	957	236	247.0
Rhodophyta	5,310	379	71.3

Data source: FAO 2023.

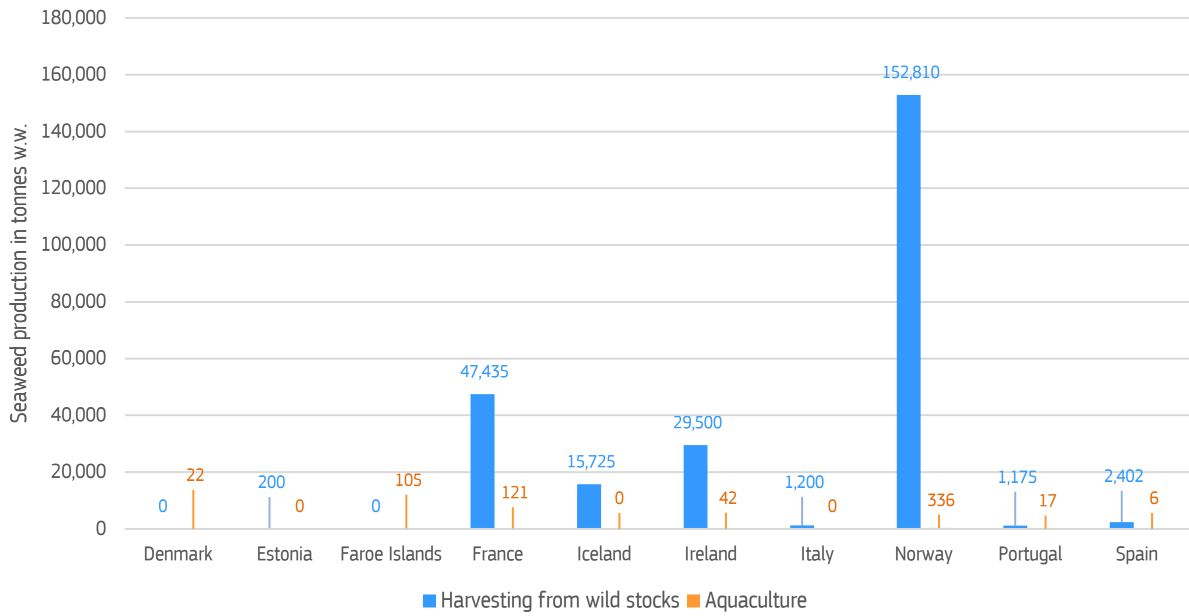
Seaweed cultivation is a nascent sector in Europe and has been focused mostly on the kelp species: *Saccharina latissima* and *Alaria esculenta*. Few other species such as the green alga *Ulva spp*., the red alga *Palmaria palmata* are also produced on a pilot scale and most of the time in the land-based system and in some cases under the IMTA system (Araújo et al., 2021b; Barbier et al., 2019).

According to FAO data (FAO, 2023), the seaweed production by aquaculture in the EU-27 amounted to 207 t.w.w., which represents 0.0006% of the global seaweed aquaculture in 2020 (375 t.w.w. or 0.001% in 2021), while the rest of European countries contributed with an additional 441 t.w.w. or 0.0012% (Table A4.2) (356 t.w.w. – 15.5% in 2021). In fact, the European production from both wild harvest and aquaculture is led by Norway and France, supplying more than half (70%) of the total European macroalgal biomass production in 2020 (Figure 40). In the EU-27 and other European countries, the production of macroalgae is still dominated by the mechanical harvest of wild stocks of kelp and the hand-picking of a variety of species. In the EU-27, seaweed aquaculture started only in 1985 with a stronger development from 2006 while in other European countries aquaculture was reported only since 2015 (Figure 41[38] and Figure 45). France reported the first seaweed cultivated biomass in 1985, followed by Italy in 1991. Italy stopped seaweed farming reporting in 2000, while Spain started in 2006 followed by Ireland and Denmark (including Faroe Islands and Greenland), respectively in 2007 and 2008. Then the countries that started the latest were Portugal in 2014 and Norway and the Faroe Island in 2015 (Figure 42).

In terms of economic value, the seaweed aquaculture production in the EU-27 represented 0.021% (EUR 2.98 million) of the global seaweed aquaculture in 2020, while in the rest of European countries it represented 0.009% (EUR 1.2 million) (Table A4.2).

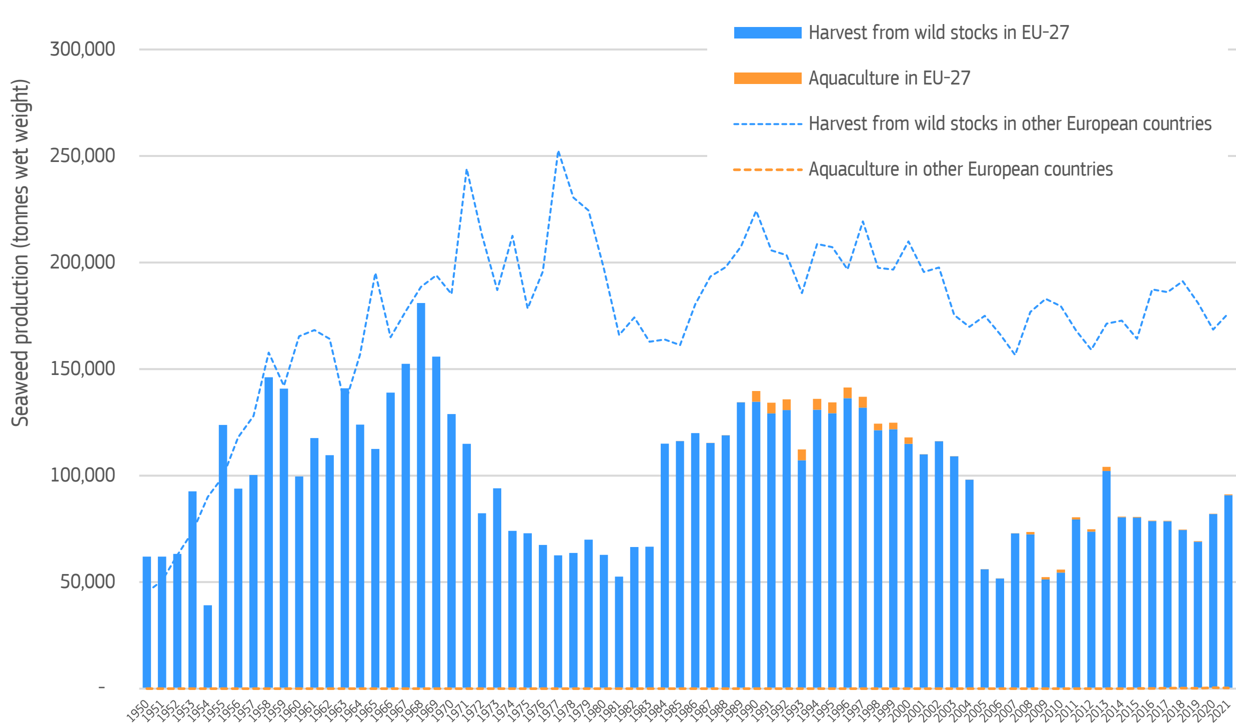
[38] It should be noted that for EU-27, only 7 Member States reported seaweed production values in 2020 (DK, EE, ES, FR, IE, IT, PT) while for other European countries these values refer to 3 countries (FO, IS, NO). It should also be noted that during 1990 to 2000 Italy was reporting between 3,000 and 5,000 t.w.w of seaweed produced by aquaculture but stop reporting after 2000.

Figure 40. Seaweed production in tonnes of wet weight for some European countries in 2020 by aquaculture (orange bar) and harvesting from wild stocks (blue bar).



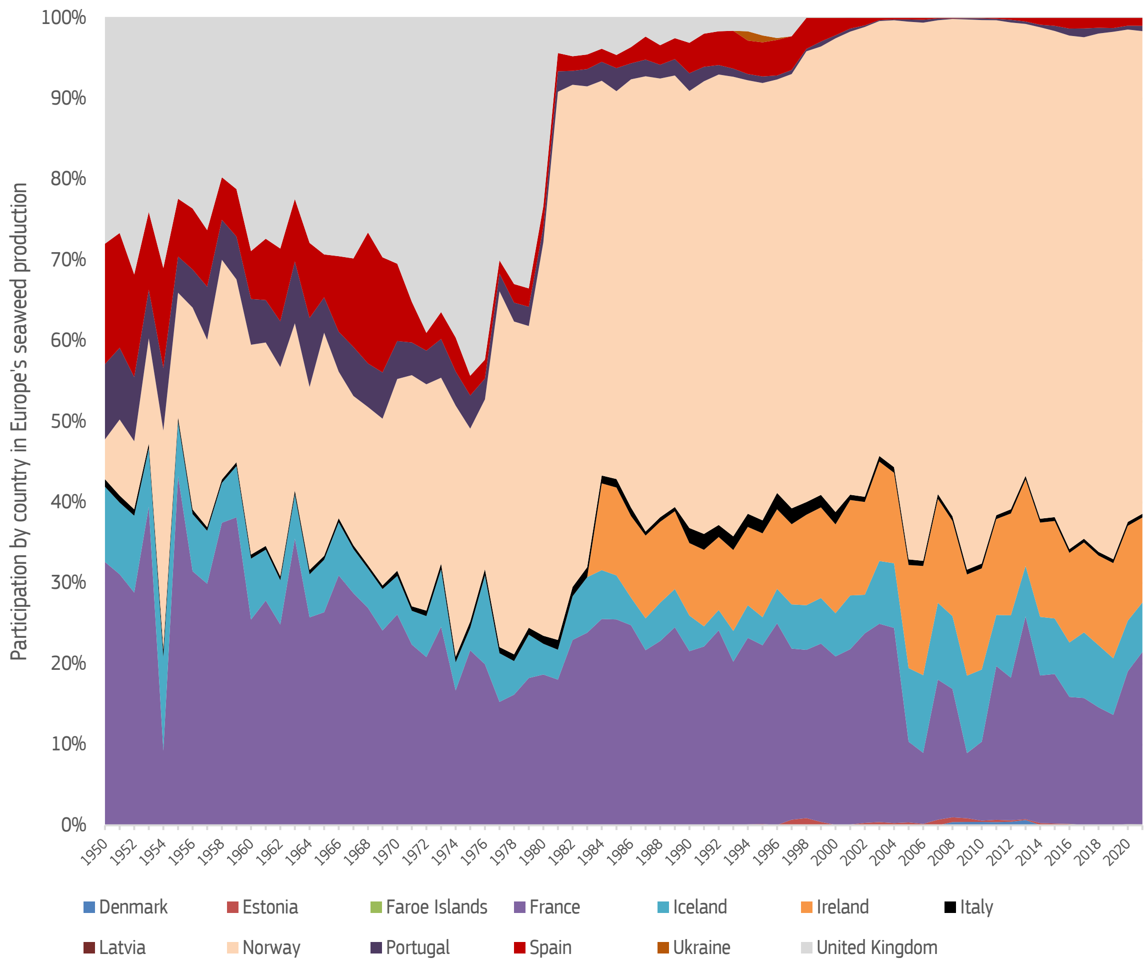
Data source: FAO 2023.

Figure 41. European seaweed production in tonnes wet weight. Quantity farmed and harvested from wild stocks from 1950 to 2021.



Data source: FAO 2023

Figure 42. Countries percentage (%) participation in the total European seaweed production (wild harvesting and aquaculture) from 1950 to 2021.

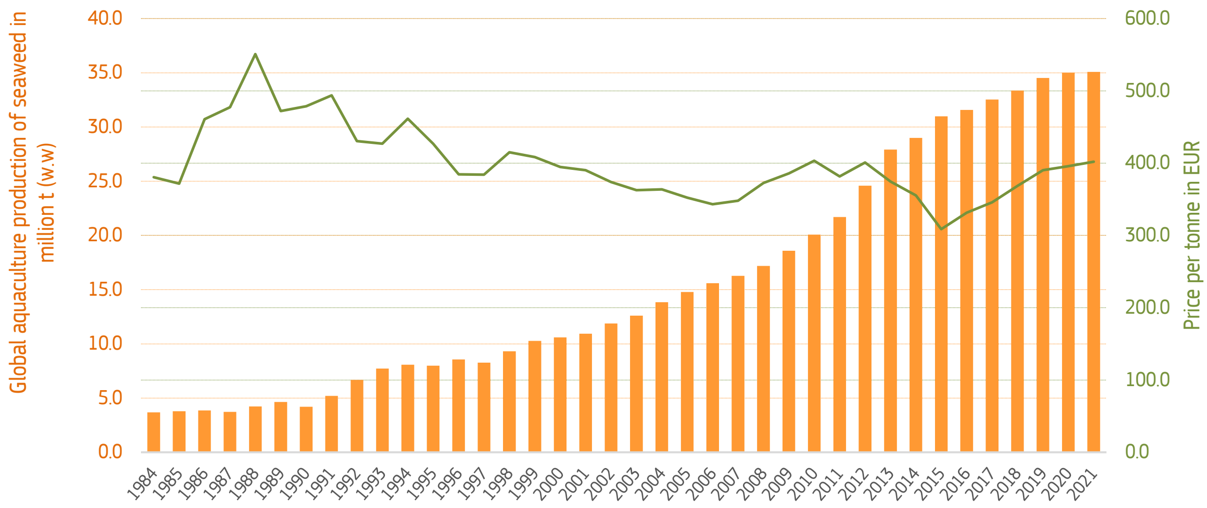


Data source: FAO 2023

4.3 Macroalgae supply, uses and flows

Worldwide, the average price for farmed seaweed, derived from the absolute values of aquaculture and the quantity produced, has not changed since the 1950´s and fluctuates around 399 EUR per tonne (Figure 43). However, there is a high variability in prices between the producer's country and the species sold (Table 2). Seaweed commodities are exchanged under a variety of names in the FAOSTAT and UN Comtrade data.

Figure 43. Global seaweed aquaculture production and seaweed price EUR per tonne from 1984 to 2021.



Data source: FAO 2023.

Table 3. Seaweed commodity name and quantity in tonne of product weight traded worldwide in 2019 and 2020.

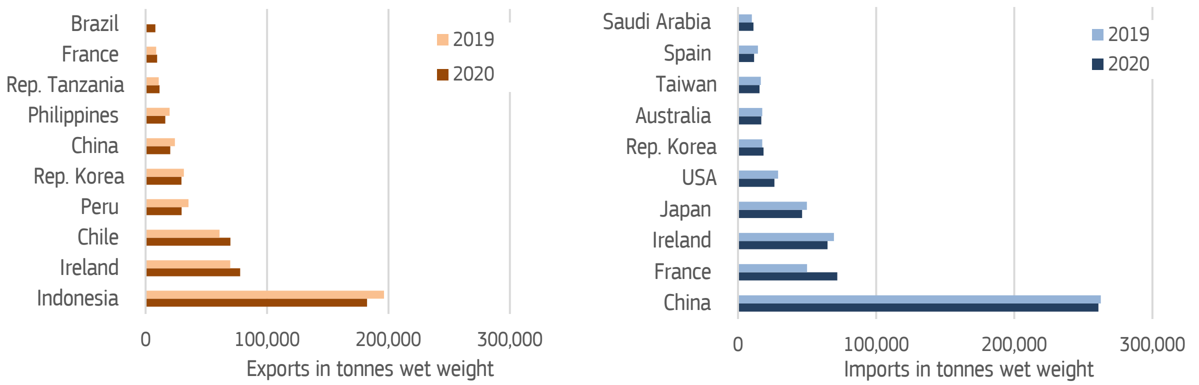
Commodity (Name)	2019	2020
Agar agar in powder	778	632
Agar agar in strips	67	79
Agar agar nei	29,219	27,785
Green laver	78	75
Hizikia fusiforme (brown algae)	6,382	5,485
Laver, dry	15,370	13,205
Laver, nei	1,592	1,477
Other brown algae (laminaria, eisenia/ecklonia)	15,085	13,729
Other red algae	149,457	150,654
Other seaweeds and aquatic plants and products thereof	22,225	22,504
Seaweeds and other algae, fit for human consumption, nei	269,352	256,765
Seaweeds and other algae, unfit for human consumption, nei	556,040	584,190
Undaria pinnafitida (brown algae)	62,445	54,918
Total	1,128,091	1,131,499

Data source: FAO 2022

In 2019 and 2020, 124 countries are reporting to export seaweed, 199 were importing seaweed products and only 11 countries were re-exporting. In 2020, the 10 main exporting countries, in order of volume, were Indonesia, Ireland, Chile, Peru, Republic of Korea, China, Philippines, United Rep. of Tanzania, France, and Brazil. In terms of imports, the 10 main importing countries in 2020 in order of volume were China, France, Ireland, Japan, United States of America, Republic of Korea, Australia, Taiwan Province of China, Spain, and Saudi Arabia (Figure 44 and

Table A4.3). Out of the 11 re-exporting countries, only 4 are producers (United States of America, Canada, New Zealand, Grenada) and 3 (Saudi Arabia, Republic of Moldova, Kuwait) do not report export but only import-re-export. The fact that the quantities traded between countries are much lower than the global production indicates that most of the seaweed commodities are sold as extracts or consumed mainly in the country of production.

Figure 44. The top 10 countries with the largest seaweed exports (left) and imports (right) in 2019 and 2020.

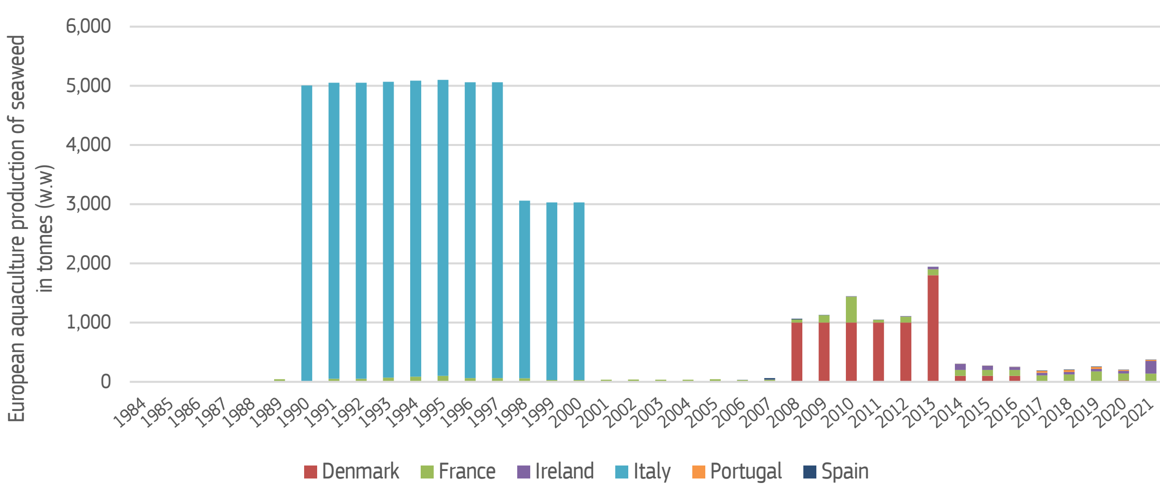


Data source: FAO 2022.

In Europe, larger variations in the quantity of farmed seaweed are observed according to FAO data (Figure 45). Italy reported an annual production of seaweed from aquaculture between 3,000 and 5,000 t.w.w. in the period 1990-2000 but stopped reporting after that date. A similar case is found for Denmark, which was reporting between 1,000 and 1,800 tonnes of farmed seaweed between 2008-2013 while the value reported in the last 8 years decreased to the range 9 to 100 tonnes.

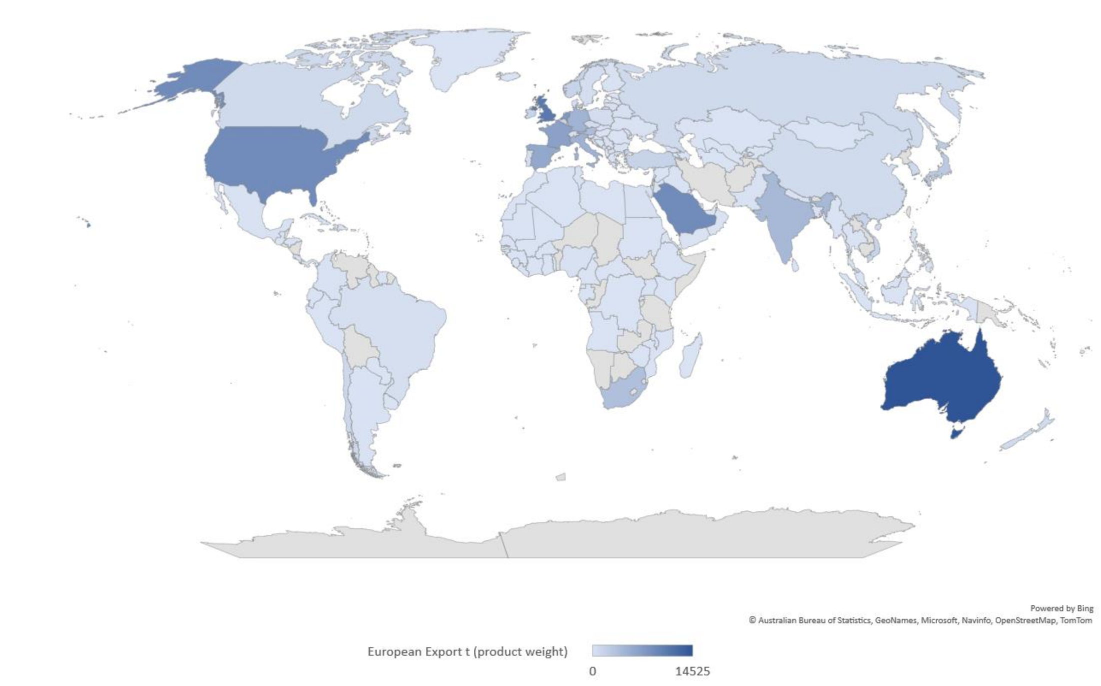
The trade of seaweed is a global market. European countries (as listed in Table A.4.3) export seaweed products to 156 countries worldwide (Figure 46). At the same time, Europe imports seaweed from 101 countries worldwide for which 76.4 % are within the European region (Figure 47).

Figure 45. Seaweed aquaculture production in the EU-27 from 1985 to 2021.



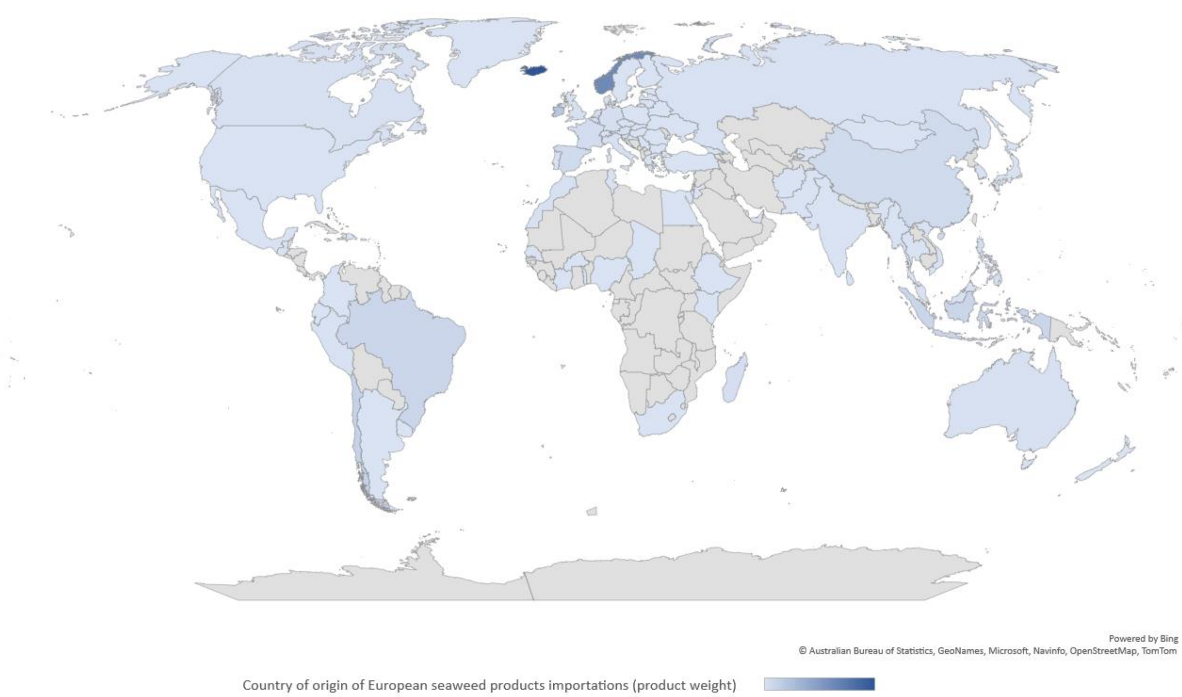
Data source: FAO 2023.

Figure 46. Map over the countries to which European countries exports seaweed commodities (tonnes product weight) in 2020.



Data source: FAO 2022

Figure 47. Map over the countries from which European countries imports seaweed commodities (tonnes net product weight) in 2020.



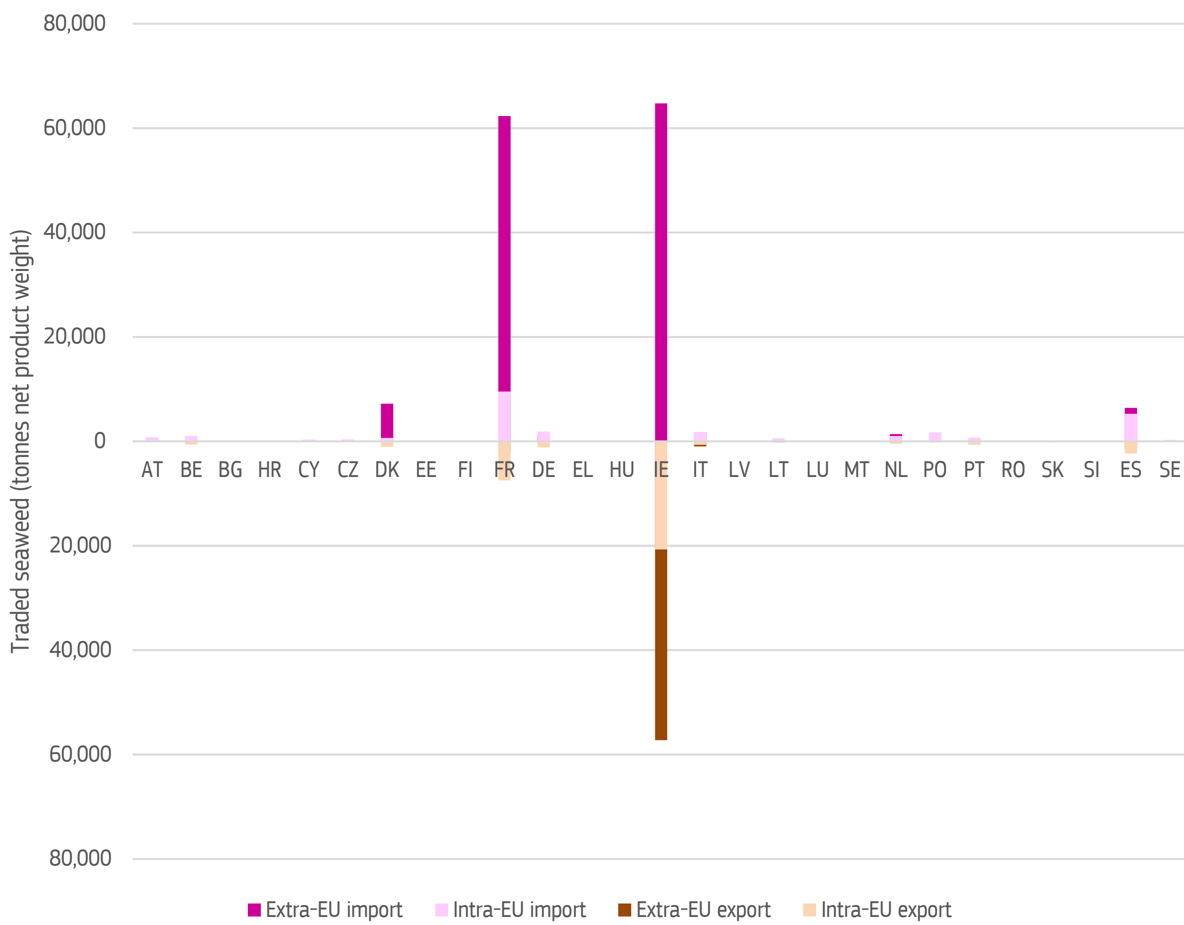
Data source: FAO 2022.

According to FAO data (FAO, 2022), in 2019 the EU-27 Member States imported from outside the EU (extra-EU imports) a total of 134.0 thousand tonnes of seaweed products (measured in net product weight) while the intra-EU imports amounted to 23.3 thousand tonnes. In regards to the exports of seaweed products, the EU-27 Member States in 2019 exported outside the EU (extra-EU exports) a total of 52.7 thousand tonnes and 36.7 thousand tonnes to EU-27 Member States (intra-EU exports). In 2020, the trade of seaweed products increased, both imports and exports within the EU-27 Member States and outside: 146.6 thousand tonnes of seaweed products were imported from outside the EU together with additional 26.9 thousand tonnes of intra-EU imports; at the same time, 62.8 thousand tonnes of seaweed products were exported outside the EU while 35.5 thousand tonnes were intra-EU exports.

In 2020, the Member State that recorded the largest traded seaweed products in the EU-27 Member States area was Ireland with 64.8 thousand tonnes imported (99.8% from outside the EU) and 77.9 thousand tonnes exported (73.4% outside the EU), followed by France (71.8 thousand tonnes of net product weight imported, 86.7% of which from outside the EU, and 9.5 thousand tonnes exported, 21.3% of which outside the EU) as shown in Figure 48.

The seaweed products most traded are those categorised as 'seaweeds and other algae, unfit for human consumption, nei', both for imports (94%) and exports (92.4%).

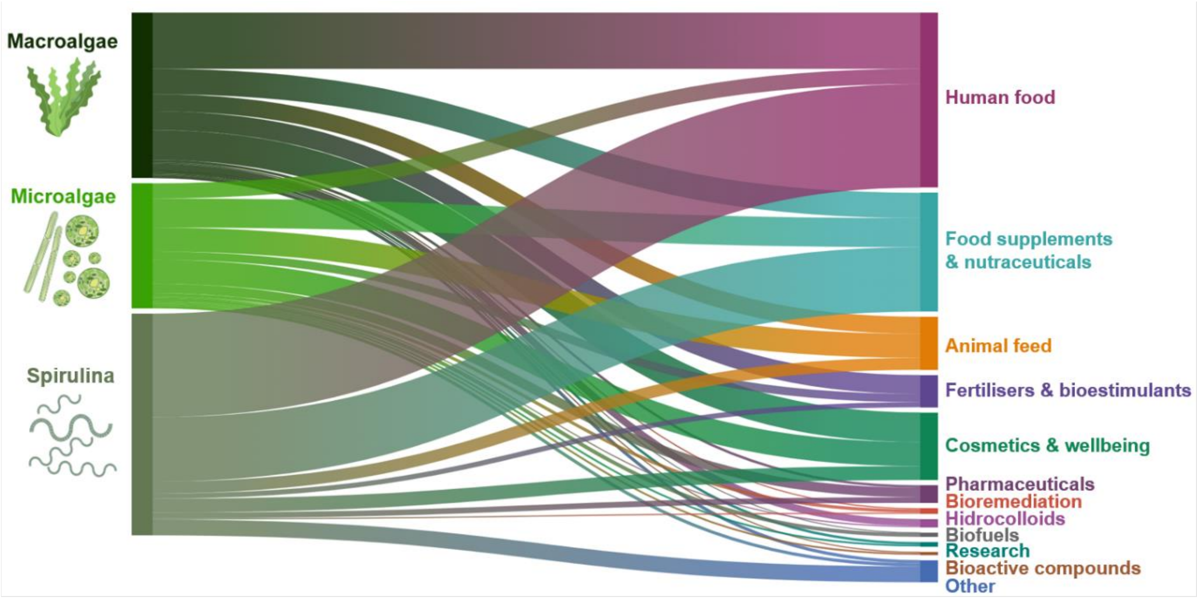
Figure 48. Extra-EU and intra-EU imports and exports of seaweed products in 2020 by the EU-27 Member States.



Data source: FAO, 2022.

Regarding seaweed uses, data on the quantity of macroalgae biomass dedicated to different bio-based uses could not be derived in this study due to the poor quality of the information available at the time of this study. The best available data have been collected by Vázquez Calderón and Sánchez López (2022), who report on the number of enterprises dedicating the biomass produced to broad groups of uses. According to that study (Figure 49), the food and feed sectors, including human food, food supplements and nutraceuticals and animal feed, are the main markets for macroalgae biomass (up to 60% of the enterprises identified in Europe). Other minor uses are cosmetics (18% of the enterprises) and fertilisers and biostimulants (11%).

Figure 49. Algae biomass uses based on number of enterprises producing algae in Europe. Note: lines represent the number of enterprises supplying biomass for the different uses (i.e. they do not represent biomass volumes).



Source: Vázquez Calderón and Sánchez López (2022).

4.4 Gaps, uncertainties, future development and recommendations

Worldwide the biomass harvested or cultivated is reported annually to the Food and Agriculture Organization (FAO). Unfortunately, the national reporting system varies yearly and across countries, thus mistakes can occur during the reporting, including in Europe. Many of the species are not correctly recorded or recorded under generic and or higher group names such as “Phaeophyceae”, “Plantae aquaticae”, “Rhodophyta”, “Chlorophyceae” or “Algae”.

For example, Portugal reported only at genus level (namely Chlorophyceae, Rhodophyceae, and Phaephyceae) making it challenging to represent the variety of seaweed farmed today. In Spain, more than 80% of the seaweed produced from aquaculture since 2015 is being reported as the generic category “Algae”. Furthermore, 222,708 tonnes and 2,262 tonnes of the generic category “Plantae aquaticae” from wild harvesting and aquaculture respectively were reported worldwide in 2021. While a share of these aquatic plants may actually be seaweeds, some others may not be algae but phanerogams, as those farmed in freshwater or those reported to be harvested in inland waters.

Recommendation: a system similar to the harvest recording by species developed in Chile could be investigated and adapted to be implemented in Europe. Training programmes for harvesters, producers and personnel recording and processing the data should be developed to ensure the correct identification of the species.

Some volume may be reported as dried biomass, others as wet weight without any report on the dried matter content, making it difficult to collect data that really reflect the biomass harvested or produced at each farm. For example, this different in the reporting units is the reason behind the large mismatch between the values reported by China in its national annual yearbook[39] (in dry weight, see Table A4.4) (Pers. Comm. Prof. Shaojun Pang) and the ones reported in the FAO data based (reported in wet weight, see Table A4. *5*). Further, the reported quantity does

[39] http://www.stats.gov.cn/sj/ndsj/2021/indexeh.htm.

not mention the loss that happened during harvesting or pre-processing of the product before the first transaction, making it complex to accurately evaluate the volume farmed in Europe.

Recommendation: The national reporting system could be aligned across Europe to ensure harmonisation (e.g. units of measure, species classification used, time, location) in the reporting of seaweed biomass collected from both wild and farms.

Some countries known to be historical harvesters of seaweed in Europe seem to have stopped reporting to the FAO. For example, The United Kingdom gathered by hand on shore (drift or attached) a variety of brown, red, and green species: *Alaria esculenta*, *Ascophyllum nodosum*, *Chondrus cripus*, *Coralina officinalis*, *Fucus* ssp, *Himanthalia elongata*, *Laminaria digitata*, *L. hyperborea*, *Mastocarpus stellatus*, *Palmaria palmata*, *Porphyra umbilicalis*, *Saccharina latissima*, and *Ulva* ssp. The main centers for harvesting were the Outer Hebrides for food, health, and wellbeing products and, in the Orkney and Shetlands and Northern Ireland for agricultural uses. *Porphyra* species were reported to be collected in South Wales for food (Netalgae report 2013). However, the FishstatJ database only reports for production in the category "Phaeophyceae" and no harvest have been recorded since 1997. Other examples of inconsistencies/absences in the reporting of data is Italy, that reported the same quantity of farmed *Gracilaria* spp. for a specific period of time (5,000 tonnes per year from 1990 to 1997 and 3,000 tonnes per year from 1998 to 2000) and then stopped reporting (Figure 45).

Recommendation: All European countries could have in place a user-friendly system to easily record the quantity of seaweed produced by harvest or aquaculture.

The food balance statistics (FAO, 2020) and the global fish processed products productions statistics (FAO, 2022) currently refer respectively to FAO capture and aquaculture and world annual production of processed fishery and aquaculture products statistics of all fish, crustaceans, molluscs and aquatic organisms only and thus do not include aquatic plants.

Recommendation: Similar data collections could be developed about the Aquatic plants to facilitate the analysis and understanding of this sector and contribute to a well-managed development.

The Global fish trade statistics only report for the years 2019 and 2020, making it difficult to analyse the trends. The commodity list seems not to be reported on all known algae products or species.

Recommendation: All the products containing seaweed could be reporting its content in seaweed with more details (species, quantity) to facilitate understanding of the trade patterns of seaweed worldwide.

Some country seems to be exporting more than they produce and import. For example, Denmark reported a production of 22 tonnes (wet weight) and an import of 7,880.2 tonnes (product weight), and export of 1,151.32 tonnes (product weight). This could be due to the system used to measure the quantity that is different between seaweed in bulk or pre-process and seaweed extracts.

Recommendation: A homogenous system to measure the seaweed biomass flow could be established.

Finally, following the algae data collection and analysis conducted in this study, some recommendations regarding the need for provision of accurate, robust, consistent and complete data on algae biomass production can be derived. The Commission through the recently adopted initiative 'Towards a strong and sustainable EU algae sector' (COM/2022/592), is trying to tackle the lack of algae-related data, specifically by the action no. 20 which aims to "*prepare an overview of the availability of algae-related data (e.g. production, employment, turnover and other socioeconomic data) and issue a recommendation on centralising the sources of such data*".

Recommendation: In line with action 20 from the Commission's communication COM/2022/592, to take stock of the algae-related data already available (at least at European level) to clearly identify the gaps, data errors, misreporting, data inter/extrapolation, etc. Efforts should be undertaken and centralised to improve data quality and ensure coordination with the EU Data Collection Framework.

4.5 Conclusions for Chapter 4

Algae play an important role in marine ecosystems contributing to the global primary production and supporting complex food webs in coastal zones. At the same time, algae biomass is a valuable resource in the European Bioeconomy, mainly by the food and chemical industry. While the exponential growing global production is based on seaweed farming, the macroalgae production in Europe primarily rely on the harvesting of wild stocks. The European aquaculture sector represents an alternative to meet the global increasing demand for high quality sustainably produced algae biomass. However, for Europe to find its place on the global seaweed market, there are still many knowledge gaps regarding the European algae sector mainly related biology, technology and market.

Furthermore, management guidelines are needed to ensure the sustainable exploitation of algae resources considering climatic and anthropogenic pressures on the marine environment and the ecological and economic viability of the biomass production sector. Sustainable algae biomass production and use can be developed as an application of EU environmental and maritime policies related to the Bioeconomy, Blue Growth and Circular Economy.

However, the low quality and availability of production data, flows and uses prevent an overarching approach to assess the potential use and value of this biomass source in the bio-based European economy. Several initiatives are still needed to be organised to improve the quality of the available information and support knowledge-based policies for the assessment of the development potential and support of the algae sector in Europe. Therefore, an improvement on the reporting systems at the national level is needed as well as harmonisation of such systems at the European level (in terms of e.g. units of measure, species, time, origin, seaweed content of processed products). Finally, improvements in the reporting systems could include a user-friendly system to easily record the quantity of seaweed produced by harvest or aquaculture or the development of training programmes for harvesters, producers and personnel recording and processing the data.

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5 Fisheries and aquaculture biomass production, supply, uses and flows

Jordi Guillen, Jarno Virtanen, Michaël Gras, Alessandro Mannini, Christoph Konrad, Sven Kupschus, Henning Winker, Paris Vasilakopoulos, Hendrik Doerner

Key Messages

- There has been a reduction in the EU seafood supply from marine fishing since 2016. This reduction in the supply is largely driven by the efforts to reduce overexploitation and external factors that have undermined the performance of the EU fishing fleet, such as Brexit, the impact of the COVID-19 pandemic and more recently, high fuel prices.
- The latest results indicate a reduction in the overall exploitation rate and an increase in biomass of stocks in the NE Atlantic, even if some stocks still remain overfished and/or outside safe biological limits. The situation regarding stocks in the Mediterranean and Black Seas remains challenging, with annual fishing mortality estimates around twice of the reference fishing mortality (FMSY).
- Improvements in fish stocks should result in slight increases in future fishing opportunities, which would improve the resilience of the EU fishing fleet.
- The economic performance and overall viability of the sector, remains still very dependent on the fuel prices paid by the fisheries sector. Overall, the EU fishing activity struggles to be viable in the short-term; but it is not viable in the long term, since the sector does not earn enough to be able to replace its capital factors (i.e. the fishing vessels) in the future.
- In this period of high fuel prices, the importance to decouple economic performance from fuel price variations by reducing fossil fuel consumption is even more important as it can result in cost decreases for the sector as well as environmental benefits.
- The high energy prices, but also difficulties and higher costs in procuring some raw materials, are also affecting the aquaculture and fish processing sectors. However, first estimates would indicate that the aquaculture and fish processing sectors face smaller reductions in their economic performance than the fishing sector.
- Aquaculture and fisheries products tend to have a relatively low environmental impact compared to other protein-sources. Aquaculture has the potential to become a major sustainable food system, in particular: low environmental impact aquaculture (i.e. micro and macro-algae, non-fed species such as filter feeders like molluscs, organic aquaculture and integrated multi-trophic aquaculture - IMTA). However, the success of these non-traditional species will largely depend on the EU consumers' uptake.

After a radical reform in 2002, the EU Common Fisheries Policy (CFP) became one of the European Union's tools for the sustainable management of fisheries and aquaculture. Currently, its main objective is to ensure the sustainability of the fishing and aquaculture sectors' activities in the long-term by reducing their impact on marine ecosystems and living aquatic resources, ensuring the availability of food supplies, with the final aim to provide social and economic benefits to EU citizens. The purpose of this chapter is to provide up to date information on fisheries and aquaculture biomass supply, production, uses and flows.

5.1 Marine fishing biomass supply

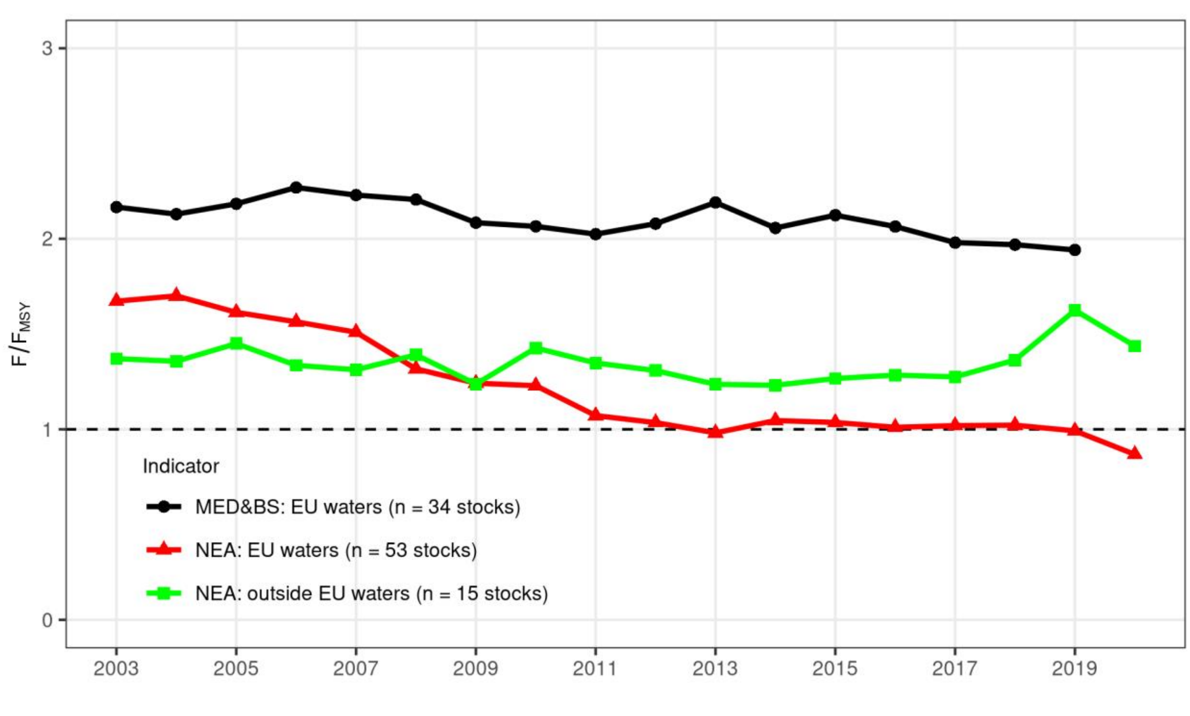
During 2022 the state of European stocks was monitored, as in previous years, through the Common Fisheries Policy (CFP) monitoring report[40]. The state of European stocks is monitored by looking at two main indicators: the rate of exploitation (F/F_{MSY}) and the state of the biomass (B/B2003). F/F_{MSY} is the ratio of current Fishing mortality

[40] https://stecf.jrc.ec.europa.eu/reports/cfp-monitoring

(F) over the reference Fishing mortality (F_{MSY}) (i.e. the value of F at which the stock would be exploited sustainably). The current state of the biomass (B) is put in relation to the biomass at the beginning of the time series (B2003) to show the tendency of its trend through time. Both indicators are estimated for two main areas of European waters, FAO area 27 (North East Atlantic, North Sea, and Baltic Sea regions) and FAO area 37 (Mediterranean and Black Sea region).

Trends in the median values for F/F_{MSY} over time for inside and outside EU waters in the North-Est (NE) Atlantic and for the Mediterranean and the Black Sea are summarised in Figure 50. In the NE Atlantic EU waters, the model-based indicator of fishing pressure (F/FMSY) shows a gradual downward trend over the period 2003-2020. For stocks located in the NE Atlantic but outside EU waters, the median indicator has remained above 1 since 2003, with no increasing or decreasing trend. The indicator for fishing pressure computed for stocks from the Mediterranean & Black Seas has remained at a high level during the period 2003-2019. While there appears to be a slight downward trend in the median value for F/F_{MSY} since 2013, it remains close to twice F_{MSY}, which is not in line with the objective of the CFP.

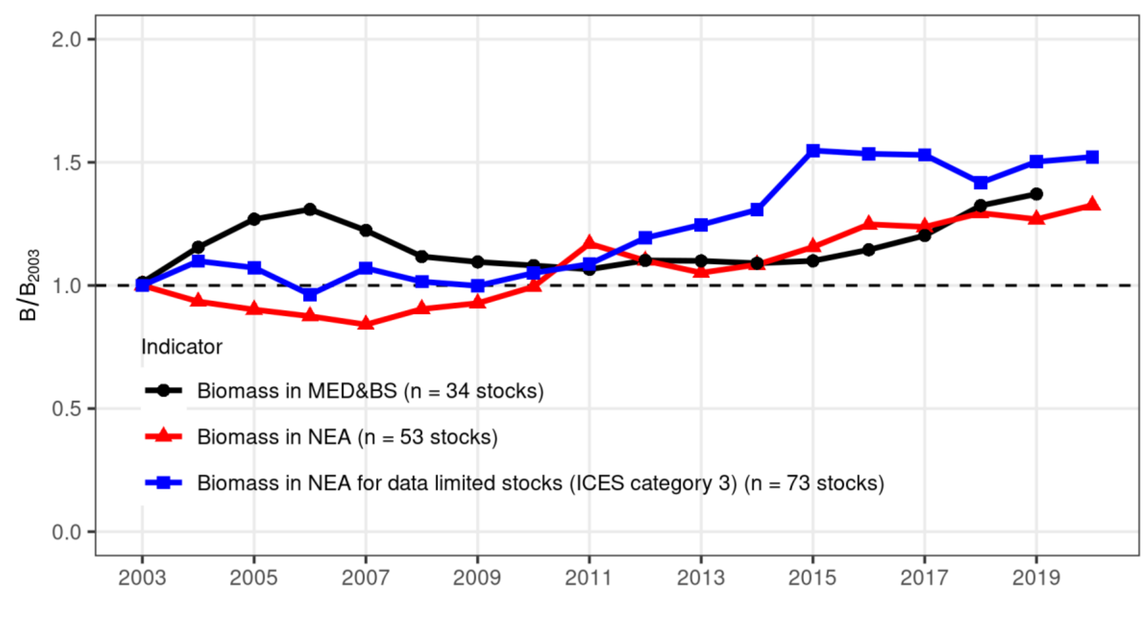
Figure 50. Temporal trend of F/F_{MSY} for stocks in FAO area 37 (black line), for stocks solely in European waters (red line) and for stocks shared with non-European waters (green line) in FAO area 27.



Source: (STECF-ADHOC-22-01)

Trends in the median values for biomass over time are summarised in Figure 51. The Scientific, Technical and Economic Committee for Fisheries (STECF) noted a large uncertainty around this indicator (STECF, 2022a). The model-based indicators for the trend in biomass show a general increase over time since 2007 in the NE Atlantic (EU waters only), both for assessed stocks and for data-limited stocks for which only a relative biomass index is available from scientific survey data. On average, in 2020, biomass was around 35% (for assessed stocks) and 50% (for data limited stocks) higher than in 2003. In the Mediterranean and the Black Sea, the median biomass was higher at the beginning of the time-series, but declined and remained stable from 2006–2015, after which it showed a gradual increase.

Figure 51. Temporal trend of B/B2003 for stocks in FAO area 37 (black line), for stocks of category 1-2 (red line) and for stocks in category 3 (blue line) in FAO area 27.

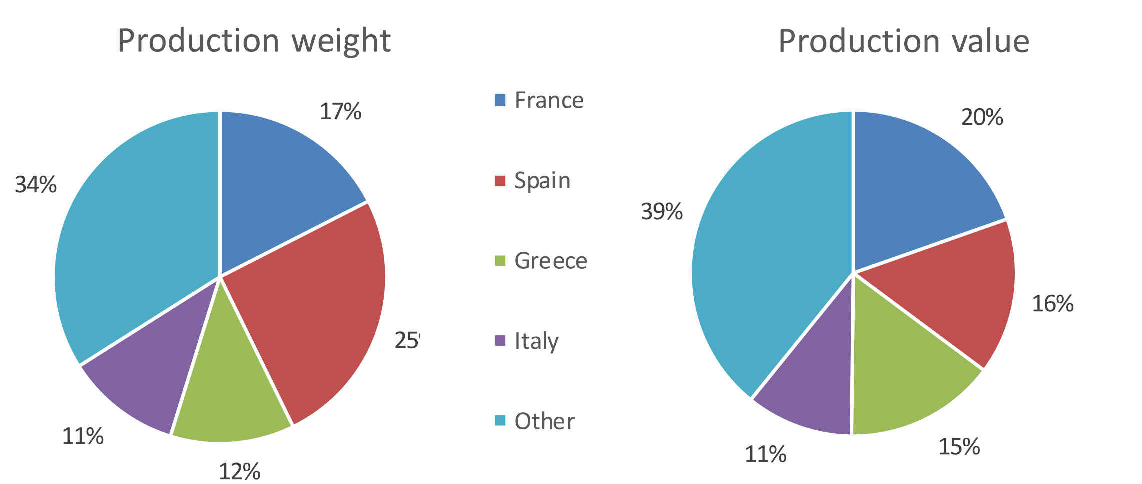


Source: STECF-ADHOC-22-01.

5.2 Aquaculture biomass supply

According to FAO data, EU-27 aquaculture production in 2020 reached 1.1 million tonnes (live (wet) weight), worth EUR 3.7 billion. Spain, France, Greece, and Italy represent 66% in weight and 61% in value of the total EU aquaculture production in 2020, according to FAO data (Figure 52).

Figure 52. Share of production in weight and value in the EU aquaculture sector per MS in 2020.



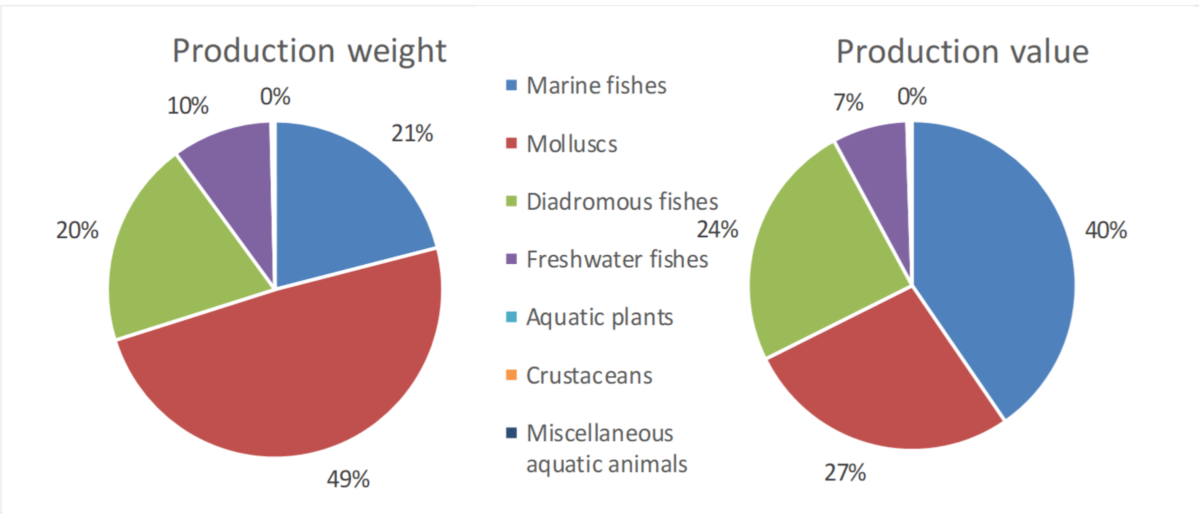
Source: JRC 2022, based on FAO data, 2022.

Marine fish represent 21% of the weight and 40% of the value of the EU aquaculture production. Molluscs represent 49% of the weight and 27% of the value. Diadromous fishes[41] represent 20% of the weight and 24% of the value. Freshwater fishes represent 10% of the weight and 7% of the value. The aquaculture production of aquatic plants, crustaceans and other animals are reported in Figure 53.

The main species produced in weight are mussels (with unidentified sea mussels, blue mussels, and Mediterranean mussels) that account for 37% of the total production, followed by rainbow trout (17% of the total production), seabream (9%), oysters (8%), seabass (7%), and carp (7%) (Figure 53).

The main species produced in value terms are rainbow trout (17% of the total value), seabream (13%), seabass (13%), oysters (11%), tuna (10%), mussels (10% considering the 3 items reported), carp (5%) and clams (4%) (Figure 54).

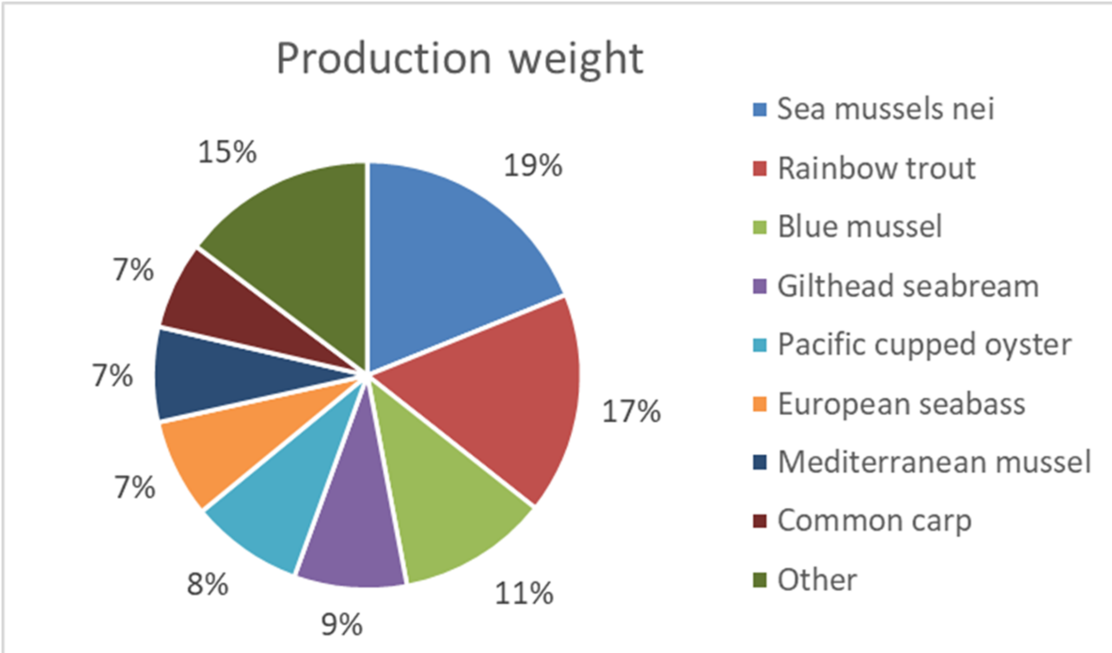
Figure 53. Share of production in weight and value in the EU aquaculture sector per species groups in 2020.



Source: JRC 2022, based on FAO data, 2022.

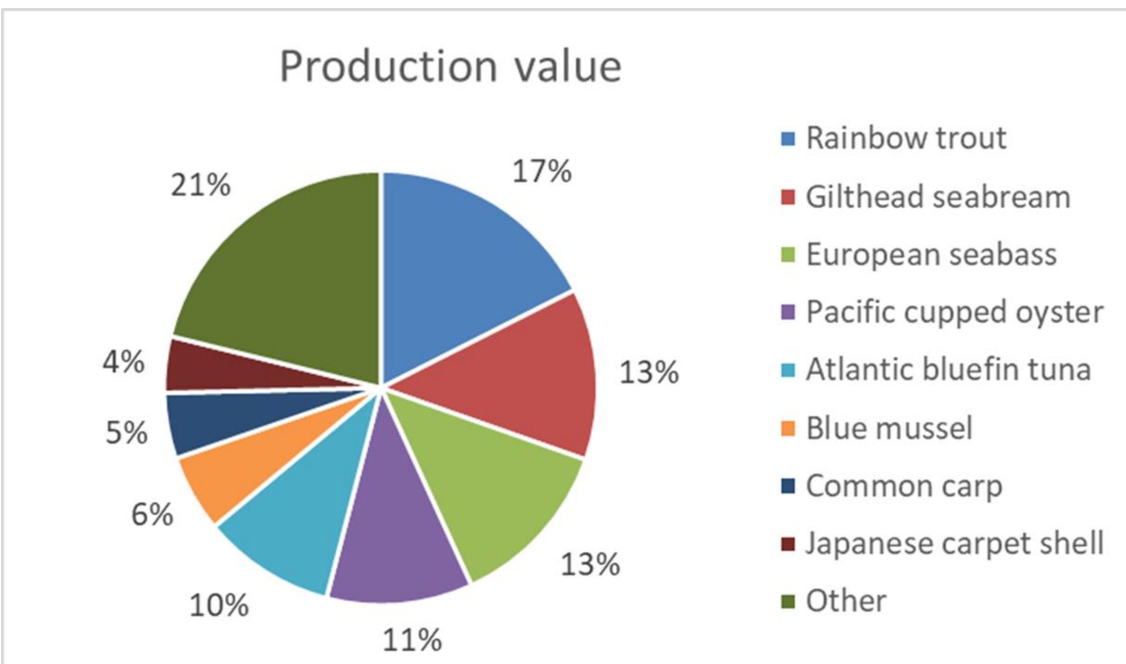
[41] Diadromous fishes are fishes that migrate between freshwater and saltwater. For example, salmon, sea trout species and anguillid eels.

Figure 54. Share of production in weight in the EU aquaculture sector by species in 2020.



Source: JRC 2022, based on FAO data, 2022.

Figure 55. Share of production in value in the EU aquaculture sector by species in 2020.



Source: JRC 2022, based on FAO data, 2022.

5.3 Marine fishing production, uses and flows

In 2020, the EU fishing fleet numbered 73,716 vessels with a combined gross tonnage (GT) of 1.3 million tonnes and engine power of 5.26 million kilowatts (kW). There were 17,605 inactive vessels (23.8% of the total number of vessels), bringing the number of active vessels to 56,111. Of the active vessels, 75% were Small-Scale Coastal Fleet (SSCF) vessels, 24% Large-Scale Fleet (LSF), and less than 0.5% Long-Distance-Water Fleet (DWF). The EU fleet capacity has decreased at a similar rate as in previous years (STECF, 2022b).

Direct employment generated by the sector amounted to 124,636 fishers, corresponding to 82,272 Full Time Equivalents (FTEs). These values follow a similar trend as the capacity indicators. Almost 29% of the employed persons were estimated as being unpaid labour (similar to 2019). The average annual wage per FTE was estimated at EUR 25,654, an increase compared to 2019. The considerable dispersion among the different Member States is remarkable, ranging from an average wage of EUR 1,127 for Cypriot fishers to EUR 107,461 for Belgian fishers. Both cases have higher figures than in 2019 (STECF, 2022b).

To perform, the EU fishing fleet consumed 1.9 billion litres of fuel and spent 5.3 million days-at-sea in 2020. This combination produced 3.9 million tonnes of seafood (including fish) landings with a value of EUR 5.8 billion (STECF, 2022b).

The amount of Gross Value Added (GVA) and gross profit (all excl. subsidies) generated by the EU fishing fleet in 2020 was EUR 3.3 billion and EUR 1.16 billion, respectively. GVA as a proportion of revenue was estimated at 55%, higher than in 2019 and gross profit margin at 19.7%, similar to the one obtained in 2019. After accounting for capital costs, 7% of the revenue generated by the fleet was retained as net profit, again a drop from that obtained in 2019 (STECF, 2022b).

There has been a reduction in the EU seafood supply and economic performance from marine fishing since 2016-17 (Figure 56). This reduction in the supply is largely driven by the efforts to reduce overexploitation and external factors that have undermined the performance of the EU fishing fleet, such as Brexit, the impact of the COVID-19 pandemic and more recently, high fuel prices.

With 2020 marking the start of the COVID-19 pandemic, the EU fisheries sector registered a gross profit of EUR 1.2 billion (a 10.5% decrease from 2019) on a total landings value of EUR 5.8 billion. While overall, the EU fishing fleet was profitable, performance deteriorated compared to 2019. Three of the 22 coastal Member States fleets suffered net losses in 2020: Cyprus, Finland, and Germany. Results also varied by the scale of operation and fishing region (STECF, 2022b).

The lower values of landings are the main reason for this reduction, even in a situation of a sharp decrease in energy prices. The 2020 is a continuation of the decreasing trend observed in 2019, with the added impact of the COVID-19 outbreak, with several short-sized value chains closed in several months of the year 2020 (STECF, 2022b).

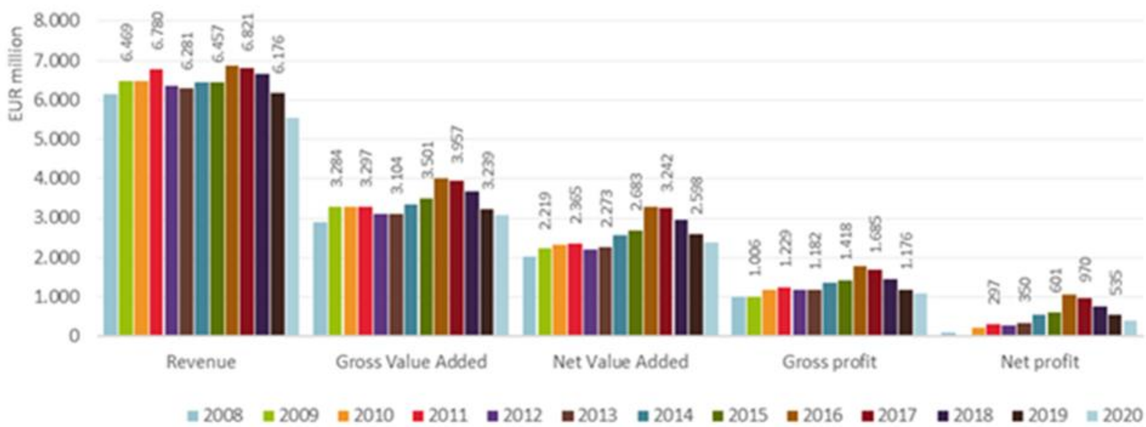
In this context of the COVID-19 pandemic, the change in economic performance of the EU's fishing fleet in 2020 is driven by factors including, inter alia: i) lower demand for product (reduced purchasing power and closure of HORECA channels), ii) weaker first sale price of many fresh fish and shellfish, iii) price variance followed by price stabilisation, for example by supporting cold storage, since fishers, retailers and processors are also confronted with limited stocking capacity (e.g. freezing products); iv) reduced fishing effort, due to lower demand and COVID-19 restrictions (i.e. social distancing of crew members at sea); and v) lower fuel costs due to reduced fuel prices and reduced fishing effort (STECF, 2022b, European Commission, 2022).

Estimates indicate that the fleet's performance will deteriorate in 2021 and even further in 2022 due mainly to the effects brought on by the Russian invasion of Ukraine, particularly with high fuel costs and inflation rates.

According to the 2022 AER report (STECF, 2022), estimates for 2021 put GVA and gross profits of the EU fleet at EUR 3 billion and EUR 850 million, respectively, indicating a decrease of around EUR 300 million compared to 2020. The deterioration was primarily due to higher fuel costs, as the average fuel price in 2021 was 0.57 EUR/litre, while in 2020 it was 0.40 EUR/litre.

Currently, the EU fishing sector faces paying up to about EUR 1.0 per litre of fuel; even if in June 2022, at the peak of the crisis, it was paying EUR 1.2 per litre, which is around three times the usual price (Figure 57). The high fuel prices are jeopardising the viability of the sector, which is largely fuel intensive and particularly vulnerable to fuel price increases.

Figure 56. Trends on revenue and profit for the EU fleet: 2008-2020.



Source: STECF, 2022.

Figure 57. Average monthly fuel price evolution in EU fishing ports (EUR per litre): 2002-2022 (up to August 2022).

Source: EUMOFA, 2022a.

In response, the European Commission adopted on 23 March 2022 a temporary State aid framework to support the economy against the impacts of Russia's invasion. It allows Member States to grant fishery and aquaculture companies up to EUR 35,000 in liquidity support through state guarantees and subsidised loans and to provide aid to compensate for high energy prices. On 25 March 2022, the European Commission triggered the European Maritime, Fisheries and Aquaculture Fund (EMFAF) Regulation crisis mechanism (Article 26(2)) by declaring the occurrence of an exceptional event causing significant disruption to markets. This allows the Member States to financially compensate operators for forgone income or additional costs. In addition, the Member States can define the specific measures to be used (EUMOFA, 2022b; Frederik, 2022). It is currently discussed whether existing support is enough to make fisheries activity viable.

Assuming an average fuel price of EUR 1.0 per litre in 2022, all else being equal to the 2021 estimates and without considering public support, the economic performance of the EU fishing fleet deteriorates significantly. The EU fishing fleet would obtain EUR 2.2 billion in GVA, above EUR 50 million in gross profits and almost EUR 700 million in operating losses. This would be the lowest economic performance ever registered for the EU fishing fleet in the last two decades. The economic performance would be much worse if assuming an average fuel price of EUR 1.2 per litre.

The economic impact of the fuel price increase on the fleet differs by vessel length and fishing gear used, as the fuel consumption varies, e.g. larger vessels and active gears tend to consume more. The LSF and the DWF appear more affected than the SSCF by this increase in fuel prices, because of their higher fuel consumption rates.

This suggests that a 10 cents increase in the fuel price per litre would lead to a loss of around EUR 185 million. Hence, overall gross profits would be null, on average, at a fuel price of about EUR 1.03 per litre (short-term break-even revenue), while the EUR 0.60 per litre reported by the EU fisheries sector (Europêche, 2022), corresponds with the fuel price that would lead to overall net profits to be null on average (long-term break-even revenue), which is about EUR 0.62 per litre on our estimates.

Higher seafood prices may partially offset some of the increased costs and the reduction in landings, while, together with the financial support, offset the negative social impacts in the sector.

Data on the 2022 landings are rather scarce and incomplete. EUMOFA (2022c) estimates that landings in 10 EU countries decreased by 1% during the period January-May 2022 compared to the same months in 2021, while landing values increased by 8%. However, some preliminary data makes us think that the weight of landings for the EU-27 fleet will decrease more than just 1% for the whole 2022.

The profitability and resilience of the EU fisheries sector is one of the Commission's main drivers to keep improving the sustainability of fish stocks to increase the economic performance of the sector and its resilience.

In this particular period, the energy transition to a less fuel-intensive activity also increases its importance as it can result in cost decreases for the sector and in environmental benefits.

5.4 Aquaculture production, uses and flows

According to the 2021 Economic Report of the EU aquaculture sector (STECF 2021), there are about 15 thousand aquaculture enterprises. More than 80% of these enterprises are micro-enterprises, employing less than 10 employees. The sector employed about 69 thousand employees, 39 thousand measured in FTE in 2018, but this number may have decreased in recent years due to the COVID-19 pandemic.

The EU aquaculture sector generated about EUR 1.7 billion in GVA, and Earnings Before Interest and Taxes (EBIT) of EUR 666 million in 2018, which are also expected to be slightly reduced in recent years (STECF 2021).

There have been a number of indications of strong negative impacts of COVID-19 and the preventive health measures associated with the pandemic for all food sectors. However, there is increasing evidence that the picture is quite nuanced where the COVID-19 related measures create challenges for some and opportunities for others (Nielsen et al., 2023).

Preliminary results indicate that, on average, the impact of COVID-19 is negative on the income side, increasing cost and therefore negative with respect to profit. However, in every category the average covers both positive and negative answers suggesting that what was a challenge for some was a window of opportunity for others (Nielsen et al., In Press).

The high-energy prices, but also difficulties and higher costs in procuring some raw materials, are also affecting the aquaculture and fish processing sectors. However, first estimates consider that the aquaculture and fish processing sectors face smaller reductions in their economic performance than the fishing sector (EUMOFA, 2022, b).

The strategic guidelines for a more sustainable and competitive EU aquaculture (European Commission, 2021) emphasise the potential of aquaculture as a major contributor to building a sustainable and responsible food system, in particular as a low-carbon footprint source of protein. As such, these guidelines aim to boost low environmental impact aquaculture, which is identified as the production of low trophic species (micro and macro-algae, non-fed such as filter feeders like molluscs, organic aquaculture and integrated multi-trophic aquaculture (IMTA).

The EU aquaculture sector is dominated by employees that are national (citizens) of the same country as they are employed, male, between 40 and 64 years old, and have a low to medium level of education (Nicheva et al., 2022).

5.5 Processing and distribution

In 2019, the EU fish processing sector was made up of about 3,200 firms and employed about 111,000 people to produce a turnover of EUR 28.5 billion and a GVA of EUR 4.2 billion (STECF, 2022c).

The processing and distribution of seafood products are heavily dependent on the supply of raw materials from the primary sector. High consumption and increased demand for seafood products together with the stagnation in the primary sector make these activities increasingly dependent on imports from third countries (European Commission, 2022).

The main seafood products consumed are tuna (mostly canned), cod, salmon, Alaska pollock, shrimps, mussel and herring. These species exemplify the great heterogeneity of the EU seafood sector. Tuna mostly comes from distant waters and is processed either inside the EU or processed abroad and imported. The Bluefin tuna, typical from the Mediterranean, is mostly exported to Japan, since they are willing to pay higher prices for this species. Cod is partly caught in northern European waters, but mostly imported from Iceland and Norway. Salmon is mainly farmed in Norway and, when processing takes place, it is often in the EU (e.g. smoking). Alaska Pollock is caught in distant waters and mostly imported and processed. Mussels are mostly farmed in the EU, but there are some imports from other extra-EU countries like Chile. Herring is caught in northern European waters. Shrimps in the EU market have multiple sources, from local to distant fisheries as well as aquaculture in developing countries.

The EU is the largest importer of seafood in the world. The EU self-sufficiency in meeting a growing demand for seafood products from its own waters is around 30%; i.e. EU citizens consumed more than three times as much as they produced. EU citizens on average consume around 24 kg of seafood and spend around EUR 100 on seafood per year (European Commission, 2022; FAO, 2022).

The impacts of the COVID-19 pandemic on the EU fish processing industry have been changing as the pandemic waves evolved. Since the first European outbreak in March 2020, the processing industry moved from a boost in demand, caused by consumer's fear, to a less optimistic scenario of disrupted supply, increasing costs and contraction in demand. Overall, the EU fish processors seem to have managed the impacts of the pandemic disruptions quite well. Despite the initial shocks in labour productivity and the disruptions in the supply of raw materials, sales and prices of processed fish products recovered since the end of 2020 and returns may have increase in many segments. The initial shocks on labour productivity and the supply chains started mitigating by the end of 2020, heading for recovery in the levels of activity and economic performance in 2021 (STECF, 2022c).

In 2019, there were 111,000 people employed in the fish processing sector, with a FTE of almost 100,000 employments. The proportion of females and males in this sector was quite similar, with 50% females, 48% males and 2% unknown. Overall, the 40-64 age class made up the largest proportion (50.5%) of people employed in the processing industry, followed by the 25-39 age class (32.7%). A further 8.6% were apportioned to the 15-24 age class, 1.6% to the over 65 years category and 6.6% were unknown. The majority (73%) of people employed in the EU fishing processing sector were nationals of their own country, followed by 18% from EU, 5% from non-EU/EEA nations, 1% from EEA countries and 3% were unknown (STECF, 2022c).

5.6 Conclusions for Chapter 5

5.6.1 Marine fishing

The EU fishing fleet landed about 3.9 million tonnes (live fresh weight) of seafood with a value of EUR 5.8 billion in 2020. There has been a reduction in the EU seafood supply from marine fishing since 2016-17. This reduction in the supply is largely driven by the efforts to reduce overexploitation and external factors that have undermined the performance of the EU fishing fleet, such as Brexit, the impact of the COVID-19 pandemic and more recently, high fuel prices.

Regarding the progress made in the achievement of F_{MSY} in line with the CFP, STECF concluded that the latest results indicate a reduction in the overall exploitation rate and an increase in biomass of stocks in the NE Atlantic over the period 2003-2020. Nevertheless, many stocks remain overfished and/or outside safe biological limits and the objective of the CFP to ensure that all stocks are fished at or below F_{MSY} in 2020 has not been achieved. STECF also concluded that the situation with regard to stocks in the Mediterranean and Black Seas remains challenging, with annual fishing mortality estimates around twice the reference fishing mortality (F_{MSY}) for the entire time-series (2003-2019). There remains a need to increase the number of stocks that are assessed in the Mediterranean and Black Seas, to increase the representativeness of the indicator values.

The improvements in fish stocks, especially in the NE Atlantic, are improving the resilience of the EU fishing fleet. It is expected that the status of fish stocks will continue to improve, resulting in potential slight increases in the fishing opportunities.

However, the economic performance and overall viability of the sector, remains still very dependent on the fuel prices paid by the fisheries sector. Estimates suggest that on average, fuel prices above EUR 1.0-1.1 per litre threat the short-term viability of the EU fishing sector; while the long-term viability would be at stake when fuel prices are above EUR 0.6-0.7 per litre.

Hence, in this period of high fuel prices, it raises even more the importance to decouple economic performance from fuel price variations by reducing fossil fuel consumption as it can result in cost decreases for the sector as well as environmental benefits.

5.6.2 Aquaculture

According to FAO data, EU-27 aquaculture production in 2020 reached 1.1 million tonnes (live weight), worth EUR 3.7 billion. Spain, France, Greece, and Italy represent almost 2/3 in weight and value of the total EU aquaculture production.

The main species produced in weight are mussels (with unidentified sea mussels, blue mussels, and Mediterranean mussels) that account for the 37% of the total production, followed by rainbow trout (17% of the total production), seabream (9%), oysters (8%), seabass (7%), and carp (7%).

There have been a number of indications of strong negative impacts of COVID-19 and the preventive health measures associated with the pandemic for all food sectors. However, there is increasing evidence that the picture is quite nuanced where the COVID-19 related measures create challenges for some and opportunities for others.

The high-energy prices, but also difficulties and higher costs in procuring some raw materials are also affecting the aquaculture and fish processing sectors. However, first estimates consider that the aquaculture and fish processing sectors face smaller reductions in their economic performance than the fishing sector.

Aquaculture and fisheries products tend to have a relative low environmental impact compared to other protein-sources. Sustainable aquaculture has the potential to become a major sustainable food system.

The strategic guidelines for a more sustainable and competitive EU aquaculture aim to boost low environmental impact aquaculture (i.e. micro and macro-algae, non-fed species such as filter feeders like molluscs, organic aquaculture and integrated multi-trophic aquaculture - IMTA). However, the success of non-traditional species will largely depend on the EU consumers' uptake.

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6 Forest Biomass Production

Valerio Avitabile, Roberto Pilli, Mirco Migliavacca, Andrea Camia, Sarah Mubareka

Key messages

- This chapter presents an ensemble of various EU forest biomass reference datasets, based on best available data, with a higher level of harmonisation and spatial resolution compared to existing data published independently by National Forest Inventories (NFI) or produced for international reporting.
- In Europe, National Forest Inventories (NFI) refer to different definitions, spatial scales, monitoring periods and temporal frequency. For this reason, data harmonisation is essential to perform any meaningful pan-European assessment.
- The harmonised statistics presented in this report provide unbiased estimates, which partially overcome the limits of official statistics, but they remain limited in their temporal and spatial resolution. Such harmonisation can only be achieved with a long-term acquisition and integration of ground and remote sensing data that are designed and acquired in a way to be highly compatible between EU Member States.
- Based on the specific assessment carried out by JRC within the present chapter, the total living aboveground biomass stock of the EU forests estimated for the year 2020 is equal to 18.4 billion tonnes of dry matter, corresponding to an average biomass density[42] of 117 tonnes per ha.
- The countries with the largest biomass stock are mostly located in central Europe (DE, FR, PL) and in Fennoscandia region (SE, FI).
- 89% of the forest area and 92% of the biomass stock of EU-27 is available for wood supply (Section 6.3).
- Economic restrictions, mostly linked to low profitability, were responsible for 60% of the forest not available in terms of area but only 42% in terms of biomass, as they affected forests often characterised by low productivity and hence low biomass stock.
- EU forests in 2015 produced a Net Annual Increment (NAI) of 770 million m^3, or 85% of the gross increment.
- The biomass stock in EU forests has continuously increased since 1990, by about 1-2% per year, but its growth has slowed down during the last 5 years, due to different concomitant factors, including ageing processes, an increasing impact of natural disturbances and other climatic drivers.
- The harvest level in the EU was relatively stable between 1960 and 1985 and then presented a clear upward trend, with FAOSTAT removals increasing from 3.0 to 4.0 m^3 ha^{-1} yr^{-1} between 1990 and 2015. Moreover, these values are likely underestimated by up to 13%, mostly because of the lack of data reported for the fuelwood sector (see also Chapter 7).
- The fellings rate slowly decreased from 82% to 78% of the NAI between 2000 and 2015, but taking into account that the absolute amount of removals reported by FAOSTAT increased to 4.3 m^3 ha^{-1} yr^{-1} in 2020 (i.e. +12% compared to 2010), it is estimated to grow and reach the 88% of the NAI in 2020.
- An unprecedented reference database of forest biomass statistics at sub-national scale in Europe was produced. The maps contained in this chapter have been published and are available at https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/BIOMASS/SUSBIOM/LATEST/

[42] This value, referred to 2020, includes all aboveground biomass compartments of the living trees (i.e. the aboveground part of the stump, stem, branches and foliage), and it is derived from the harmonisation of different data sources, integrating NFI data directly provided from Member States, with various remote sensing surveys (see section 6.1.3 and Avitabile et al., 2020). For this reason, the total forest area considered within this assessment is slightly different (-1.3%) from the area reported by ESTAT, FAO and State of Europe 2020 (see Pilli et al., 2023).

Biomass is a finite renewable resource and a rise in demand related to the green transition and climate neutrality for the EU raises questions regarding the biomass availability to satisfy this demand. Forest biomass is becoming increasingly relevant for several forest-related policies in the European Union (EU) under the Green Deal, such as the Bioeconomy Strategy and Bauhaus, the Forest Strategy, the Biodiversity Strategy, the Renewable Energy Directive, the LULUCF Regulation, the Nature Restoration Law and the Regulation on deforestation-free products.

There are issues with respect to biomass sourcing that should clearly be addressed in policies at all scales. There are environmental, social and economic impacts associated with the sourcing of woody biomass in particular, however in this Chapter we concentrate on quantifying the biomass in the EU's forests, as well as identifying the biomass that is so called "available" for harvest. In fact, the accurate and updated assessment of the available forest biomass stocks and related changes is an essential prerequisite to plan an appropriate management of forest resources and to balance different and sometimes competitive interactions between various ecosystem services provided by European forests.

While assessing the standing stock and its share available for wood supply is important to quantify the living aboveground biomass "capital" existing in the European forests, particular attention is given to the increment, which represents the "interest" that can be utilised without reducing the capital. The biomass increment is also related to the status and health of the forest. The increment provides information on the actual carbon sequestration, forest productivity and its response to climate, including extreme events. Therefore, monitoring forest biomass increment is pivotal to inform the sustainable use of forest resources.

With this perspective, the temporal trend of the increment during the last two decades is also assessed to check the stability of biomass resources and to detect early signs of change. Similarly, data on forest harvest and their temporal trend are analysed and compared with the increment information towards an overall assessment of the stability of the forest ecosystems and biomass resources, and to support policy decisions related to forest management.

The present chapter provides an overview of biomass data (i.e. statistics and maps) in Europe related to the amounts of standing forest biomass, the share available for wood supply, its growth rate (or biomass increment), and the harvest dynamics. Here, we present an ensemble of EU forest biomass reference dataset, based on best available data, that has a higher level of harmonisation and spatial resolution compared to existing data published by most EU National Forest Inventories independently (NFI) or produced for international reporting, such as the Forest Resource Assessment 2020 or the State of Europe's Forests (SoEF) reports of FOREST EUROPE (2020). As a consequence of this harmonisation effort - explained in detail within the following sections - each of these data, may diverge from the original data sources.

This chapter emphasizes the importance of harmonised and spatially-resolved data, which are essential to better assess the status of EU forests and their ability to produce biomass and other ecosystem services. For example, Grassi et al. (2021) and Petrescu et al. (2021) showed how different forest definitions (regarding management and anthropogenic effects) led to large discrepancies between carbon fluxes estimated with countries' GHG inventories and models at global and EU level. Similarly, spatial disaggregation of national data at sub-national scale and even more the wall-to-wall mapping of forest resources is essential for a variety of applications, such as a better assessment of biomass accessibility and extraction costs and their impacts on the local socio-economic forestry system.

Every European Member State has a National Forest Inventory (NFI) system, often repeated every 5 – 10 years, from which it is possible to obtain reliable statistics on forest biomass resources (Vidal et al., 2016). However, the NFI statistics are not always recent or frequently updated, while they employ country-specific definitions and inventory designs that can be substantially different. Besides, NFI statistics do not often provide data with fine-scale spatial distribution but only summary statistics at national or sub-national scale. Consequently, the NFI data refer to different periods, biomass pools and spatial scales that impede their integration for a quality assessment of European biomass resources (McRoberts et al., 2010; Neumann et al., 2016). It is therefore essential to harmonise the national biomass data to perform any meaningful pan-European assessment.

The results presented in this chapter are based on a multi-annual dedicated effort and collaboration of several EU NFIs, where the national statistics on biomass stock, biomass available for wood supply and biomass increment were harmonised using the same reference definitions and a common methodology. Then, the data were further harmonised temporally by the JRC to a common reference year (2020) using a forest growth model - the Carbon Budget Model (CBM, Pilli et al., 2022) - adapted to European conditions and calibrated for each EU country by the JRC using NFI data.

This data harmonisation effort produced an unprecedented reference database of forest biomass statistics at sub-national scale in Europe. The harmonised statistics were further used as calibration data to produce maps that complement the statistics with spatially-explicit and fully-consistent information on forest area, biomass stocks and forest available for wood supply. Such dataset allows a comprehensive and detailed view on the current biomass resources in Europe.

The harmonisation effort also included the statistics on forest biomass increment. Even more than for biomass stock, the increment data provided individually by the European NFIs and regionally compiled for international reporting (e.g., SoEF reports) are based on different approaches and definitions, adapted to national circumstances (Gschwantner et al., 2016; 2022). In this chapter, we present the recent results of the harmonisation work performed by ten EU NFIs to produce comparable statistics at sub-national scale of gross and net forest biomass increment.

Ad-hoc harmonised statistics of forest biomass loss and long-term trend analysis of the changes in biomass stock, increment and harvest are, instead, not yet available. Therefore, we present the latest results based on data produced for the SoEF reports or derived from the outcomes of the Carbon Budget Model.

Lastly, this chapter provides an overview about the upcoming challenges on the production of biomass in European forests and some suggestions about how to improve the monitoring of biomass in European forests considering the opportunities arising from the latest developments in the field of forest monitoring with remote sensing.

6.1 Biomass stock in the European forests

6.1.1 Summary in numbers: key indicators

According to our harmonised statistics, which include all aboveground parts of the trees, the total living aboveground biomass stock of the EU forests in the year 2020 is equal to 18.4 billion tonnes of dry matter over a forest area[43] of 157 million ha, corresponding to an average biomass density of 117 tonnes per ha.

The forests of central Europe store most of the biomass stock (10 billion tonnes) and present the highest biomass density (176 tonnes/ha), which gradually decreases moving towards southern and northern Europe. The countries with the largest biomass stock are mostly located in central (DE, FR, PL) and northern (SE, FI) Europe, where the lower biomass density (73 tonnes/ha) is compensated by the large forest extents. Southern forests present a biomass density similar to northern forests but their smaller extent reflects in a lower biomass stock.

The EU Forest biomass is almost equally distributed between broadleaves (50.7%) and conifers (49.3%), and is mostly produced by two conifers, *Picea* sp. (21.5%) and *Pinus sylvestris* (19.8%), followed by the broadleaves *Fagus sylvatica* (11%), *Quercus robur* (8%), *Betula* sp. (6%) and *Quercus cerris* (4%).

The biomass density of our harmonised statistics is depicted with high spatial resolution (1 ha) by a biomass map that matches the 2020 statistics. Remote sensing technologies are rapidly developing, and it can be expected that

[43] This area, referred to 2020, includes all aboveground biomass compartments of the living trees (the aboveground part of the stump, the stem, dead and living branches, and foliage) and it is derived from the harmonisation of different data sources, integrating NFI data directly provided by the Member States However, a few NFIs reported the biomass statistics according to the national forest definition instead of the definition used for international reporting, and thus their forest area differ from the value reported in the SoEF. For this reason, the total forest area harmonised at EU-27 level, is slightly different (-1.3%) from the area reported by ESTAT, FAO and State of Europe 2020, equal to about 159 million ha for 2020 (see section 6.1.3).

earth observation data will soon be used in combination with ground-based surveys for the operational monitoring of forest biomass.

The temporal trend of forest biomass, derived from SoEF data[44], indicates that the biomass stock of EU-27 has increased during the period 1990 – 2020 but its growth has slowed down during the last 5 years. In fact, the annual percent growth increased from 1% to 2% during the period 1990 – 2015 and then decreased to only 0.9% during the period 2015 – 2020.

6.1.2 Reference statistics for 2020

The reference statistics of the total aboveground forest biomass standing stock in the EU are produced by the JRC compiling, processing and harmonising the best available data provided by the National Forest Inventories at national or sub-national level. This is the first dataset that provides biomass statistics mostly harmonised in terms of biomass definition (the data refer to the same components of the trees), temporal resolution (the data refer to the same year, 2020) and with a sub-national spatial scale. The harmonised statistics at sub-national scale are available for 19 EU countries, which represent 93% of the forest biomass of the EU-27 while, for the remaining 8 countries, the data are derived from the SoEF 2020 Report at national scale (see Annex of this chapter).

The harmonisation of the biomass definition was performed by the NFIs under the coordination of the European National Forest Inventory Network (ENFIN) by adjusting the national data with ad-hoc correction and expansion factors to include all the aboveground parts of the tree, from stump to top, with branches and foliage. Instead, the harmonisation of reference year was performed by the JRC using a modelling approach that simulate the biomass changes due to forest growth, mortality, harvest, natural disturbances, afforestation and deforestation.

The harmonised biomass statistics refer to the forest area reported by the NFIs in their reporting year, updated to the year 2020 considering the forest area change estimated from the SoEF time series data on forest area. The implementation and the impacts of the harmonisation procedures on the biomass statistics are described in section 6.1.3 (Harmonisation approaches) and in Avitabile et al. (2020).

The total biomass stock of the EU forests estimated for the year 2020 is equal to 18.4 billion tonnes of dry matter over a forest area of 157 million ha, corresponding to an average biomass density of 117 tonnes per ha (Table 4). The total forest area is derived from the harmonisation of the NFI data directly provided from 21 Member States (see Avitabile et al., 2020). Because some of these countries reported to JRC a forest area slightly different from the area reported to international institutions (see the Annex to Chapter 6 for further details), the total forest area for EU-27 is slightly different (-1.3%) from the area reported by ESTAT, FAO and State of Europe 2020, equal to about 159 million ha for 2020 (see section 6.1.2 and Pilli et al., 2023 for further details).

According to this analysis, the forests of central[45] EU countries store most of the biomass stock (10 billion tonnes) and present the highest biomass density (176 tonnes/ha). The forests of northern EU cover an area comparable to central EU forests (58.3 and 56.9 million ha, respectively) but store less than half of their biomass (4.7 billion tonnes). Northern and southern EU forests present a similar biomass density (81 and 86 tonnes/ha, respectively) but the smaller extent of the southern forests reflects in a lower biomass stock (3.6 billion tonnes) (Table 4).

At the national level, the countries with the largest forest area are located in northern and southern Europe (SE, FI, ES) while the countries with the largest biomass stock are mostly located in central (DE, FR, PL) and northern (SE, FI) Europe (Figure 58). Similarly, when considering the biomass density, the countries with largest values per ha are mostly located in central-east Europe (CZ, SI, SK, AT, PL, RO) while the countries with lowest biomass density are located in northern and southern Europe (PT, GR, ES, FI, SE) (see Annex of this chapter).

Moreover, in most countries our harmonised statistics present information at sub-national level ranging from NUTS-1 to NUTS-3 that shows with more details the gradual decrease in forest biomass density when moving from central Europe towards the south and north (Figure 59). In particular, the biomass density can reach very high values (> 250 tonnes/ha) in some administrative regions of central-east Europe (especially in CZ) and very low

[44] In this case the forest area was not assumed as constant, but it is varying according to national statistics reported from in SoEF.

[45] The EU regions described in this paragraph are defined according to the SoEF 2020 Report and include the corresponding EU countries

values (< 50 tonnes/ha) in southern and northern Europe (especially in the Iberian Peninsula and northern Scandinavia).

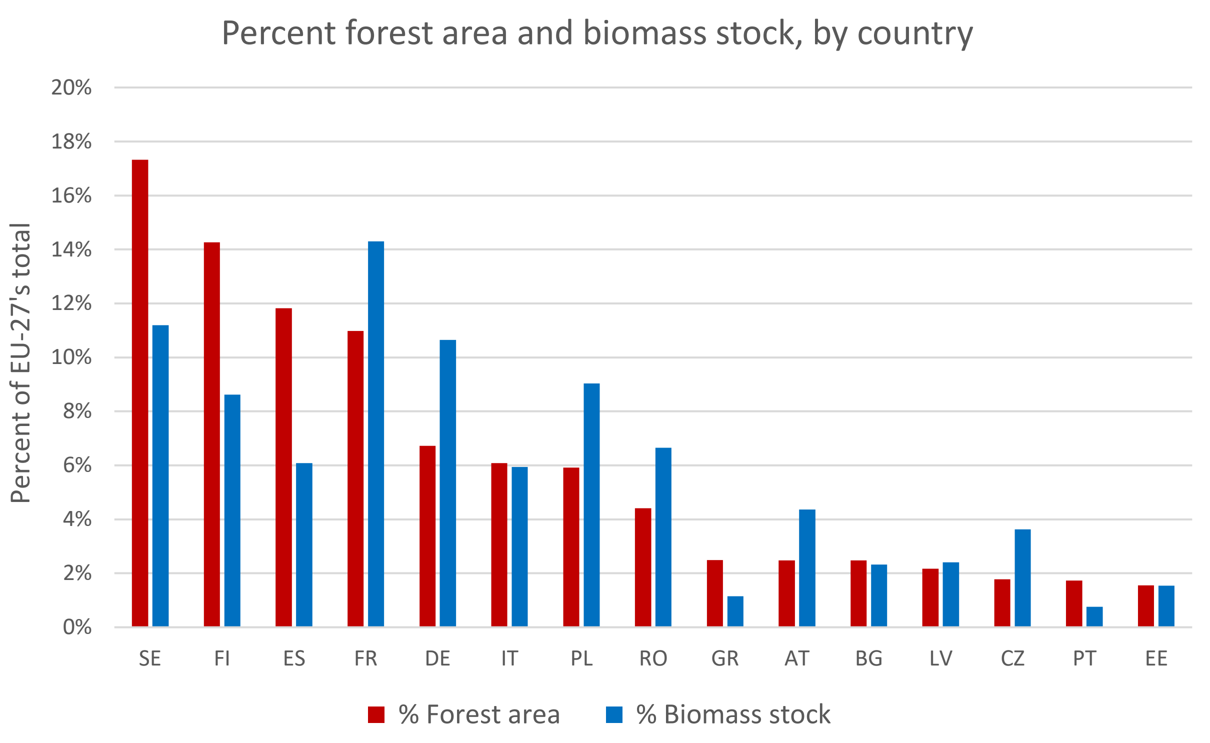
The biomass statistics are also available by tree species for 22 Member States (the EU-27 except EE, GR, LU, MT and SI), which represent 95% of the EU-27 forest area. The species information shows that the biomass stock is almost equally stored between broadleaves (50.7%) and conifers (49.3%). Interestingly, two conifer species alone store almost half of the biomass, namely *Picea sp.* (21.5%) and *Pinus sylvestris* (19.8%), followed by broadleaves as *Fagus sylvatica* (11%), *Quercus robur* (8%), *Betula sp.* (6%) and *Quercus cerris* (4%). *Abies sp.*, *Carpinus sp.*, *Fraxinus sp., Alnus sp.*, *Pinus pinaster*, *Castanea sativa* and *Populus sp.* contributed individually to about 2% of the biomass stock, and all other species for less than 2% (Figure 60).

Table 4: Forest area, biomass stock and biomass density in EU-27 for the year 2020 according to our harmonised reference dataset. The EU regions are defined according to the SoEF 2020 Report and include the corresponding EU countries.

EU regions	**Forest area**	**Biomass stock**	**Biomass density**
	(1,000 ha)	(Mill. tonnes)	(tonnes/ha)
North	58,301	4,740	81.3
Central-west	33,516	5,687	169.7
Central-east	23,350	4,357	186.6
South-west	30,850	2,352	76.2
South-east	11,115	1,262	113.5
EU-27	157,133	18,398	117.1

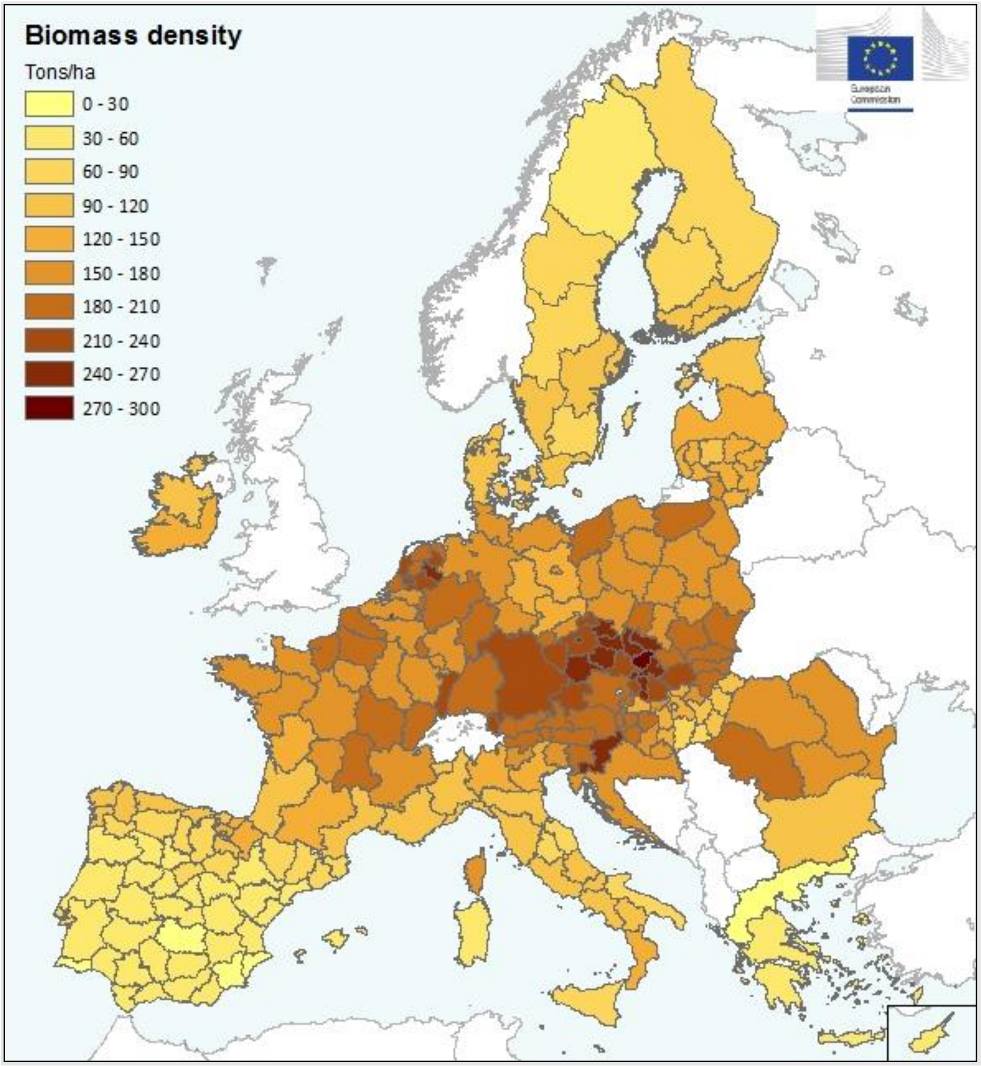
Source: JRC 2022 (own data)

Figure 58. Forest area and biomass stock per country in 2020 as fraction of EU-27's total, ranked by percent of forest area. Only the countries with a forest area larger than 1% of the EU-27 total forest area are represented.



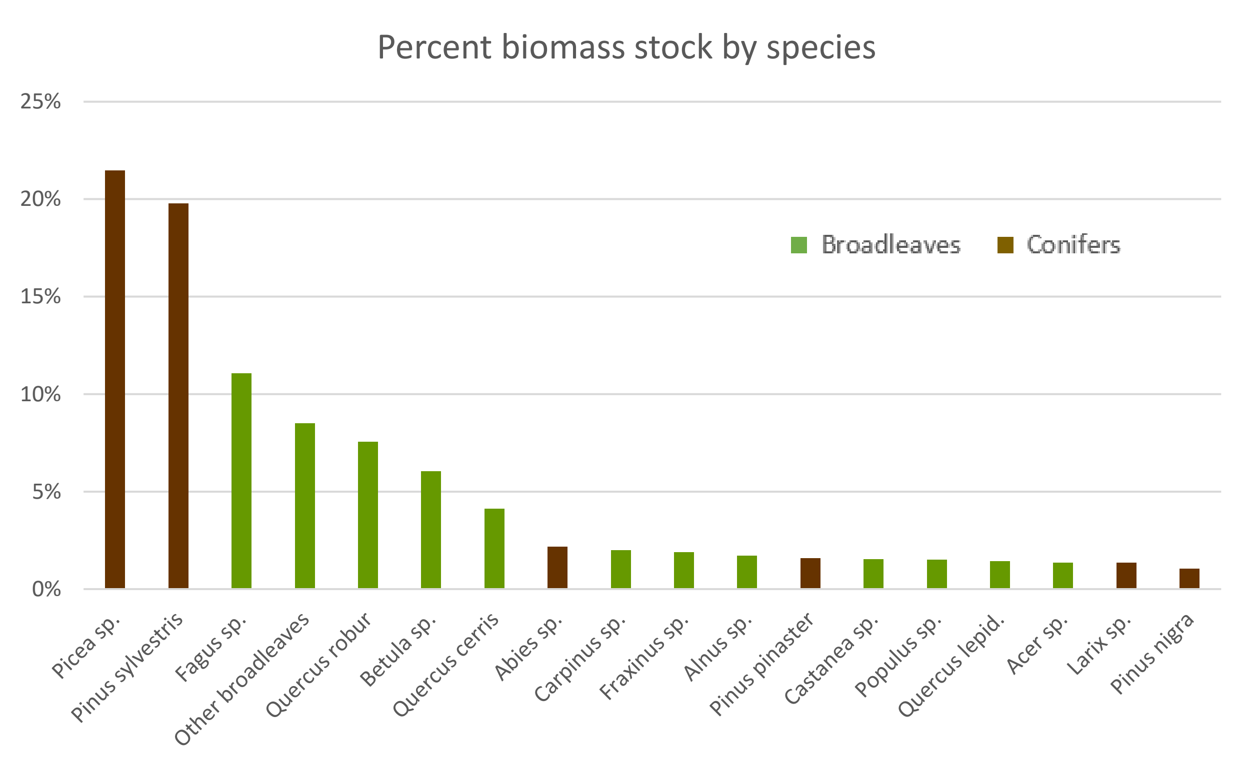
Source: JRC 2022 (own data)

Figure 59: Forest biomass density according to our reference harmonised statistics for the year 2020.



Source: JRC 2022 (own data)

Figure 60: Biomass stock per species as fraction of total value. Conifers are in brown, broadleaves in green. The data refer to 22 EU countries, covering 95% of the EU forest area. For representation purposes, only the species with a biomass stock larger than 1% of the total stock are represented.



Source: JRC 2022 (own data)

6.1.3 Harmonisation approach

6.1.3.1 Biomass definition

The forest biomass data produced by the NFIs are not directly comparable because they refer to different years and employ different definitions regarding the forest area (i.e. which conditions are necessary to classify a land area as forest) and regarding biomass (i.e. which parts of the tree are considered, and the minimum diameter applied). In addition, the NFIs may employ different approaches to estimate the biomass from the tree parameters (i.e. allometric equations or biomass conversion and expansion factors).

For these reasons, during the last years the European forestry community have performed dedicated harmonisation actions focusing on the Growing Stock Volume (GSV) statistics, such as the European Cooperation in Science and Technology (COST) Action E43 (COST Action E43, 2010) and the Distributed, Integrated and Harmonised Forest Information for Bioeconomy Outlooks (DIABOLO) project (DIABOLO, 2015). Such initiatives, funded by the European Union, have established reference definitions and bridging functions for common reporting, and produced harmonised stem volume estimates for Europe (Tomter et al., 2012; Gschwantner et al., 2019).

The JRC has a decadal collaboration with the European Network of Forest Inventory (ENFIN) to develop and apply common definitions and methodologies for the harmonised assessment of forest parameters at European level, as a contribution to the overarching objective to provide decision-makers with processed, quality-checked and policy-relevant forest data. Regarding biomass data, the JRC supported a dedicated effort of 26 European NFI institutions under the coordination of ENFIN to address the differences indicated above and to achieve a better harmonisation of the forest biomass statistics in Europe. The NFIs worked together to identify a harmonised biomass definition and a common estimator, which were applied to the NFI data to obtain biomass estimates referring to the same biomass pool and estimation method for all countries.

The harmonised biomass definition includes all aboveground biomass compartments of the living trees, namely the aboveground part of the stump, the stem from stump to top, dead and living branches, and foliage.

Using the common definition and an ad-hoc estimator (a design-based unbiased estimator called e-Forest) (Lanz, 2012), the NFIs produced harmonised and comparable biomass estimates at national and sub-national levels for 22 EU countries (Henning et al, 2016; Korhonen et al., 2014). The biomass estimates referred to the areas defined as forest according to the FAO FRA reference definition (FAO, 2000), if the countries had sufficient information to apply this definition.

The NFI estimates were derived from a total of about 400,000 field plots located in a forest area of 145 million ha and were provided for species groups (broadleaves and coniferous) and for selected species. The biomass stock of the 22 Member States was 15.7 billion tonnes (108.6 tonnes/ha) using the harmonised definition and 15.0 billion tonnes (103.6 tonnes/ha) using the national definition. Thus, the total forest biomass is 5.3% higher using the harmonised definition compared to the value based on the national definitions. This is because several countries use a national definition that does not include all aboveground biomass compartments, such as leaves or stumps (Avitabile and Camia, 2018), and highlights the impact of different definitions on the estimates of forest biomass.

Specifically, the total biomass using the harmonised definition was significantly higher than the value based on the national definitions for 10 countries (AT, BG, DK, ES, FR, HR, HU, PT, RO, SE), smaller for 3 countries (BE, IE, IT), while no significant difference was found for 9 countries (CY, CZ, DE, FI, LT, LV, NL, PL, SK). Here, significance is assessed with reference to the sampling errors provided with each estimate. The country-specific values are reported in Avitabile et al. (2020).

6.1.3.2 Reference year

Each NFI acquires ground data during different years that do not correspond across countries. Consequently, the biomass statistics mentioned above are not temporally harmonised but range from the year 2001 to 2013. Given the need for updated statistics (i.e. to the year 2020) and considering that the biomass stock may change substantially in a time span of almost 20 years because of forest growth, mortality and harvest as well as changes in forest area (deforestation and afforestation), the biomass statistics were further harmonised to a common reference year (i.e. 2020) by the JRC using the Carbon Budget Model.

6.1.3.2.1 The Carbon Budget Model

The Carbon Budget Model (CBM) is an inventory-based, yield-curve-driven model that simulates the stand- and landscape-level carbon dynamics of all forest carbon pools using information on age structure, management practices, harvest regimes and natural disturbances (Kurz et al., 2009). The model, developed by the Canadian Forest Service, was adapted by the JRC to the specific European conditions and applied to the European Union (EU) countries to estimate the forest carbon dynamics at national and sub-national level (Pilli et al., 2016a, 2016b, 2017). The input data and the modelling framework are currently being updated and revised by the JRC (Blujdea et al., 2022).

The model uses as main input data on area, increment and volume, generally distinguished by age classes and main species, as reported by the NFIs or obtained from other data sources (e.g. forest management plans). The volume and increment data are preliminarily harmonised and then converted to unit of carbon using species-specific allometric equations, which account both for the tree-species wood density and for the different tree's compartments.

The model is calibrated at country level, on annual time steps, on the historical period 2000 - 2015, according to the amount of harvest reported by official statistics (i.e. FAOSTAT) and other data sources, and considering the effect of major natural disturbances that occurred within the same period. The model simulates the dynamic of each carbon pool considering the annual gross growth, as derived from appropriate growth curves inferred from NFI increment data, and the annual losses due to natural mortality, natural disturbances (i.e. fires and windstorms) and forest management practices (i.e. fellings, also due to salvage logging).

The model provides as output the amount of carbon stored within the various pools and transferred between each pool. By reconverting these values to volume data, both the merchantable standing stock volume and the amount of removals and logging residues are estimated. These values are then used to estimate the Net Annual Increment of each time step, as difference between the merchantable volume with bark estimated on two consecutive time steps, plus the removals and logging residues.

6.1.3.2.2 Temporal harmonisation

The CBM was used to quantify the percentage biomass change (gain or loss) between the NFI year and the reference year 2020. Then, the percentage change was applied as a correction factor to the NFI statistics to update them to the reference year. This correction considered only the biomass change due to natural growth, mortality and harvest that occurred on the forest area reported by the NFI in the NFI year. Biomass changes due to changes in the forest area (i.e. afforestation and deforestation) were instead computed as follows.

Firstly, the change in the forest area between the NFI year and the year 2020 was estimated by multiplying the NFI forest area by the forest area change that occurred during this period according to the SoEF time series data on forest area. If the difference between the forest area reported by the NFI and the (closest in time) SoEF Report was < 2%, the difference was considered negligible and due to approximations (e.g., the NFI data are attributed to the NFI reference year but are usually acquired during a longer period). For most countries, the NFI forest area was in line with the area reported in the SoEF and therefore its forest area in the year 2020 corresponds with the value reported in the SoEF. In case of area difference > 2% in the NFI year (9 countries: CZ, DE, HU, IE, PL, PT, SE, SI, SK – with only IE, PT and SK having an area difference > 5%), this difference was considered due to the use of different forest definitions in the NFI and the SoEF. Since the harmonised data at sub-national level provided by the NFIs to the JRC on FAWS, biomass stock and biomass available for wood supply refer to the NFI forest area (and definition), the JRC dataset used the NFI forest area and updated it to the year 2020 considering the area change provided by SoEF.

For example, CZ reports in their NFI for 2003 a forest area of 2.752 Mha while the forest area in SOEF in 2000 and 2005 is 4% lower (2.637 and 2.647 Mha, respectively). The NFI forest area was updated to the year 2020 as follows: CZ reports in SoEF an increase of forest area of 2,000 ha (0.1%) per year between 2000 and 2020, and this annual area change was applied to the NFI forest area in 2003, multiplied by the years (17) between the NFI reference year (2003) and the year 2020.

The NFI data on FAWS/FnAWS area have been updated to the year 2020 using the same approach, while the biomass stock and the biomass available for wood supply have been updated to the year 2020 also considering (a) the biomass stock change on stable forest land, due to natural growth and forest management, estimated by the Carbon Budget Model (CBM), (b) the biomass growth on new forest land using growth rates derived from the CBM, and (c) the biomass loss due to net deforestation reducing the biomass stock according to the forest area loss.

The difference between the NFI and SoEF forest area were assessed for each country by a detailed analysis of the NFI and SoEF Country reports, and are reported in the Annex of this Chapter, after Table A6.1.

Secondly, the corresponding change in the biomass stock was estimated using the CBM. The CBM quantified the biomass gains on the afforestation areas using the growth rate of young forests and the biomass losses on deforestation areas using the biomass density of mature forests. Therefore, the harmonised statistics considered the biomass change related to forest growth, mortality, harvest, afforestation and deforestation.

The net biomass change due to these forest dynamics ranged from 0.1% to 2.7% per year at national level (see Annex of this Chapter for the biomass stock of each country in the NFI year and in the year 2020). When considering the total change between the NFI year (variable by country) and the reference year 2020, the biomass stock increased overall by 10.5% between the NFI years and the year 2020, showing the relevance of the temporal harmonisation to update of the NFI statistics, especially for the countries where the latest NFI was completed several years ago. Most of the biomass increase (9.7%) was due to the forest growth on stable forest land, while only 0.7% of the increase was due to the net biomass change in afforestation and deforestation areas.

6.1.3.2.3 Harmonised biomass statistics

In summary, the statistics were fully harmonised for biomass pool and reference year for 21 Member States representing 95% of the EU-27 forests, for which the NFI statistics were harmonised for biomass definition and the CBM was parametrised (AT, BE, BG, CZ, DE, ES, FI, FR, HR, HU, IE, IT, LT, LV, NL, PL, PT, RO, SE, SI, SK). For the remaining six Member States (CY, DK, EE, GR, LU, MT), the biomass statistics at national scale were taken from the SoEF 2020 Report (FOREST EUROPE, 2020). The SoEF reports biomass in units of carbon stock, which were converted to biomass using 0.5 as carbon fraction for dry biomass (IPCC, 2006). In this way, the biomass stock was directly assessed, for most of Member States, from the harmonised NFI statistics provided from the countries, without any further conversion of volume data to biomass.

Even though the SoEF Report provides time series of forest statistics at national scale for the period 1990 - 2020 and refers to the FAO forest definition, the NFI statistics harmonised for biomass definition and reference year were preferred, when available, for two reasons. Firstly, the harmonised NFI data are available at sub-national level, providing a much higher detail on the spatial distribution of the biomass stocks. Secondly, the SoEF data have a lower level of harmonisation because the harmonisation of definitions and reference year usually is not based on data modelling but rather it is performed either with a linear extrapolation of the NFI data, or using expected values based on expert knowledge (e.g., in national forecasts or outlook studies), or it is not performed and the closest available NFI values are used (the approach used by each country is reported in the SoEF Country Reports).

6.2 Biomass map for 2020

6.2.1 The need for a biomass map matching the reference statistics

Currently, there are several maps providing forest biomass density for Europe published in the scientific literature. These maps were assessed by comparing them with the harmonised NFI statistics and plot data for 2010 in Avitabile et al. (2020). This study showed that in Europe the biomass maps present substantial difference from the reference data at sub-national and, in particular, at pixel level, where the relative error is larger than 50%.

Considering that the added-value of the maps versus the regional statistics lie in their ability to provide accurate spatial estimates at a high and moderate resolution (i.e. at local and sub-national level) to support, e.g., local management or modelling activities, the results suggested the need for an improved product that is in line with the reference data.

The error of a map can be distinguished in two components: the random error and the systematic error (or, bias). In the case of biomass maps, the bias is often due to systematic issues in the calibration data, inaccurate model parameters and in the limited sensitivity of the remote sensing data to biomass variability. Several studies have reported that biomass maps tend to overestimate the stock in areas with low biomass density and underestimate the stock in areas with high biomass density, thus showing that the maps are affected by different systematic errors at different biomass ranges (Avitabile and Camia, 2018; Rejou-Mechain et al., 2019).

While random errors are essentially unavoidable, systematic errors can be corrected using reference data that are obtained from a statistical sample and an unbiased estimator. In this study, the reference biomass statistics for 2020 were used to correct the systematic error of a published biomass map, by removing the systematic under- or over-estimation of the map estimates at the administrative level.

The European Space Agency's (ESA's) Climate Change Initiative (CCI) biomass map for 2018 (Santoro and Cartus, 2021) was selected because, according to the maps assessment presented in Avitabile et al. (2020), the CCI maps achieved good accuracy for Europe and presented spatial and temporal resolutions appropriate for multiple applications. The ESA CCI maps, available for 2010, 2017 and 2018, were derived from a combination of Earth observation data, namely the Copernicus Sentinel-1 mission, Envisat's ASAR instrument and JAXA's Advanced Land Observing Satellite (ALOS-1 and ALOS-2), along with additional information from Earth observation sources.

In this study, the ESA CCI biomass map for 2018 was adjusted to match the reference statistics both in terms of forest area and biomass density, which required to produce a forest mask matching the forest area statistics.

6.2.2 Adjustment of forest area

The reference statistics of biomass density refer to a certain forest area (usually estimated from a sample) and a systematic difference between the statistics and a map may be due to the fact that they refer to different areas. The map assessment performed in Avitabile et al. (2020) showed that, in most cases, the reference statistics had lower biomass density than the ESA CCI biomass map in the administrative units where they represent larger forest area, most likely because the statistics include also sparse forests with low biomass. Conversely, the statistics usually had higher biomass density than the map in the NUTS units where they cover a smaller forest area, most likely because they refer to the most dense and high biomass forests. Hence, the bias correction of a biomass map using reference statistics requires to first match their forest area.

Here, the ESA CCI biomass map, provided without a forest mask, was masked using an adjusted version of the Copernicus 2018 Forest Type map. The Copernicus map was selected because it presents a good match with the statistics of forest area and is compatible with the spatial and temporal resolutions of the ESA CCI biomass map.

The Copernicus Forest Type map was first converted to a forest mask aggregating the forest classes to map only forest and non-forest areas. Then this forest mask was adjusted to match the forest area reported by the statistics using, as additional information, the Copernicus 2018 Tree Cover Density map as follows. When the statistics reported smaller forest area than the forest mask, the forest areas in the mask with lower tree cover were converted to non-forest, until the mask matches the statistics. When the statistics reported larger forest area than the forest mask, the forest areas in the mask with higher tree cover but located outside forest and outside areas with tree cover in urban and agricultural context were converted to forest.

Usually, the forest mask was expanded around the forest edges with high tree cover that were not included in the forest map because of edge effect (geolocation mismatches), and then in forest areas with lower tree cover. The resulting forest mask was applied to the ESA CCI biomass map. The map of the adjustment of forest area is here:

https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/BIOMASS/SUSBIOM/LATEST/Forest , with metadata: https://data.jrc.ec.europa.eu/dataset/35fb1231-849b-4017-89d8-9cadbaf9d555

6.2.3 Bias correction

The ESA CCI biomass map, matched for forest area with the reference data, was then corrected by removing the systematic difference (i.e. the bias) with respect to the biomass density reported by the reference statistics. The bias was removed using a correction factor, computed as ratio between the biomass density of the reference statistics (AGB^{Ref}) and the mean biomass density of the biomass map (AGB^{Map}) over the same area represented by the reference statistics.

The correction factor was computed at the spatial scale of the reference data, and then removed from the biomass map at pixel level. The correction occurs by multiplying the biomass density of each pixel (i) of the map by the correction factor, to match the reference statistics for each spatial unit (k):

$$\text{Map Corrected} = AGB^{Map}_{(i)} \times (AGB^{Ref}_{(k)} / AGB^{Map}_{(k)})$$

This approach, presented in Avitabile et al. (2020), was further improved by introducing an additional correction when the biomass map presents no biomass while the Copernicus Forest Type and Tree Cover maps indicate the presence of forest with substantial tree cover. In a bias-correction approach, the presence of large forest areas with zero biomass is compensated by higher correction factors, causing overestimates in the output map. To avoid such artifacts, the biomass map was corrected using information derived from the tree cover density.

Tree cover is spatially correlated with biomass density and, even if this relation varies with the forest type and saturates with canopy closure, it may be relatively strong during the initial phases of forest development and it has been used at national (Du et al., 2014) and regional level (Bhan et al., 2021). In this study, the relation between tree cover and biomass was estimated from the CCI and Copernicus maps using linear models for the forest areas of the central Iberian Peninsula, excluding the areas with trees outside forest (e.g. plantations, urban areas, agricultural land). This relation was then applied to correct the biomass map in the forest areas where it estimated zero biomass, and located in the same region where the model was calibrated. The corrected biomass map was then used to quantify and remove the bias at sub-national level as indicated above.

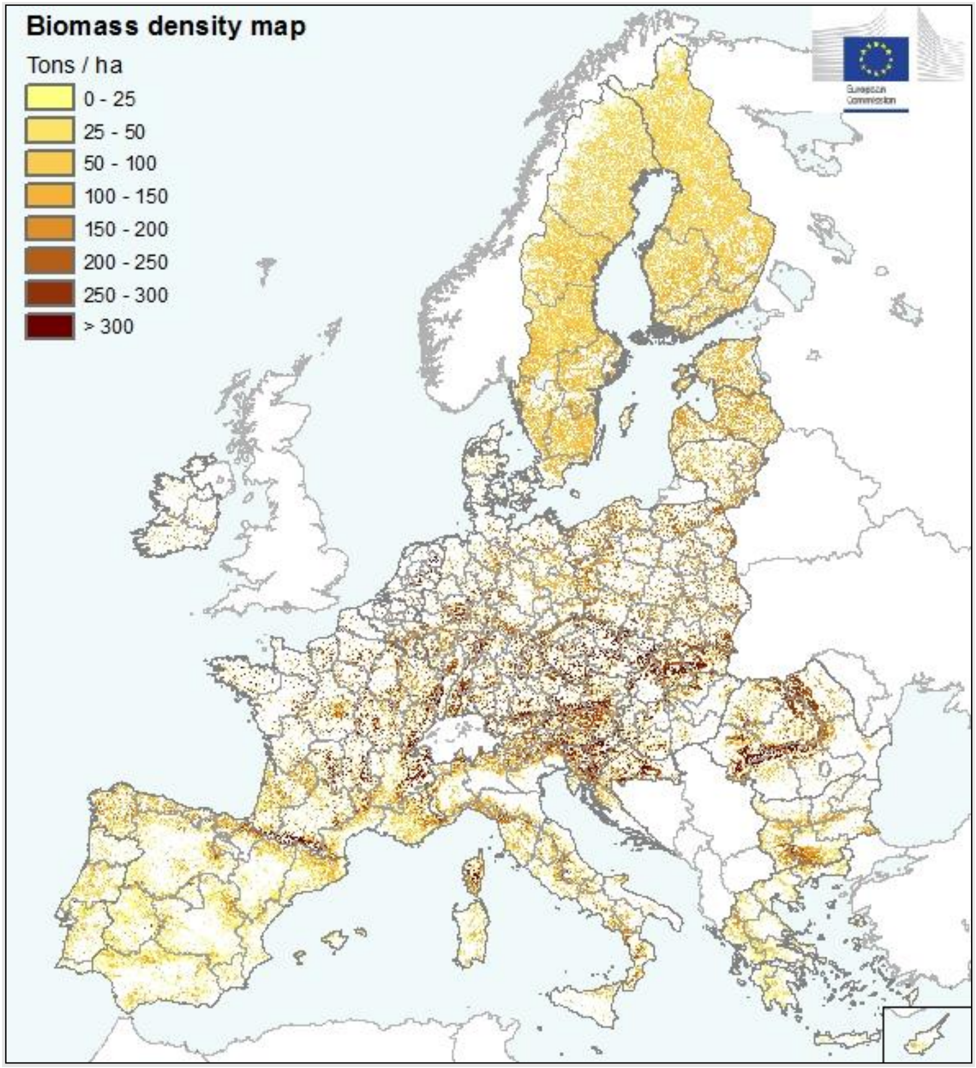
6.2.4 The harmonised biomass map

The result of the bias correction of the ESA CCI map is a biomass map of Europe at 100 m spatial resolution that matches the harmonised reference statistics for the year 2020 (described in section 6.1.3 and 6.1.3.2) in terms of forest area and biomass density at the administrative level of the statistics (Figure 61). The forest biomass map is described in the JRC-FOREST collection of the JRC Data Catalogue https://data.jrc.ec.europa.eu/dataset/35fb1231-849b-4017-89d8-9cadbaf9d555 and is available at https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/BIOMASS/SUSBIOM/LATEST/Biomass/

The methodology used to produce this map assures that the map presents the same total amounts and major spatial patterns of the forest biomass provided by the statistics. Compared to the original map, the harmonised biomass presents lower biomass in Scandinavia, Balkan region and Greece, it has higher biomass in Spain and along the Atlantic coast and remained relatively stable in central Europe and Italy.

Compared to the reference statistics, the map presents the added value of describing the fine-scale local biomass variability and it can be integrated with other spatial data to derive novel information. For example, in section 6.3 we integrate this biomass map with the map of the forest areas available for wood supply to estimate the current supply of biomass resources from European forests. Moreover, the biomass map can be used for multiple management and modelling purposes, from quantifying the harvesting cost to supporting the estimation of the GHG fluxes from the forest sector. Any use of this map shall take into account that the bias adjustment can only correct systematic differences with the reference data, but the random errors remain and affect the map accuracy at local and pixel level.

Figure 61: Map of forest biomass density (tonnes/ha) matching the harmonised reference statistics for 2020.



Source: JRC 2022 (own data)

Box 1: Mapping biomass from remote sensing

Satellite and airborne data can integrate and support ground-based forest inventory data with wall-to-wall forest monitoring over large areas and are being increasingly used in the NFI systems mostly to assess forest area and forest area change. Instead, satellite data are not yet commonly used for the country estimates of forest biomass because, until recently, the sensors had limited sensitivity to biomass variations, and the biomass maps achieved only moderate accuracy at local scale in Europe (Goetz et al., 2015; Avitabile and Camia, 2018).

However, the field of biomass mapping from space has evolved rapidly in the last years thanks to new satellite missions and advanced modelling approaches. For example, the ESA CCI Biomass map achieved good accuracy at sub-national scale in Europe thanks to the combined use of data from multiple sensors (optical, radar and lidar) and their careful calibration with various NFI data. This project has also produced global biomass maps for 2010 and 2018 in a consistent way to directly estimate the biomass change at high spatial resolution, which can support the carbon cycle and climate modelling (Santoro and Cartus, 2021).

Moreover, the NASA Global Ecosystem Dynamics Investigation (GEDI) mission has recently deployed in space the first high resolution lidar sensor. This sensor acquires precise measurements of the forest vertical structure with a dense sampling scheme and the derived data, released recently, have improved substantially the knowledge of the spatial distribution of forest biomass at global scale (Dubayah et al., 2022).

In addition, two satellite missions planned for launch in the coming years will provide new data for biomass mapping: the ESA BIOMASS mission will bring in space for the first time a P-band radar sensor operating at longer wavelengths that have an enhanced sensitivity to forest biomass with no saturation effects in dense forests, and the NASA-ISRO SAR (NISAR) mission will provide data with higher spatial and temporal resolutions particularly useful for mapping low-biomass forests and their dynamics.

However, due to the orbit characteristics, the GEDI sensor is not able to acquire data on northern Europe (above 51.6° N), while international restrictions will impede the BIOMASS satellite to operate over Europe, suggesting the need for Europe to develop an integrated forest monitoring system using the wide variety of new-generation sensors from space, air and ground.

Besides better satellites, new remote sensing technologies such as airborne and terrestrial lidar are highly promising for the acquisition of high-quality biomass reference data from local to sub-national scale (Morton et al., 2016). Compared to the spaceborne lidar, the airborne lidar has a much higher point density that provides a detailed analysis of the forest vertical structure that is highly correlated with biomass density (Asner et al., 2014) and, thanks to its good balance between accuracy, coverage and cost, it is already used by some European NFIs for the detailed monitoring of forest properties in targeted areas and to improve the national estimates.

In turn, the terrestrial lidar acquires detailed three-dimensional measurements of the forest canopy from the ground from which tree biomass can be estimated at local scale with very high accuracy, comparable to that of destructive measurements (Disney, 2019; Calders et al., 2015). The terrestrial lidar can also be used to construct new allometric models to better estimate tree biomass using the plant parameters usually acquired in the traditional field plots (Réjou-Méchain et al., 2017).

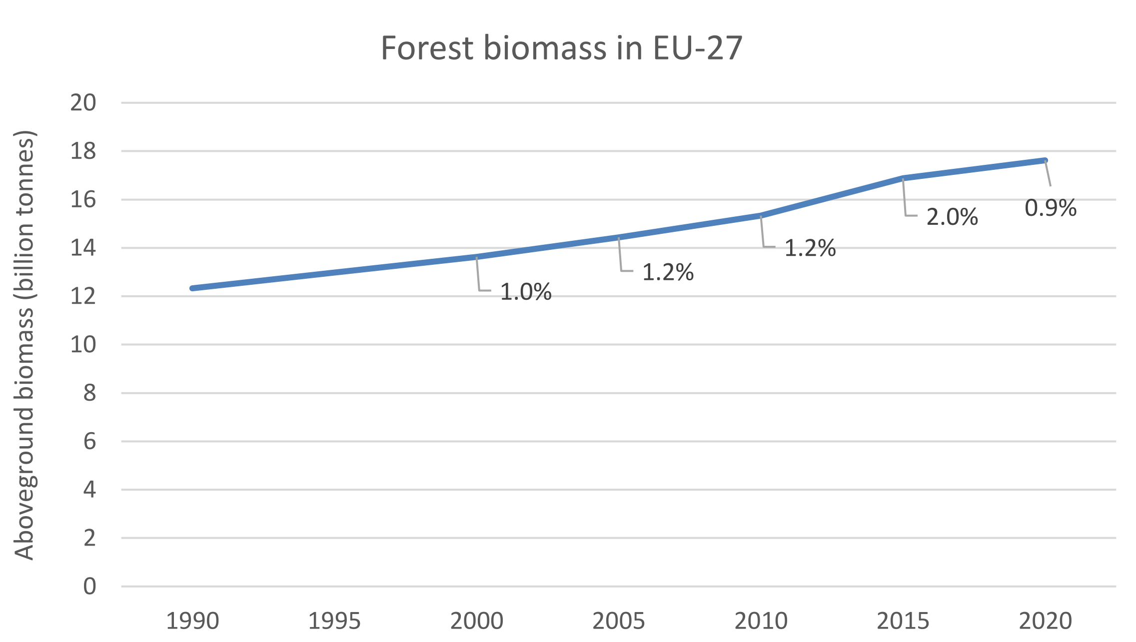
In conclusion, thanks to the latest and upcoming satellite sensors and as the new airborne and terrestrial technologies are rapidly maturing and becoming operative, it is expected that monitoring forest biomass using remote sensing data will improve considerably in the near future.

6.2.5 Trend of biomass stock

The evolution of the forest biomass in the EU is assessed using the national statistics provided by the SoEF for the period 1990 – 2020 (FOREST EUROPE, 2020). The SoEF reports time-series data on forest aboveground carbon stock at national scale. The carbon stock was converted to biomass using the default conversion factor of 0.47. Six EU countries presented some missing values in the time series, which were filled using the linear extrapolation of the values available in the time series.

This time series shows that the biomass stock of EU-27 has always increased during the period 1990 – 2020. However, the annual percent growth has recently changed trend, as it increased from 1% to 2% during the period 1990 – 2015 and then decreased to only 0.9% during the last 5-year period (Figure 62). A similar trend is observed also regarding the forest area, and it suggests that, according to the national statistics, the growth of European forests is slowing down. Considering that the SoEF data are usually derived from extrapolation of the NFI data that are often not very recent, this trend is further assessed in this chapter considering the increment and removal data obtained also from other sources to better understand the latest and upcoming changes that are occurring in the European forests.

Figure 62: Development of the forest aboveground biomass stock of EU-27 during the period 1990 – 2020 according to the SoEF 2020 data. The percentage values represent the annual change rate compared to the previous reporting period. There is no reporting for the year 1995.



Source: JRC 2022 (own data)

6.3 Biomass available for wood supply

6.3.1 Summary in numbers: key indicators

Our reference database shows that 89% of the forest area and 92% of the biomass stock of EU-27 is available for wood supply. In most countries, the Forest Available for Wood Supply (FAWS) is larger than 85% both in terms of area and biomass, but it tends to decrease in very hot or cold climate. The countries with the largest extents of forest not available for wood supply are located in the northern (SE, FI) and southern (IT, PT) Europe. The countries with the largest amount of FAWS area (ES, FI, SE) not always coincide with the countries with the largest amount of biomass available because of their low biomass density (< 80 tonnes/ha).

Overall, the economic restrictions were responsible for 60% of the forest not available in terms of area but only 42% in terms of biomass, as they affected forests often characterised by low productivity and hence low biomass stock. Instead, the environmental restrictions were responsible for 35% of the forest not available in terms of area but 47% in terms of biomass, because they included protected areas with old-growth forests characterised by high biomass density. The social restrictions played a smaller but not negligible role, being responsible for 5% of the forest not available in terms of area and 11% in terms of biomass, mostly because of the recreational use of the forest or other intangible goods and services.

The FAWS area and biomass are also mapped at 1 ha resolution using spatial information of the main restrictions to wood availability (high slope, high altitude, protected areas, protected species, poor accessibility and low productivity). The FAWS maps use consistent definitions and approach and can be integrated with the national statistics to obtain a more accurate depiction of the FAWS areas in Europe.

The temporal evolution of the forest area, assessed using SoEF data, indicates that the EU forests have expanded during the period 1990 – 2020 but their growth rate has declined steadily, and that the FAWS area has become stable since 2005, suggesting that the recent forest expansion either did not occur on areas available for wood supply, or that there has been an expansion of the restrictions (economic, environmental or social) on existing forest land.

6.3.2 Reference statistics 2020

Knowledge of the amount and spatial distribution of the FAWS is key to assessing the woody biomass potentially available in European forests and more generally the state of forest resources. For this reason, reporting on FAWS has been included in the Sustainable Development Goals (SDGs) of the UN 2030 Agenda for Sustainable Development (Sachs, 2012) and in the criteria and indicators for sustainable forest management of the SoEF Reports (FOREST EUROPE, 2020).

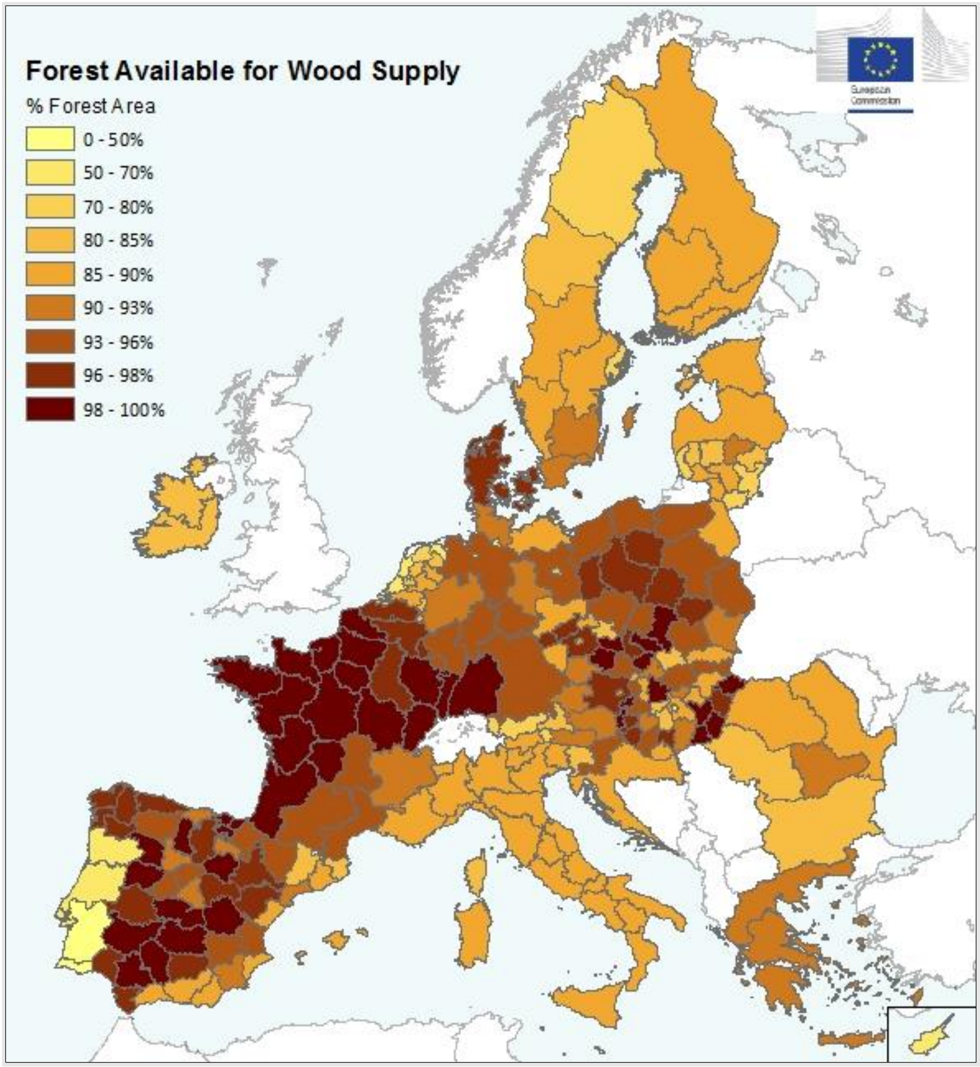
The FAWS dataset presented here for the EU is a compilation of the best data currently available. For 16 EU countries, NFI data on forest area and biomass available for wood supply at sub-national scale were harmonised using a common definition and methodology by the NFIs and were updated to a common reference year (2020) by the JRC (see section 6.3.3). For the remaining 11 EU countries, the FAWS data were derived from the SoEF 2020 (FOREST EUROPE, 2020). In addition, the limitations on wood supply were analyzed to quantify the impact of each restriction on the availability of forest area and biomass stock (section 6.3.4).

Updated and comparable statistics on FAWS are an essential component to better understand and model the factors limiting the forest availability for wood supply in Europe and the potential biomass available in the future. In particular, our dataset provides harmonised data on FAWS for 239 administrative areas, providing a much higher spatial detail of the distribution of the FAWS area, stock and related restrictions compared to the data available only at national scale from international reporting (e.g., FAO, SoEF). This spatial information is key to quantify the factors limiting the wood availability at local level, to support and guide the mapping of FAWS using remote sensing data, and to model the wood resources available at a fine spatial resolution.

Overall, our reference database shows that, in total, 89% of the forest area and 92% of the biomass stock of EU-27 is available for wood supply. In most countries, the FAWS is larger than 85% in terms of both, area and biomass, with values slightly lower (76% – 84%) in BG, IE, LT, NL and SE, but it tends to decrease in very hot or cold climate, reaching less than 60% in PT and CY. In absolute terms, the countries with the largest extents of forest not available for wood supply (i.e. more than 1 million ha) are located in the northern (SE, FI) and southern (IT, PT) Europe (Figure 63).

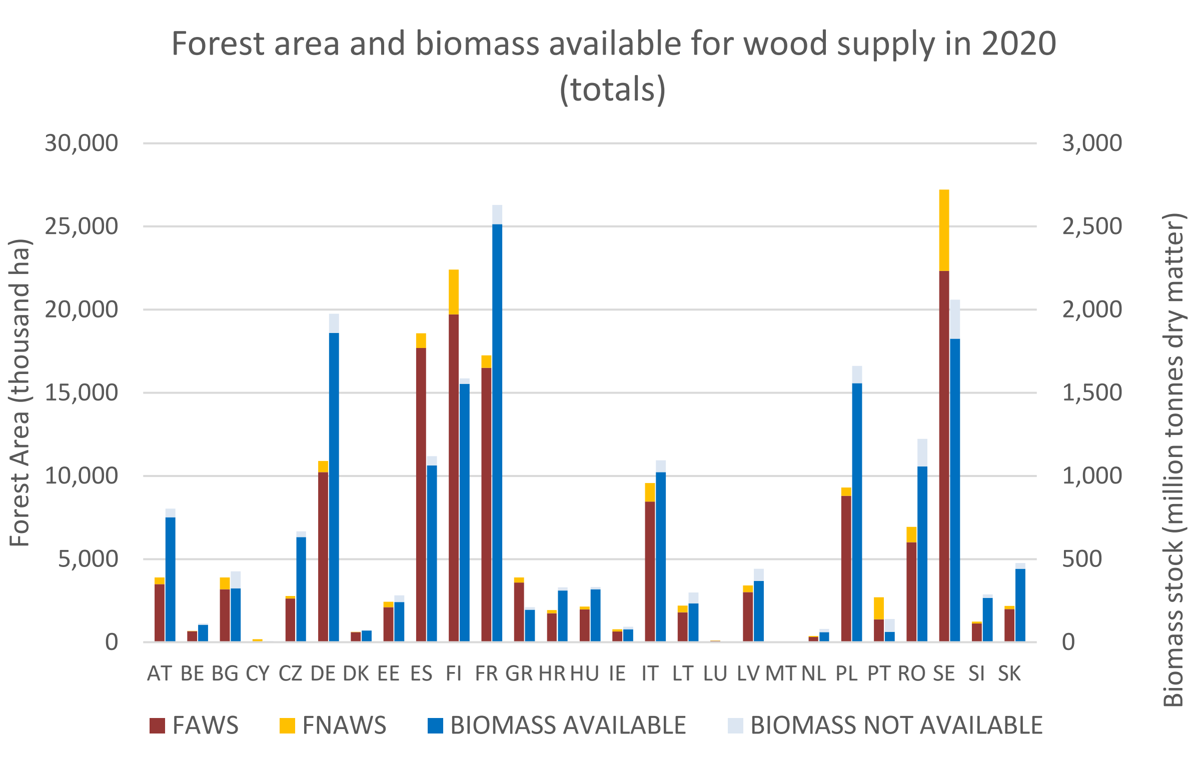
The countries with the largest amount of FAWS (i.e. above 8% of the EU-27's total) in terms of area (ES, FI, FR, SE) not always coincide with the countries with the largest amount of biomass available (DE, FI, FR, PL, SE), with ES and FI presenting large areas available for wood supply with a low biomass density (< 80 tonnes/ha) and, conversely, DE and PL presenting substantial extents of forests with high biomass density (approx. 180 tonnes/ha) (Figure 64 and Figure 65).

Figure 63. Percent of forest area available for wood supply according to our reference harmonised statistics for the year 2020.



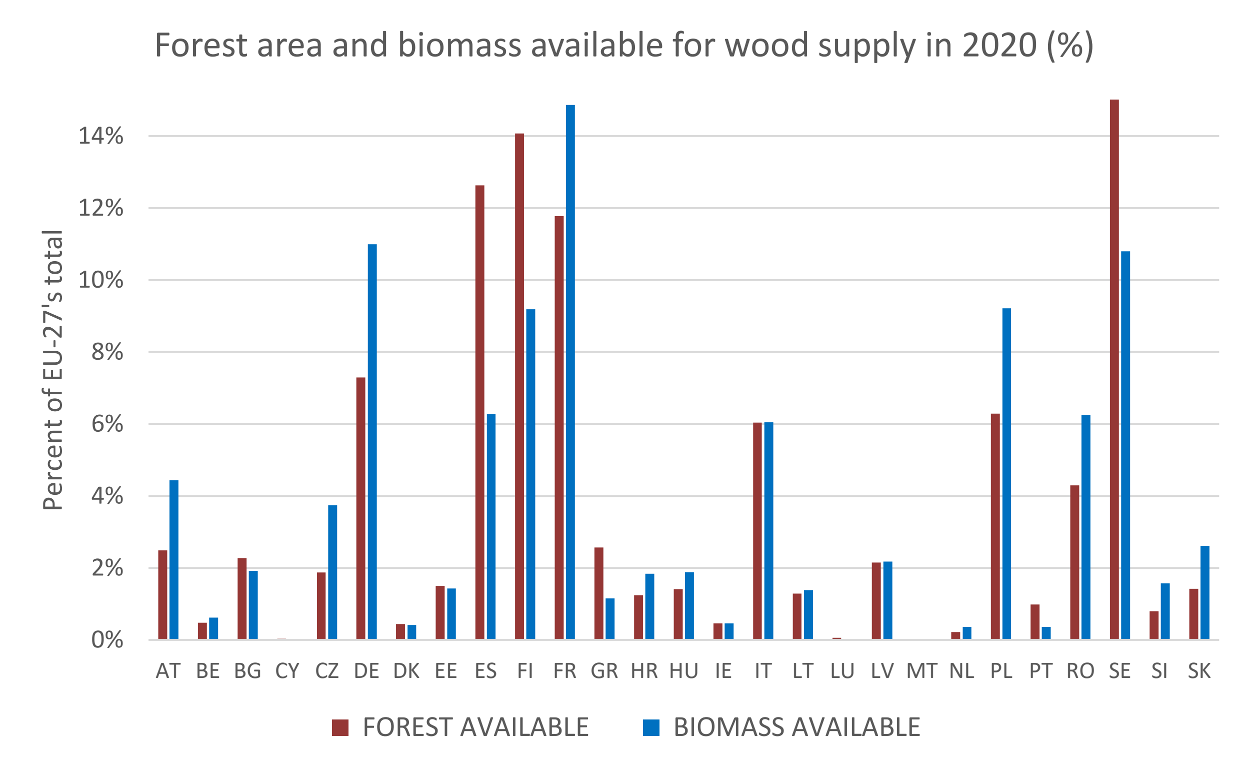
Source: JRC 2022 (own data)

Figure 64. Forest area (left axis) and biomass stock (right axis) available and not available for wood supply in 2020, by country.



Source: JRC 2022 (own data)

Figure 65. Forest area and biomass available for wood supply in 2020, by country, as percentage of EU-27's totals.



Source: JRC 2022 (own data)

6.3.3 Harmonisation approach

6.3.3.1 Harmonised definition

The reference definition for international reporting of FAWS, used also in the SoEF, is based on the FAO (2000) definition and agreed upon under the framework of the COST Action FP1001 (COST 4137/10, 2010). This definition identifies FAWS as "*forests where there are no environmental, social or economic restrictions that could have a significant impact on the current or potential supply of wood*" (Alberdi et al., 2016).

However, the different interpretation of the reference definition or the use of different restrictions and related thresholds by each country caused the FAWS estimates in the international reporting to be, in practice, of limited comparability (Alberdi et al., 2016; Fischer et al., 2016). Moreover, such FAWS data are limited to summary statistics at national scale, while more detailed spatial information is needed to better assess and model the potential supply, and related costs, of woody biomass from the European forests.

Given these limitations, the JRC supported a dedicated effort of 22 European NFI institutions under the coordination of ENFIN to assess, in a harmonised approach, the main restrictions to wood availability and quantify the forest area and biomass stock not available for wood supply (Alberdi et al., 2017, 2019). Namely, the 22 countries participating in the methodological analysis were AT, BG, CH, CZ, DE, DK, ES, FR, HU, IE, IS, IT, LT, LV, NL, NO, PL, PT, RO, SE, SK, SI. The area and biomass not available for wood supply were then estimated for 20 countries, i.e. all participating countries besides FR and DK.

The consortium, according to the reference definition on FAWS, identified and agreed upon a reference definition for the Forest Not Available for Wood Supply (FNAWS), which was accompanied by an explanation of the key terms, a harmonised list of restrictions to wood supply, and the comparison of the national and harmonised definitions (Alberdi et al., 2020). The FNAWS are defined as "*Forests where there are environmental, social or economic* *restrictions that have a significant impact on the current or potential supply of wood. These restrictions can be based on legal acts, management decisions or other reasons*".

The restrictions to wood availability are further defined as follows: *"The environmental restrictions should consider protected areas, protected habitats or species, and also those protective forests meeting the above requirements. Age or diameter class restriction should not be taken into account (except in the case of protected ancient forest). The social restrictions include restrictions to protect aesthetic, historical, cultural, spiritual, or recreational values, areas where the owner has made the decision to cease wood harvesting in order to focus on other goods and services (e.g. leisure, landscape, aesthetic value). The economic restrictions are considered as those affecting the economic value of wood utilization (profitability). These include accessibility, slope and soil condition. Short-term market fluctuations should not be considered.*"

The FNAWS area and biomass were quantified using the NFI plot data and a common estimator at national and sub-national level, applying both the national and the reference definitions. The differences between FAWS estimates based on national and harmonised definitions were small, suggesting that the harmonised definition was appropriate. The results are based on the same methodology and data used for the calculation of the harmonised biomass stock, making the statistics on total standing forest biomass and the fraction available for wood supply directly comparable. Then, the harmonised FAWS area and biomass were obtained by the JRC subtracting the total area and biomass to the FNAWS area and biomass, at the respective administrative unit.

6.3.3.2 Reference year

The FAWS data, similarly to the biomass stock, are derived from NFI ground data acquired during different years that do not correspond across countries. In particular, the FAWS statistics harmonised for reference definition produced by the NFIs are not temporally harmonised but range from 2002 to 2014. In order to obtain statistics that are updated and compatible with biomass statistics, the FAWS statistics were further harmonised to a common reference year (i.e. 2020) by the JRC using the linear adjustment factors.

The FAWS area was updated considering the forest area change using a linear adjustment factor, namely by multiplying the FAWS reported for the NFI year by the ratio between the SoEF forest area in 2020 and the forest area in the NFI year. Similarly, the biomass stock available for wood supply for the year 2020 was computed by multiplying the stock available for wood supply provided by the NFI in their reference year to the ratio between the total stock in 2020 estimated by the JRC (see section 6.2) and the total stock reported by the NFI in their reference year. In other words, if the total national forest area (or biomass) increased by, e.g. 2% between the NFI year and the year 2020, the harmonised FAWS area (or biomass) was increased by the same amount.

In summary, the FAWS area and biomass statistics were fully harmonised for reference definition and reference year for 16 EU countries representing 54% of the EU forests area (AT, BG, CZ, DE, ES, HU, IE, LT, LV, NL, PL, PT, RO, SE, SI, SK). For the remaining 11 countries, the FAWS area and biomass statistics were obtained from the SoEF 2020 Report at national scale (FOREST EUROPE, 2020). Since the SoEF reports the wood available only in units of Growing Stock Volume (GSV), the biomass available for wood supply was derived multiplying the total biomass stock by the ratio between the GSV available for wood supply and the total GSV.

As for the biomass stock, the harmonised NFI FAWS statistics presented here, when available, were preferred to the SoEF data for three reasons. Firstly, the harmonised FAWS data are available at sub-national level, providing a much higher detail on the spatial distribution of the forest area and biomass stock available for wood supply. Secondly, the SoEF Report provides time-series of FAWS statistics at national scale for the period 1990 - 2020 in terms of area and growing stock but information on biomass or carbon stock are missing. Thirdly, the harmoniszation of definitions and reference year of the SoEF data is highly variable according to the country, and it is usually performed either with a linear extrapolation of the NFI data, or using expected values based on expert knowledge, or simply using the closest available NFI values.

6.3.4 Restrictions on biomass availability

The limitations to the availability of forest for wood supply, reported in this section, were assessed by the 20 countries that participated in the harmonisation of the reference definition. These countries used a common list of restrictions that allowed to quantify, in a consistent way, the impact of each restriction at regional, national and sub-national level. Here, based on Avitabile et al. (2020), we report the aggregated result for the 20 countries involved in the study, but it should be noted that the results are not harmonised for reference year and that the impact of the restrictions to the availability of forest area and biomass varied largely across the countries. A detailed analysis of the results for a subset (13) of countries is reported by Alberdi et al. (2020).

Overall, the economic restrictions were responsible for 60% of the forest not available in terms of area but only 42% in terms of biomass, as they affected forests often characterised by low productivity and hence low biomass stock. Instead, the environmental restrictions were responsible for 35% of the forest not available in terms of area but 47% in terms of biomass, because they included protected areas with old-growth forests characterised by high biomass density. The social restrictions played a smaller but not negligible role, being responsible for 5% of the forest not available in terms of area and 11% in terms of biomass (Figure 66).

Among the economic restrictions, the low profitability was the main factor limiting the use of the forest, causing 40% of the area (18% of the biomass) being not available for wood supply, which was mostly located in the low-productive Scandinavian forests. The low accessibility to the forests was responsible for 10% of the area (10% of biomass) to be unavailable, mostly related to the excessive distance from forestry roads. Similarly, the excessive slope of the terrain caused 10% of the area and 13% of the biomass to be not available for wood supply.

Among the environmental restrictions, the protected areas, habitats and species all together accounted for 28% of the area and 37% of the biomass not available for wood supply, with the protected areas being the main category (18% of the area and 26% of biomass) followed by protected habitats, mostly represented by the Natura 2000 network, and the protected species, mostly due to oak trees in the Iberian Peninsula and Pinus mugo in the Alps. The protective forests, including the forests for soil protection and water regulation, were responsible for 7% of the area and 10% of the biomass not available for wood supply.

Among the social restrictions, the main limiting factor was the use of forest for intangible goods and services, mostly for recreational purposes and to a lesser extent for cultural and spiritual sites. The use of the forests for physical goods and services, such as forestry nursery, game enclosures and power lines, affected a smaller area. However, the specific social restriction was not reported for 37% of the area, where the forest was generically used for non-harvesting goods and services.

Figure 66. Percentage contribution of each restriction to the forest available for wood supply in terms of area (left bars with light colors) and biomass (right bars with dark colors). The restrictions are divided into three main categories: economic (red), environmental (green) and social (orange) restrictions. The results refer to 20 countries indicated in the text and were harmonised in terms of definitions (i.e. using a common list of restrictions).

Source: JRC 2022 (own data)

6.3.5 Mapping biomass available for wood supply

6.3.5.1 How to map the FAWS?

The map of the forest area available for wood supply (henceforth called the FAWS area map) was produced using the reference statistics on FAWS presented above (section 6.3), the forest map matching the reference data on total forest area, and six maps representing the main restrictions to wood availability. Then, the FAWS area map was applied as mask to the harmonised biomass map (section 6.2.4) to obtain the map of biomass available for wood supply (henceforth called the FAWS biomass map, available here (https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/BIOMASS/SUSBIOM/LATEST/BAWS/ with metadata here: https://data.jrc.ec.europa.eu/dataset/5258cc23-7c0a-4462-af65-04500e2f0d48). The maps were produced using the reference data at national scale and were then compared with the reference statistics at sub-national scale (where available) to assess the ability of the maps to depict the spatial distribution of the biomass availability at local scale.

The reference data to calibrate the FAWS area map were the harmonised information on the restrictions to wood availability provided by the NFIs for 16 countries, which quantified the FNAWS for each restriction. These reference area statistics were mapped using maps of the restrictions to wood availability. Even though not all restrictions to wood availability can be mapped (e.g. there are no spatial information on the forest used for recreational, cultural or other non-harvesting purposes or for protective forests against erosion or wind), we produced six maps that capture the main limitations to wood availability. Namely, the maps identified the forest areas not available due to: high slope, high altitude, protected areas, protected species, poor accessibility and low productivity.

The spatial distribution of these restrictions was obtained as follows. The forest areas located on too steep slopes or above the maximum altitude were identified using the European Digital Elevation Model (EU-DEM). The protected areas were defined as the areas classified as IUCN I and/or II category and were mapped using the World Database on Protected Areas (WDPA). The protected species were mapped as the areas classified as the appropriate forest type (Broadleaf or Coniferous) according to the Copernicus Forest Type map and with probability of species occurrence > 5% according to the JRC European Atlas of Forest Tree Species. The protected species were *Quercus suber* and *Quercus ilex*, protected by law in Portugal, and *Pinus mugo*, which however was already included in the altitude restriction because located in areas above the maximum altitude. The forests with poor accessibility were identified according to their distance to paved and unpaved roads, which were mapped using the Open Street Map database. The forest areas with low productivity were identified using the kernel Normalized Difference Vegetation Index (kNDVI), a vegetation index highly correlated to the vegetation Gross Primary Production, which was computed using the MODIS NDVI data.

For each restriction, the threshold that defines the areas not available for wood supply was set separately for each country to consider the differences in forest management and legislation. The threshold was usually identified as the value that maps the area indicated by the reference statistics as not available. When the reference data do not provide information on the restriction to wood availability (i.e. when the FAWS area is derived from the SoEF), the thresholds are set using the values from the neighboring country (or the average of neighboring countries) that have similar ecological conditions.

The country-specific thresholds are relatively constant for altitude and productivity, because usually the forests are not available for wood supply above 2,000 m or with a productivity below 1 - 2 m^3 ha^{-1} $year^{-1}$. Similarly, the protected forests usually include the IUCN category I and/or II. Instead, the thresholds for other restrictions may vary substantially by country. For example, the maximum slope that allows harvesting can vary from 20-25 degrees in Mediterranean countries to 40-45 degrees in mountainous countries, or the maximum distance to roads may range from 500 m to 3,000 m, according to the timber value and the technological capacities of the harvesting systems.

6.3.5.2 FAWS map for EU-27 in 2020

The area available for wood supply in Europe is 89% of the total forest area according to the reference statistics and 87% according to the FAWS area map. In terms of biomass, the stock that is available for wood supply is 92% of the total standing stock according to the reference statistics and 88% according to the FAWS biomass map. Therefore, the FAWS maps based on the six main restrictions captured most of the limitations to wood availability. The FAWS maps are available in the JRC-FOREST collection of the JRC Data Catalogue (Figure 67 and https://data.jrc.ec.europa.eu/dataset/768d2620-1619-4953-8c7d-42511a43ff8a and https://jeodpp.jrc.ec.europa.eu/ftp/jrc-opendata/FOREST/BIOMASS/SUSBIOM/LATEST/FAWS/.

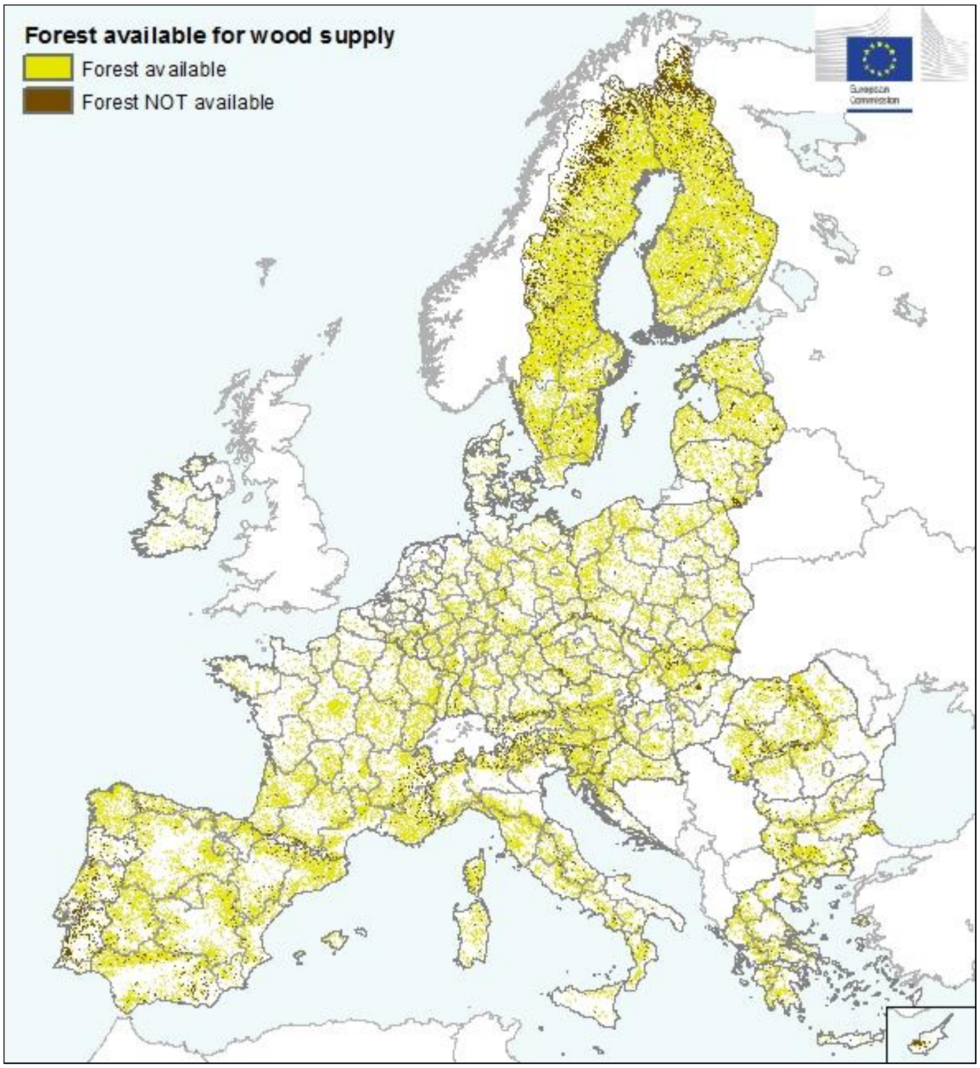
The added value of the FAWS maps over the reference data is that they depict the spatial distribution of the area and biomass not available for wood supply. According to the maps, most of the biomass not available for wood supply is located in PT (protected species), ES (protection forests), on the Alps (steep slopes and high altitude), and in northern Scandinavia (low productivity).

As mentioned above, the FAWS/FNAWS maps did not match exactly the reference data at national level because not all restrictions to wood availability could be mapped. According to the data reported by 20 countries (see section 6.3.3), the six restrictions considered in the FAWS maps cover 82% of the forest area not available for wood supply and 71% of the corresponding biomass.

However, some restrictions that cannot be mapped tend to overlap (i.e. occur on the same area) with others that can be mapped, such as protection forests to prevent erosion that are usually located on steep slopes. Moreover, the FAWS maps identified six restrictions that limit the wood availability in all countries but, in some cases, the reference statistics did not include such restrictions in their reporting, probably due to a lack of data. For these reasons, the FAWS maps identified a percentage of the area and biomass not available for wood supply comparable with the values reported by the reference values, and the two datasets should be integrated to obtain a more accurate depiction of the FAWS in Europe.

The FAWS maps, besides matching relatively well with the reference statistics, use consistent definitions and approach, resulting in consistent maps across Europe of these parameters. Still, each country has specific circumstances that cannot be accommodated in an EU-wide map, and the FAWS maps can certainly be refined and improved at national scale using country-specific maps of restrictions that are either not available at EU scale or that are spatially and thematically more detailed.

Figure 67. Map of forest area available and not available for wood supply in 2020.



Source: JRC 2022 (own data)

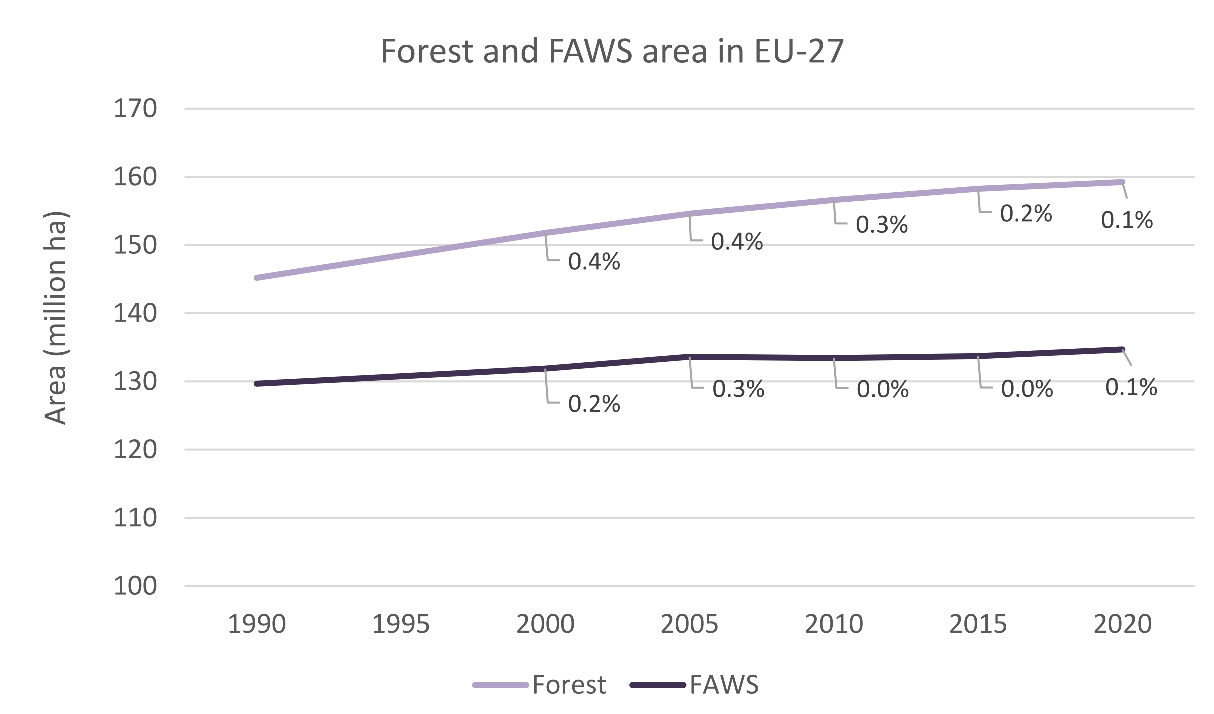
6.3.6 Trend on FAWS (1990 – 2020)

The evolution of the FAWS in the EU, in relation to the forest area, is assessed using the national statistics provided by the SoEF for the period 1990 – 2020 (FOREST EUROPE, 2020). The SoEF reports complete time-series data on forest area and FAWS for almost all EU countries[46]. Only 3 countries presented some missing values for FAWS, which were filled multiplying the forest area by the ratio between FAWS and forest area of the nearest reporting year. No temporal information is available regarding the FAWS in terms of biomass stock.

This time series shows that the forest area of EU-27 has always increased during the study period, but the intensity of growth has declined steadily, with an annual percent growth that decreased from 0.4% before the year 2000 to only 0.1% between 2015 and 2020 (Figure 68). Instead, the FAWS area has increased always at a smaller rate than the forest area, with about null annual growth rate in the period 2005 – 2015.

This analysis indicates that, while the growth of the forest area has gradually slowed down during the period 1990 – 2020, the FAWS area has flattened already since the year 2000, suggesting that the recent forest expansion either did not occur on areas available for wood supply, or that there has been an expansion of the restrictions (economic, environmental or social) on existing forest land.

Figure 68. Development of the total forest area (above) and FAWS area (below) of the EU-27 during the period 1990 – 2020 according to the SoEF data. The percentage values represent the annual change rate compared to the previous reporting period. There is no reporting for the year 1995 and the annual change rates in 2000 refer to the period 1990 – 2000. For representation purposes, the y axis does not start from 0.



Source: JRC 2022 (own data)

[46] Since data are based on SoEF, these directly represent the net forest area change (i.e. afforestation-deforestation) as reported by MS. Therefore afforestation (also due to the natural forest expansion on marginal lands) was not specifically assessed.

6.4 Biomass growth: Gross and Net Annual Increment

6.4.1 Summary in numbers: key indicators

According to our reference dataset on forest volume increment, the EU forests in 2015 produced a Gross Annual Increment (GAI) of about 902 million m^3 of wood, of which 132 million m^3 were lost due to Annual Natural Losses (ANL), resulting in a Net Annual Increment (NAI) of 770 million m^3, or 85% of GAI.

When considering the increment per ha, the average GAI was 5.7 m^3 ha^{-1} yr^{-1} of which 4.9 m^3 ha^{-1} yr^{-1} of NAI and the remaining 0.8 m^3 ha^{-1} yr^{-1} of ANL. The increment values on the FAWS were usually higher, when scaled against the area but they were smaller in terms of total increment due to the lower forest area.

The growth rate of the forests varies largely across Europe according to a latitudinal gradient: the largest NAI (> 8 m^3 ha^{-1} yr^{-1}) is found in central Europe while the Scandinavian and Mediterranean countries presented the lowest rates (< 4 m^3 ha^{-1} yr^{-1}). For the Mediterranean and some east European countries, the low NAI is also due to large natural losses, with the ANL between 16% and 43% of the GAI.

The long-term evolution of the NAI, estimated by combining multiple data sources, highlights that for EU-27 the increment is continuously increasing from about 3 m^3 ha^{-1} yr^{-1} in 1950 to about 5.1 m^3 ha^{-1} yr^{-1} in 2005 (a percent annual increment of about +3% yr^{-1}). According to most data sources, the average NAI remained quite stable (5 m^3 ha^{-1} yr^{-1}) between 2005 and 2015 and then, assuming the continuation of the forest management practices applied between 2000 and 2015, it is expected to decrease to 4.8 – 4.9 m^3 ha^{-1} yr^{-1} during the period 2020 – 2025.

These results confirm the ongoing reduction of the NAI already reported by other studies at EU level and, more recently, also at country level, such as in SE, FI and AT. Other countries, however, report a stable or slightly increasing NAI, possibly due to favourable effects of climate change.

The recent stabilisation of the NAI and the expected reduction within the coming decades is likely due to the ageing of the European forests. According to our modelling results, the average age of the even-aged forest stands increased from 58 to 64 years from 2000 to 2020, and most of this increase is due to the ageing of the broadleaves stands.

6.4.2 Some definitions on gross and net growth

An accurate assessment of the woody biomass net growth is an essential prerequisite of any forest management strategy. The average annual increment of all living trees within a certain time period is defined as Gross Annual Increment (GAI). But, to estimate the potential amount of woody biomass available for wood supply, we need to subtract from the GAI the Annual Natural Losses (ANL) due to the trees that died for natural causes during the same period of time. The resulting value represents the Net Annual Increment (NAI).

Periodically, an amount of woody biomass, usually smaller than the NAI, is harvested and accounted as fellings. Most of the fellings are taken away from the forest (removals), besides some residues that remain in the forest and gradually decompose (logging residues). The difference between the NAI and the fellings corresponds to the net change in the woody biomass in the forest (Alberdi et al., 2016) (Figure 69). This last parameter allows to estimate the forest mitigation potential since it determines the net carbon uptake provided from the aboveground living biomass[47].

Here, first we report the gross and net annual increment of European forests and then we focus our analysis on the NAI, which is generally considered most informative as it allows to quantify and monitor the net growth of woody biomass. The NAI also best informs on the amount of biomass that can be sustainably harvested and on the carbon sequestration due to the net biomass accumulation in the forests, in addition to the carbon stored into harvested wood products.

[47] In most cases, the net carbon sink attributed to the other pools (belowground living biomass, dead organic matter and soil) derives from the net carbon uptake attributed to the aboveground living biomass pool.

Figure 69. Schematic representation of the components related to forest volume and biomass change (from FOREST EUROPE, 2020).

<table>
<tr><td colspan="4">Gross increment</td></tr>
<tr><td rowspan="3">Natural losses</td><td colspan="3">Net increment</td></tr>
<tr><td colspan="2">Fellings</td><td rowspan="2">Net change</td></tr>
<tr><td>Logging residues</td><td>Removals</td></tr>
</table>

Source: JRC elaboration of Alberdi et al 2016.

6.4.3 Data sources for the forest increment

The GAI, ANL and NAI are included amongst the forest variables for international reporting, such as the SoEF, but in the national reporting the NFIs usually report only the GAI and not the other two variables. The NAI is a relatively recent indicator of forest growth and it is often not included in the national reporting for the difficulty to obtain accurate data on the natural losses (ANL), and also to maintain consistency with the historical time series of information that is acquired in terms of GAI. Consequently, in most cases, the NAI data produced for the international reporting are obtained by adjusting the national GAI data, using different approaches and variable levels of accuracy.

In fact, the analysis of the latest SoEF data on NAI published in 2020 (FOREST EUROPE, 2020) revealed some level of incompleteness and inaccuracy. In terms of completeness, we noticed that at EU-27 level only 20 countries provided data on NAI for 2015, and 6 of them reported the NAI only for the forest area or for the FAWS area but not for both, resulting in NAI data covering 58% of the forest area and 68% of the FAWS (FOREST EUROPE, 2020). In every reporting period, the NAI reporting for total forest area was less frequent than for FAWS. Also, the area included in the SoEF reporting on NAI was quite variable across the reporting years, with incomplete reporting in 1990, 2000 and 2015 when it included only 44%, 51% and 66% (respectively) of the FAWS of EU-27, while a larger coverage (83% and 85% of FAWS, respectively) was reported in 2005 and 2010 (FOREST EUROPE, 2020).

In terms of accuracy, a detailed analysis of the increment values highlighted that, in some cases (e.g. CZ, IT, RO and ES), the NAI reported by SoEF is in line with the GAI reported by the NFI data, and therefore overestimated, because referring to the gross rather than the net increment. In addition, we note that some countries (i.e. AT, FI, LU, NL, SK and SE) report for 2015 almost the same NAI values reported for 2010, while IT reports the same increment for the entire time series 1990 - 2010.

Overall, these considerations suggest that, in some cases, the NAI figures reported by SoEF are not derived from direct NFI field measurements but from adjustments and simplified assumptions that reduce their accuracy. It is also important to notice that the SoEF reports NAI only in terms of volume (m^3 ha^{-1} yr^{-1}) rather than biomass (tonnes ha^{-1} yr^{-1}) and only as summary statistic at national scale.

For these reasons, the JRC processed and compiled the best available data provided by the NFIs, the SoEF 2020 Report and the outputs of the CBM to obtain a NAI dataset for EU-27 that is harmonised, as much as possible, in terms of increment definition, forest area and reference year.

6.4.4 Harmonisation approach

6.4.4.1 Increment definition

The JRC supported a dedicated effort of 10 EU NFI institutions under the coordination of ENFIN to achieve a better harmonisation of the forest increment statistics. The countries involved in this work, which covered most of the forest area of EU-27, were AT, CZ, DE, ES, FI, FR, IT, PL, RO SE. Similar to the work performed for biomass stock and

FAWS, the NFIs worked together to identify and apply a harmonised definition and estimation method of forest increment to the national data, using adjustment factors and a common estimator.

In particular, the harmonised increment is defined as the average annual increment of living trees over the specified forest area during the period between two NFIs, and includes the growth components of survivor, ingrown, cut and mortality trees with a diameter at breast height (dbh) ≥ 7.5 cm. Volume increment includes the over-bark increment of the stem from stump height to the top diameter of 7 cm, and for broadleaves additionally includes large branches with a minimum diameter of 7 cm. The diameter thresholds were defined to focus on the increment of the "merchantable industrial wood", that is 2 m logs with at least 7 cm diameter at the thinner end. Biomass increment includes the stem biomass from ground to the stem tip, and large and small branches, and perennial foliage (needles).

The implementation of the harmonised definition and method, reported in Gschwantner et al. (2022), takes into consideration the difference in sampling designs, applies a common dbh-threshold, and includes specified tree parts and components of change. The results of this harmonisation effort were NAI estimates for volume and biomass at sub-national scale referring to the same growth components for the 10 countries mentioned above.

The increment estimates were also stratified by forest types (i.e. coniferous, broadleaved, mixed and temporary unstocked forests) according to plot-level information or forest maps, following the definitions used in Forest Europe, namely: coniferous forests present >75% tree cover of conifers, broadleaved forests present >75% tree cover of broadleaves, mixed forests have neither coniferous nor broadleaved species with more than 75 percent of tree cover. Instead, the temporary unstocked areas can be due to harvest or forest damage and subsequent logging, where the forest type cannot be assigned due to absent or sparse trees.

The impact of the harmonisation of the NAI definition, computed as the difference between the harmonised and the national estimates divided by the national estimates, varied among the countries, ranging from -13% to +12% in terms of volume increment and from –6% to +2% in terms of biomass increment. In general, the effect of the harmonisation for the biomass increment was lower compared to the volume estimates, because usually the same above-ground tree parts are included in national and harmonised estimates.

For the remaining 17 Member States not involved in this study, the NAI estimates were obtained from the SoEF (for 15 countries) or, if not reported in the SoEF, from the CBM (see the following sections).

6.4.4.2 Reference year

The increment estimates produced by ENFIN, harmonised for definition and estimation method, were usually obtained using the latest two completed NFI cycles and thus refer to different periods among countries, spanning between 1986 and 2020. Considering that the increment rates may change substantially in such time frame because of changes in the forest area, age structure, mortality and harvest, the increment statistics were linearly adjusted to a common reference year by the JRC using the time series of increment provided by the FOREST EUROPE (2020).

The reference year was set to the year 2015, because this is the latest reporting year available in SoEF 2020. For 5 countries (CZ, FI, PL, RO, SE) the temporal adjustment was not necessary because their reference period was approx. 2010-2020 and therefore their estimates were considered representative of the mid-year 2015. For the remaining 5 countries, the adjustment was performed using a correction factor, obtained as a ratio between the SoEF mean GAI value for FAWS for the year 2015 and the corresponding average SoEF value for the ENFIN reference period, which quantifies the relative change of the mean GAI during this period. The correction factor was computed using the SOEF GAI data relative to FAWS rather than all forest area because the increment for FAWS is reported more frequently and is considered more accurate than the increment for all forests due to the larger density of field samples placed in productive and accessible forests. In the case of Spain, which reported in SoEF the mean GAI only for 2010, the temporal adjustment could not be performed.

The correction factor was computed at national level and then it was multiplied by the ENFIN mean GAI of each country to update it to the year 2015. Instead, since the mean ANL is considered as a relatively stable percentage of the GAI, it was adjusted to 2015 by multiplying the corrected mean GAI by the ratio between the mean ANL and the mean GAI before correction. Then, the mean NAI was obtained as difference between the mean GAI and the mean ANL. Lastly, the adjusted mean GAI, ANL and NAI were attributed to forest or FAWS (see section 6.3.5) and then multiplied by the respective forest or FAWS area for the year 2015 reported by SoEF to obtain the total increment values for 2015 harmonised with the SoEF forest or FAWS area.

The impact of the temporal harmonisation to the year 2015 of the mean increment values was in the range of ± 2%. Instead, the impact of the temporal harmonisation for the total increment values was usually larger, ranging from –6% to +10%, because it also included the adjustment in forest area to match the 2015 SoEF values.

For the countries without the ENFIN harmonised estimates, the temporal harmonisation was not necessary because the increment data were obtained from the SoEF or from the outputs of CBM, which provide the increment values at national scale for the year 2015.

6.4.4.3 Reference forest area

Similar to the other forest variables, the increment estimates refer to a certain forest area (usually, total forest area or FAWS area) and should be interpreted accordingly. In order to produce complete and consistent data on the forest increment, we computed the forest increment for the EU-27 countries both for the total forest land and for the FAWS area.

The ten NFIs with harmonised increment estimates applied the forest definition used in the FAO Forest Resources Assessment (FAO, 2000) when possible, otherwise used the national forest definition. The analysis of the results revealed some variability among the countries regarding the types of forest included. All 10 countries included productive and temporary unstocked forests, and excluded permanently unstocked forests, but some variability remained regarding the unproductive forests. Five countries provided increment estimates including all protective and unproductive forests, while 4 countries excluded unproductive forests, protective forests without yield and inaccessible forests. One country included poorly productive forests but excluded unproductive forests.

These categories do not match exactly the Forest/FAWS categories but, the comparison with the Forest and FAWS areas reported in the SoEF showed that the forest area excluding unproductive and inaccessible forests is close to the FAWS area (which usually excludes also the protective forests with yield) while the area including the unproductive forests is close to the total forest area of the country. Therefore, the NFI harmonised increment estimates were attributed either to the total forest area or to the FAWS area.

Then, the harmonised increment values for the missing category (forest or FAWS) were obtained as follows. If the SOEF did not report increment data, the mean increment was simply considered equal for forest and FAWS, and the total increment was obtained by multiplying the mean increment for the respective (forest or FAWS) area. Instead, if the SoEF reported mean gross increment data for both Forest and FAWS, the ratio between the two GAI values was used to compute the missing increment value, to consider the variability of the increment between forest and FAWS. In fact, the mean increment often resulted to be slightly higher for FAWS than for forests because the FAWS usually includes the most productive forests. Thus, if the NFI missing value was for forest, the ratio of the SOEF Forest/FAWS mean increment was multiplied by the NFI value for FAWS, and vice-versa if the missing value was for FAWS. The correction was applied also to the increment data at sub-national scale.

For the remaining 17 countries without harmonised data, the increment values at national scale were obtained directly from SoEF or CBM. When a country reported only increment estimates for forest but not for FAWS (or vice-versa, which was more common), the mean increment was simply considered equal for forest and FAWS. For these countries it was not possible to obtain increment values at sub-national scale. In 2 cases (BG and LU), the SoEF reported only the NAI and the GAI was estimated multiplying the NAI by the ratio GAI/NAI reported by a neighbouring country (RO and BE, respectively).

6.4.5 Comparison of increment statistics

The NAI estimates of the 10 countries harmonised for definition and estimation method by ENFIN and by year and forest area by the JRC were compared with the NAI values reported by SoEF (FOREST EUROPE, 2020) and by CBM for the corresponding area (forest or FAWS) and for the same reference year (2015, or 2010 in case of missing data for 2015). This comparison allowed a better understanding of the information provided by the data sources and the magnitude of their differences (Table 5).

Overall, the JRC NAI estimates tended to be comparable but lower (9% and 4%, respectively) than the corresponding SoEF and CBM values over a similar forest area. At country level, the JRC values were between –31% and +5% than the SoEF values, with largest differences for ES (-31%), RO (-31%) and IT (-21%), and with smaller differences (below ±10%) for 5 countries (AT, DE, FI, FR, PL). The comparison between the JRC and the CBM values reported similar results for most countries, with lower JRC values especially for ES (-36%), CZ (-23%) and SE (-19%) and instead a higher JRC estimate for RO (+32%).

The differences among the datasets are due to various factors. In general, some differences are due to the differences in the increment definitions and estimation methods, where the JRC values were obtained through an ad-hoc harmonisation for all 10 countries while the SoEF and CBM values were derived from the NFI data based on the national definitions and methods or after some approximated adjustments (see section 6.4.4).

In the case of SoEF, since most NFIs provide only estimates of the GAI because of the scarcity of data on the ANL, their NAI data are obtained by adjusting the GAI values with variable approaches, and we found that for some countries (CZ, FI, IT, RO) the SoEF values for NAI were closer to the JRC values for GAI rather than for NAI. In the case of CBM, some differences are likely due to the input data used for model calibration, which do not include the most recent NFIs used instead for the JRC dataset (e.g., RO and CZ). Similarly, in the case of Spain, the JRC values are based on NFI data for total forest land spanning and for a long timeframe (1986 – 2008), which introduces larger uncertainty in their update to 2015, while the SoEF values may be higher because they refer to the FAWS area.

Table 5. Comparison of the NAI values (total and per ha) and respective forest area reported by the harmonised dataset (JRC), the SoEF (2020) and the CBM for a certain year (2010 or 2015) and Reference area (total forest area or FAWS area).

ISO	Year	Ref. Area	JRC (1)			SOEF (2)			CBM (3)			Notes
			Area	Tot NAI	NAI	Area	Tot NAI	NAI	Area	Tot NAI	NAI	
			1000 ha	1000 m^3 yr^{-1}	m^3 ha^{-1} yr^{-1}	1000 ha	1000 m^3 yr^{-1}	m^3 ha^{-1} yr^{-1}	1000 ha	1000 m^3 yr^{-1}	m^3 ha^{-1} yr^{-1}	
AT	2015	FAWS/Forest	3,319	27,477	8.28	3,319	27,024	8.14	3,889	34,756	8.94	(4)
CZ	2015	Forest	2,668	21,110	7.91	2,668	24,262	9.09	2,668	27,358	10.25	
DE	2015	Forest	11,419	119,419	10.46	11,419	119,890	10.50	10,792	103,186	9.56	
ES	2010	Forest/FAWS	18,551	26,435	1.42	17,082	35,478	2.08	18,348	40,667	2.22	(4)
FI	2015	Forest	22,409	91,556	4.09	22,409	100,412	4.48	22,521	99,256	4.41	
FR	2015	FAWS	16,015	85,371	5.33	16,015	81,375	5.08	15,499	83,878	5.41	
IT	2010	FAWS	8,216	26,425	3.22	8,216	33,512	4.08	8,088	29,515	3.65	
PL	2015	Forest	9,420	77,808	8.26	9,420	79,374	8.43	9,400	68,668	7.31	(5)
RO	2015	Forest	6,901	28,709	4.16	6,901	52,253	7.57	6,871	27,251	3.97	
SE	2015	Forest	27,980	94,716	3.39	27,980	114,047	4.08	27,354	119,285	4.36	
Total/Mean			126,899	599,026	4.72	125,430	667,625	5.32	125,428	633,820	5.05	

(1) Harmonized for definition and estimation method by ENFIN and by year and forest area by the JRC
(2) Data derived from https://fra-data.fao.org/FE/panEuropean/home/
(3) Data derived from Pilli et al. (2022)
(4) The SoEF data is only available for the FAWS area while the CBM data is only available for the total forest area
(5) The SoEF NAI data for PL are not reported and are estimated from the reported GAI values multiplied for the JRC ratio NAI/GAI

Source: JRC 2022 (own data)

6.4.6 Reference statistics on volume increment

The JRC reference dataset on forest volume increment provides consistent data for the average and total GAI, ANL and NAI for forest land and FAWS area in 2015 for the EU-27 countries at national or sub-national level. The reference statistics were produced by the JRC compiling, processing and harmonising the best available data provided by the NFIs, the SoEF 2020 dataset and the outputs of the CBM, following an approach similar to that used for the assessment of the biomass stock and FAWS.

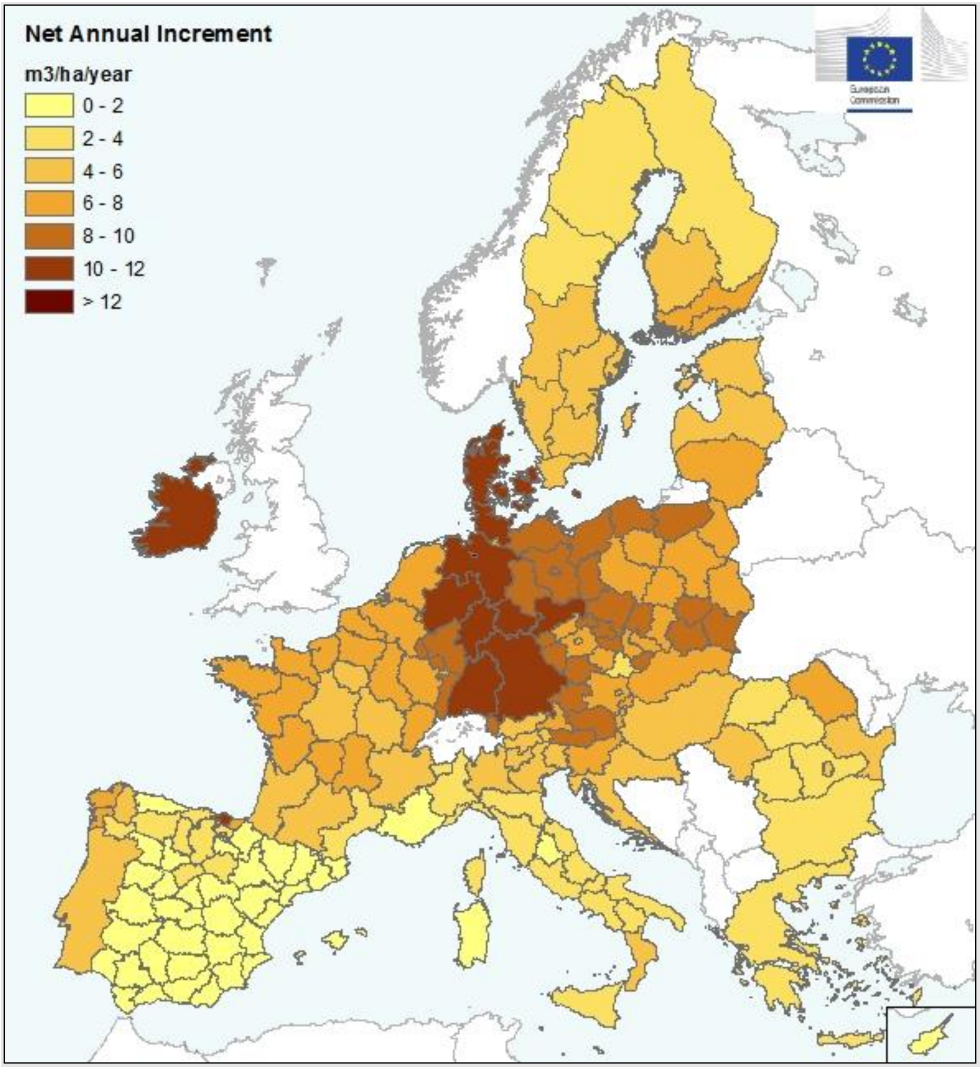
The increment estimates were harmonised for definition, reference year and forest area (as described in section 6.1.2) at sub-national scale for 10 countries covering about 82% of the EU-27 forest area. For the remaining countries, the increment data were obtained by the SoEF (FOREST EUROPE, 2020) at national scale for 15 countries covering 14% of the EU-27 forest area and by the CBM for the 2 countries that did not report increment values in SoEF (GR and PT, 5% of the EU-27 forest area). For all countries, the increment estimates were adjusted to fill missing data and to match the forest and FAWS area for 2015 reported by SoEF using the approaches described in this chapter.

The forests of the EU-27 countries in the year 2015 produced a GAI of about 902 million m^3 of wood over 158 million ha[48], of which 132 million m^3 were lost due to natural causes (ANL), resulting in a NAI of 770 million m^3 (see Annex of this Chapter). When considering the increment per ha, the average GAI was 5.7 m^3 ha^{-1} yr^{-1} of which 4.9 m^3 ha^{-1} yr^{-1} of NAI and the remaining 0.8 m^3 ha^{-1} yr^{-1} of ANL. In comparison, the increment values on the FAWS area, covering 134 million ha, were usually higher in terms of the average increment per ha, with a GAI of 6.0 m^3 ha^{-1} yr^{-1} and a NAI of 5.1 m^3 ha^{-1} yr^{-1} but they were smaller in terms of total increment due to the lower forest area, with a GAI of 796 million m^3 and a NAI of 681 million m^3 (see Annex of this Chapter). On average, the ANL on forest land affected 15% of the GAI, and thus the net increment was 85% of the gross increment.

The growth rate of the forests varies largely across Europe, with a NAI that ranges at national level from 1.1 to 10.7 m^3 ha^{-1} yr^{-1} (in CY and DK, respectively). As expected, the growth rates showed a clear latitudinal gradient: the largest increment rates (above 8 m^3 ha^{-1} yr^{-1}) were found in central Europe while the Scandinavian and Mediterranean countries presented the lowest rates (equal or below 4 m^3 ha^{-1} yr^{-1}), with intermediate values (5 – 7 m^3 ha^{-1} yr^{-1}) found in the transition between these regions (Figure 70). The spatial variability of the NAI is mostly driven by the GAI but, for the Mediterranean and some east European countries, the low NAI is also due to large ANL, which range between 16% and 43% of the GAI, while the northern and west European countries tended to report lower losses, affecting between 5% and 15% of the GAI.

[48] This corresponds to the forest area reported in SoEF 2020 for the year 2015. Since this area was not preliminarily harmonised, it is not directly comparable with the harmonised forest area referred to 2020.

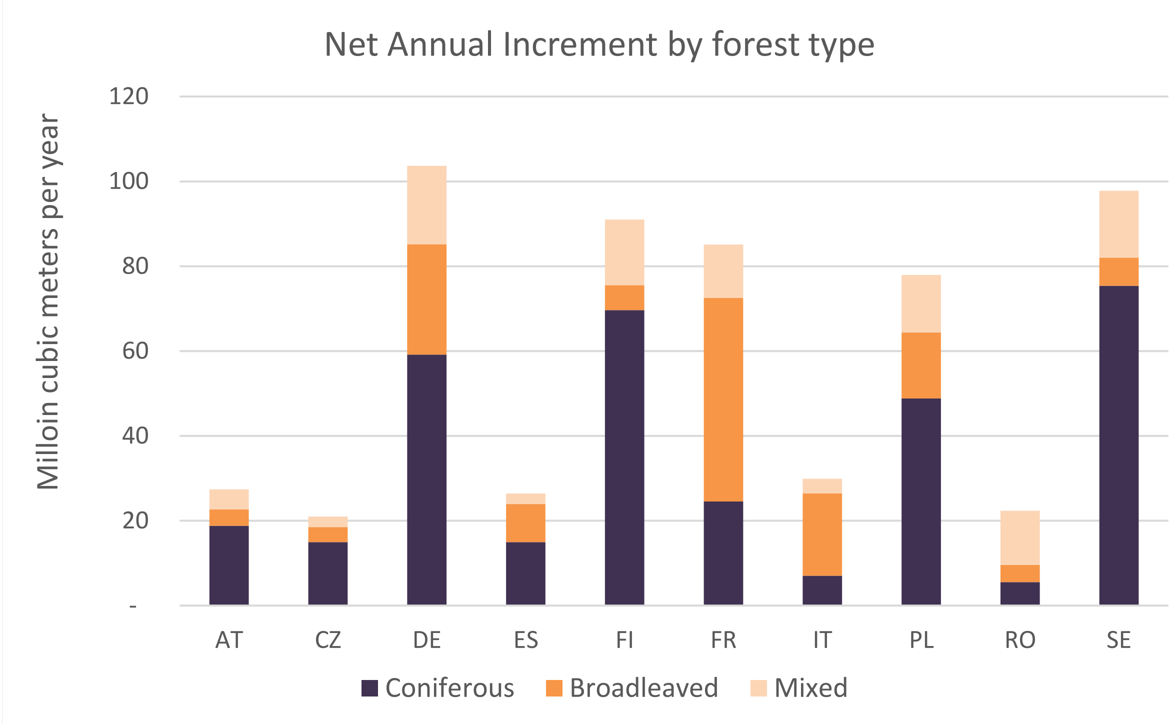
Figure 70. Net Annual Increment (NAI) in the forest area according to our reference harmonised statistics for the year 2015.



Source: JRC 2022 (own data)

The increment estimates derived from the harmonised NFIs of 10 countries, covering 82% of the EU-27 forest area, are also available by forest type. The analysis of the results shows that most of the increment (58%) is produced by coniferous forests, which are predominant in central and northern European countries (e.g., DE, FI, SE, PL), while broadleaves forests are more common and produce a substantial part (24%) of the country's wood increment in the central-southern countries (e.g., FR, IT, ES), followed by mixed forests that contributes to 18% of the total increment (Figure 71).

Figure 71. Reference statistics on the Net Annual Increment in the forest area of the 10 harmonised NFIs countries by forest type for 2015.



Source: JRC 2022 (own data)

The JRC harmonised estimates of NAI are based on a country-specific harmonisation of best available data. For 10 Member States – covering about 82% of the total forest area - the NAI was derived from increment data directly reported by countries, already harmonised to a common definition, further aligned (for 8 countries reporting the increment for FAWS) to the total forest area attributed to each Member State and scaled to a common reference year (2015). According to the data reported to JRC, the percentage error of these primary data, i.e. the harmonised total NAI, is always lower than 2% at national level. Of course, scaling these data to a different forest area and reference year, we introduced a further uncertainty. Indeed, when scaling (for 5 countries) the increment data referred to the FAWS to the total forest area, we may overestimate the average annual increment of unproductive forest sites.

For 15 Member States, the NAI was derived from SoEF. These data were not preliminarily harmonised, however, based on the information inferred from the previous group of countries, the impact of the harmonisation ranges from -13% to +12% in terms of volume increment. In this case, however, apart from the uncertainty due to the harmonisation to a common reference year, some of these data are probably referred to GAI, and should be further corrected.

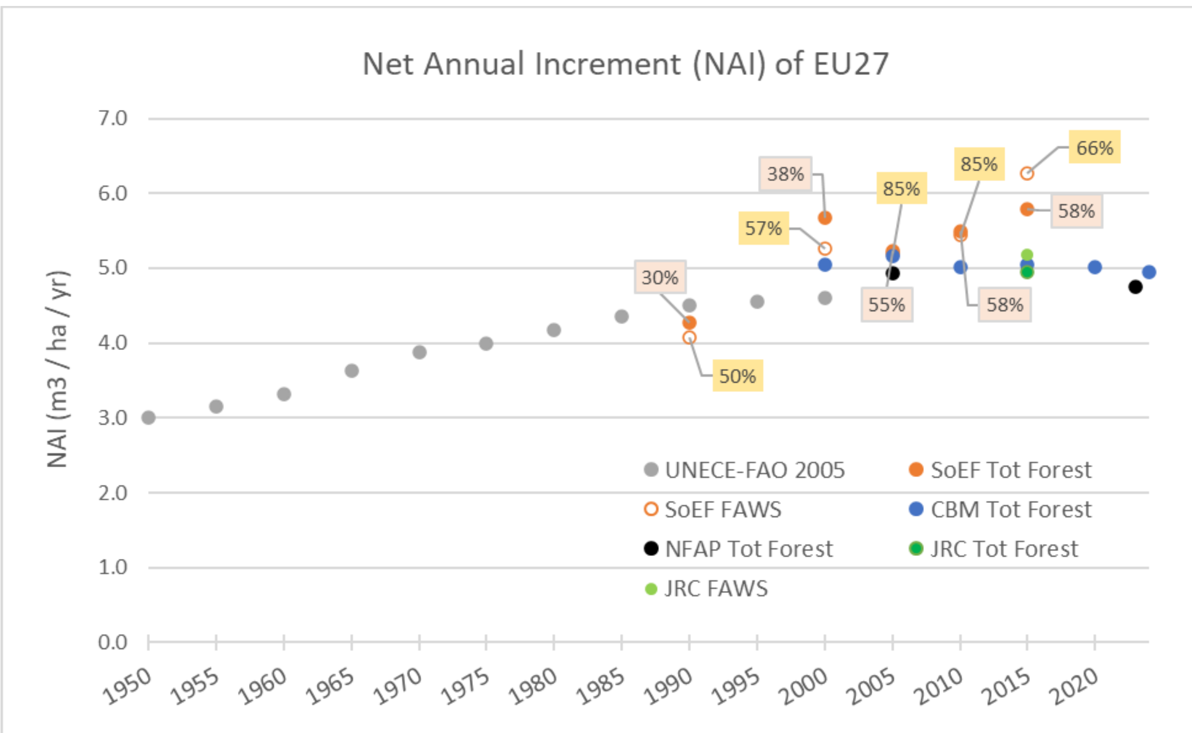
Finally for GR and PT, the NAI was derived from the estimates provided from CBM. In these cases, we do not have an assessment of the error associated to these estimates, also because at country level, no recent statistics are currently available. However, based on the comparison performed with other Mediterranean countries (IT and ES) we can infer that, for these countries, the relative difference between the CBM output and the harmonised NAI ranges between -23% and -10%.

6.4.7 Trend in the increment (1950 – 2025)

6.4.7.1 Assessing the trend

The long-term evolution of the NAI is estimated by combining multiple data sources, namely the statistics provided by the FAO, the SoEF, the Member States' National Forest Accounting Plans (NFAP)[49] and the CBM. The trend of the NAI per unit of area (in $m^3\ ha^{-1}\ yr^{-1}$) is reported here - Figure 72 - from 1950 to 2025 based on the data provided by the UNECE/FAO (2005) (with 5 years times intervals derived as simple average of the values), the SoEF 2020 (referred both to the total forest area and to FAWS for the period 1990 – 2015), the CBM (referred to the total forest area for the period 2000 – 2020) and as derived from the information reported within the countries' NFAP (reported as average for the historical period 2000-2009 and as projection for 2022, see Korosuo et al., 2021 and Korosuo et al., in prep). For the SoEF we also highlight the share of forest area covered by increment data. All data are referred to EU-27, except for UNECE/FAO (2005) and the estimates derived from the NFAPs, which also include the UK.

Figure 72. Development of the mean Net Annual Increment (NAI) of EU-27 during the period 1950 – 2020 according to multiple data sources for the total forest area (Tot Forest) or for the FAWS area (FAWS). The percentage values refer to the SoEF data and represent the fraction of the forest area (in light orange) or FAWS area (in yellow) to which the NAI values refer to. The mean NAI values provided by the CBM and JRC refer to all EU 27 countries, while the UNECE FAO 2005 and the NFAP values include also the UK.



Source: JRC 2022 (own elaboration)

These data sources highlight that for EU-27 the increment is continuously increasing from about 3 $m^3\ ha^{-1}\ yr^{-1}$ in 1950 to about 5.1 $m^3\ ha^{-1}\ yr^{-1}$ in 2005, which corresponds to a percentage annual increment of about +3% within

[49] In 2019, each EU Member State submitted to the European Commission a National Forestry Accounting Plan, as part of the EU 2018/841 Regulation's requirements. These documents include a detailed description of the forest resources of each country, in particular within the period 2000 - 2009 and its expected evolution until 2025 (Korosuo et al., 2021).

this period. For 2005, all data sources (SoEF 2015, CBM and countries' NFAPs) are quite consistent and report an average NAI ranging from 4.9 to 5.2 m^3 ha^{-1} yr^{-1}.

The estimates derived from CBM for the EU-27 between 2005 and 2015 indicate that the average NAI is quite stable and equal to about 5 m^3 ha^{-1} yr^{-1}. The CBM results match well the values estimated in our harmonised dataset, which reports an average NAI of 4.9 m^3 ha^{-1} yr^{-1} for the total forest area and of 5.2 m^3 ha^{-1} yr^{-1} for the FAWS of EU-27. The values reported in the SoEF for total forest area and for FAWS in the year 2000, 2010 and 2015, however, are on average 12% higher than the estimates provided by CBM for the same period, with the largest difference in 2015 (+15% for forest and +24% for FAWS).

As highlighted within the specific analysis based on the harmonisation of NAI (section 6.4.4), the higher SoEF values may be due to two main reasons. Firstly, not all countries report to the SoEF data on forest increment. In particular, the average NAI of the SoEF refers only to 30% - 58% of the forest area and 52% - 85% of the FAWS area of EU-27 (see Figure 72 for details) and does not include the countries with lower increments, such as ES, PT or GR. Secondly, the comparison with the increment values reported by the NFI reports indicated that, in some cases, the NAI values reported in the SoEF are in line with the data on the gross increment and thus they seem to refer to the GAI rather than the NAI.

Assuming the continuation of the forest management practices applied within the periods 2000-2015 (for CBM) and 2000 – 2009 (for countries' NFAPs), the average NAI is expected to decrease to about 4.8 – 4.9 m^3 ha^{-1} yr^{-1} within the following period 2020 – 2025 according to these two data sources. In addition, even though the overview on the NAI reported by the SoEF (2020) for the EU within the period 1990 - 2015 does not highlight any evident signal of increment's saturation or reduction, the evolution of the growing stock per ha reported by 23 EU countries (4 countries do not report a consistent time series) during this period indicates a different trend.

In fact, the relative growing stock change of 19 countries report a decreasing annual growth rate. Only CY, FR, HU, and SE report a stable or increasing annual growth rate. Since the NAI is equal to the net stock change plus the fellings, the decreasing growing stock can be partially due to an increasing felling rate (see section 6.5.4 on removals). However, the other data sources presented here (CBM and NFAPs) suggest that part of the decreasing stock is also due to a reduction of the forest NAI in European forests.

Overall, these results confirm the ongoing reduction of the NAI already reported by other studies at EU level (see for example Nabuurs et al., 2013; Pilli et al., 2022) and more recently, also at country level. For example, according to the NFAP submitted from AT, the total NAI estimated at country level decreased from 30.4 million m^3 within the period 2000 – 2009, to 29.7 million m^3 within the following period 2010 – 2018 (Austria, 2019).

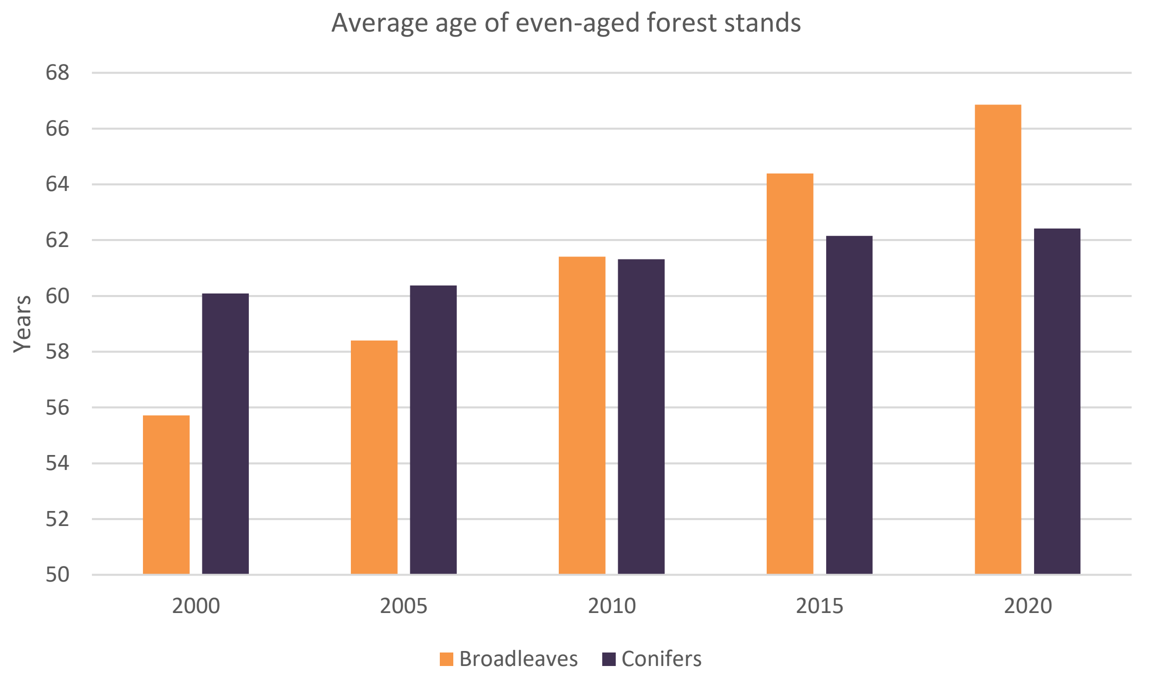
Similar results were recently reported also from other countries. In FI, according to the latest NFI, the average annual increment at country level decreased from about 4.7 m^3 ha^{-1} yr^{-1} within the period 2014-2018, to about 4.6 m^3 ha^{-1} yr^{-1}, within the period 2016-2020 (Finland, 2022). In SE, the average annual increment increased from about 4.8 m^3 ha^{-1} yr^{-1} in 2002, to 5.3 m^3 ha^{-1} yr^{-1} within the period 2010-2013, but then it decreased to 5.0 m^3 ha^{-1} yr^{-1} in 2016 and recent data collected at country level confirm this trend (Sweden, 2022).

Other countries, however, report a stable or slightly increasing NAI. In some cases, i.e. for northern European countries, this could be due to the ongoing effect of climate change which may increase the net ecosystem productivity on some European regions, and partially compensate the increment's reduction due to other natural processes (Pilli et al., 2022). In other cases, such as for some central European countries, despite the major natural disturbances occurred within the last five years, countries' statistics do not highlight any direct effect on NAI (see, for example, CZ). This may be because, in some cases, most of natural losses were removed through salvage logging and therefore, by definition, accounted as part of the NAI.

6.4.7.2 Understanding the trend

Most of the recent studies attribute the stabilisation of the NAI, and the following expected reduction within the coming decades, to the ongoing ageing process of the European forests (see for example Nabuurs et al., 2013; Pilli et al., 2022). To better understand this process, we analysed the evolution of the age class distribution of the even-aged forest stands as expected from CBM from 2000 to 2020. Within this period, the average age of these stands, which cover about 84% of the total forest area considered by CBM, increased from 58 to 64 years (Figure 73). However, according to our estimates, while the average age of the coniferous stands is quite stable, just increasing by about 0.2% per year, the average age of the broadleaves stands increases by about 1% per year. Certainly, these results are affected by the specific model's assumptions on the management practices applied on different species groups and countries. In particular, excluding afforestation, the evolution of the age class distribution is mostly determined from stand replacing activities (i.e. final cuts) and natural disturbances (windstorms and fires), which may rejuvenate existing forest stands [50].

Figure 73. Evolution of the average age of the even-aged broadleaves and coniferous stands from 2000 to 2020 in the EU-27 as estimated by the CBM. For representation purposes, the y axis does not start from 0.



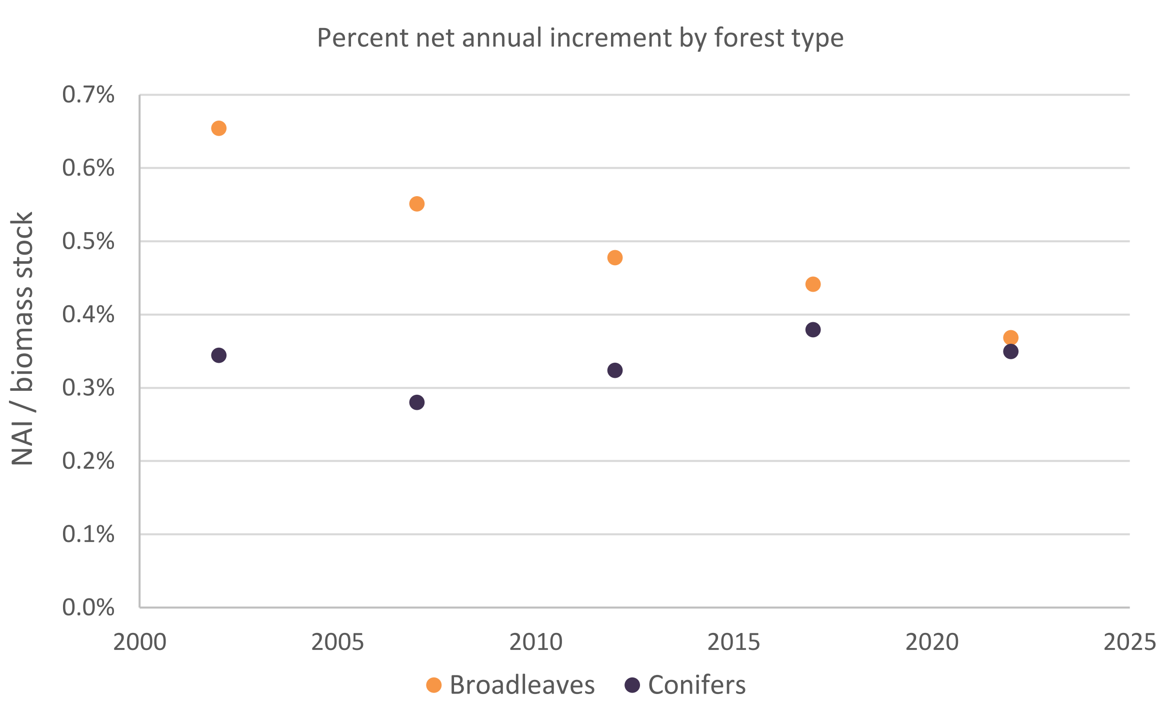
Source: JRC 2022 (own elaboration)

Despite the uncertainty on the amount of harvest reported by different data sources (Camia et al., 2018), the FAOSTAT data – used for calibrating CBM - report that the coniferous species provided about 66% of the total removals within the period 2000 – 2015. Therefore, forest management activities applied on coniferous species may have partially offset the ongoing ageing process of these stands. On the opposite, in some cases the natural ageing process acting on broadleaves stands was not offset from the management practices applied on these stands. This could be, for example, the case of coppice stands abandoned in some Mediterranean countries.

The faster ageing process of broadleaves indirectly also affects the evolution of the increment. Indeed, according to the estimates obtained from CBM between 2000 and 2025, while the living biomass stock is continuously increasing for both, coniferous and broadleaves species, for this last group the percentage annual increment derived from this biomass decreases from 0.7% to 0.35% per year (Figure 74). On the other hand, for conifers, despite the major intensity of removals, the percentage annual increment is quite stable within the entire period. This dynamic has direct consequences also on the overall evolution of net ecosystem production and net biome production (see Pilli et al., 2022).

[50] This analysis does not consider afforestation and deforestation within the period 2000 – 2020.

Figure 74. Evolution of the Net Annual Increment (NAI) of broadleaves and conifers as percentage of the biomass stock in the EU-27 in the period 2000 – 2025 as estimated by the CBM.



Source: JRC 2022 (own elaboration)

6.5 Biomass loss: forest harvest & natural disturbances

6.5.1 Summary in numbers: key indicators

According to various data sources, the harvest level in the EU was relatively stable between 1960 and 1985 and then presented a clear upward trend, with FAOSTAT removals increasing from 3.0 to 4.0 m^3 ha^{-1} yr^{-1} between 1990 and 2015. During the past years, some countries have improved the completeness of their data series, in particular on wood used for energy, which was partially unaccounted from previous statistics. FAOSTAT data series were updated according to these new data. However, since data reported by other countries need to be further revised, the overall removals estimated at EU level are still partially underestimated (see also Chapter 7 within this report for further details). Despite our effort to harmonise current data series and to account for possible inconsistencies, the lack of data collected at country level may also affect the accuracy of our results.

The trend of the fellings rate, that is the ratio between the total fellings and the NAI, determines the evolution of the forest biomass stock. The fellings rate slowly decreased from 82% to 78% of the NAI between 2000 and 2015, but it is estimated to grow and reach the 88% of the NAI in 2020. The fellings rate has been certainly increasing during the last decade but it is still below the current NAI.

However, natural disturbances, mainly caused by wind and insects, have increased by 138% during the period 2014-2018 in 17 countries, confirming the increasing trend in central Europe reported in the literature. The salvage loggings following these disturbances might be partly responsible for the increased harvesting rates observed in the EU over recent years. For instance, due to the worst bark-beetle outbreak ever recorded, CZ doubled their total removals in 2019 compared to their harvest rate in 2014. Thus, the increasing impact of natural disturbances combined with the growing harvest demand may further reduce the marginal share of increment available for wood supply.

6.5.2 Forest harvest and the carbon cycle

An accurate assessment of the amount of woody biomass removed from forests is essential not only to quantify the intensity and sustainability of current management practices but also the net carbon uptake provided from the overall forest ecosystem.

Indeed, on the one side, the ratio between the total amount of fellings and the total net annual increment condenses the evolution and the intensity of previous forest management practices, and it is an essential prerequisite to assess the future forest management strategies. On the other side, the difference between the NAI and the amount of removals is directly proportional to the living biomass carbon sink.

In addition, the absolute amount of biomass removals directly affects the net carbon sink attributed to the harvested wood products pool while the relative amount of logging residues, as well as the biomass lost due to natural disturbances, indirectly affects the net carbon sink attributed to the dead wood and litter pools (Pilli et al., 2021; Korosuo et al., in prep).

6.5.3 Data sources on forest harvest

The amount of biomass harvested in the forests is reported by various data sources, which however present some differences regarding the spatial and temporal coverage and the variable reported (see Figure 69) for an overview of the definitions).

FAOSTAT reports the total amount of roundwood removals since 1961 for all EU-27 countries (in m^3 under bark), including both wood used for energy and for material; SoEF reports the total amount of fellings at specific time intervals since 1990, including logging residues (attributed both to the total forest area and to the FAWS area, in m^3 over bark) but omitting data for some Member States; ESTAT collects, on a voluntary basis, data on removals from logging activities since 2000 and makes also available the amount of roundwood removals reported in the Joint Forest Sector Questionnaire (JFSQ). A detailed comparison between these data highlights that, at country level, they are generally mutually consistent (Pilli and Grassi, 2021; Pilli et al., 2023).

Based on the data reported in the SoEF (2020), we noticed that at least 95% of the total amount of fellings (100% for 6 out of 14 countries reporting data for 2015) of most Member States is provided for the FAWS rather than for the total forest area (only in the Netherlands, about 20% of fellings is allocated outside the FAWS). Therefore, to provide a consistent comparison between various data sources, all values are converted to over bark and scaled against the area attributed to FAWS, as reported in the SoEF (2020) for specific time intervals.

6.5.4 Trend in fellings and removals

For the EU-27, the amount of fellings reported in the SoEF shows a clear upward trend, increasing from about 2.4 $m^3\ ha^{-1}\ yr^{-1}$ in 1990 to 4.7 $m^3\ ha^{-1}\ yr^{-1}$ in 2015 (Figure 75). FAOSTAT also reports a similar trend, with removals relatively stable between 1960 and 1985 and then increasing from about 3.0 $m^3\ ha^{-1}\ yr^{-1}$ in 1990 to 4.0 $m^3\ ha^{-1}\ yr^{-1}$ in 2015. However, since fellings are (by definition) larger than removals, the SOEF data are likely underestimated, as the total amount of fellings reported by the SoEF until 2010 is lower than the FAOSTAT removals.

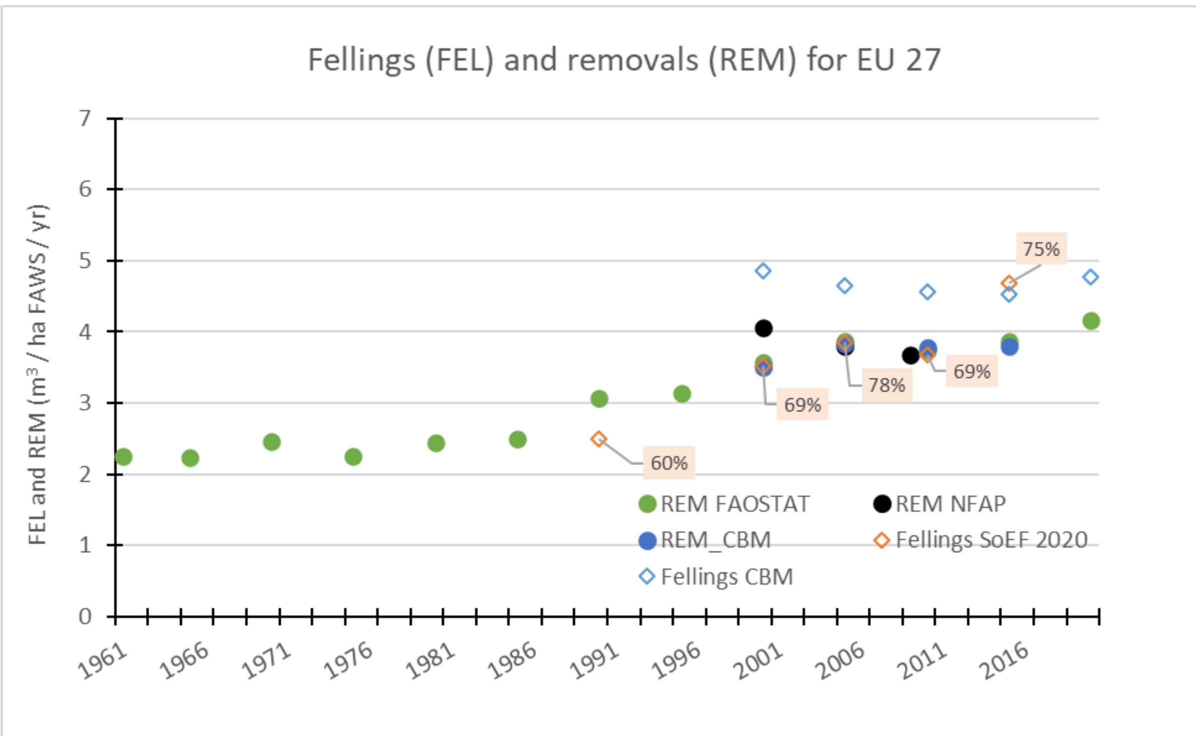
This effect is due to two reasons. Firstly, the SoEF does not report data for a few countries that, all together, cover at least 25% of the total FAWS area. Secondly, in some cases, the values reported as fellings in the SoEF are probably referred to the removals, as described in Pilli and Grassi (2021). Moreover, as highlighted from Camia et al. (2018), also the removals reported by FAOSTAT resulted to be underestimated by up to 20%, mostly because of the lack of data reported for the fuelwood sector.

Recently, a detailed analysis of the data reported by the Member States within their National Forestry Accounting Plans highlights that some countries (such as DE, BE and NL) improved the completeness of their data series, including for example the amount of wood used for energy, which was partially unaccounted from previous statistics (Korosuo et al., 2021; Päivinen et al., 2022). These adjustments were taken up by FAOSTAT, which was partially revised accordingly to these updates, improving the overall accuracy of the data series (Päivinen et al., 2022) and making it well in line with the total removals derived from the NFAPs for EU-27 in 2005 and 2009.

However, considering that the data reported by some countries, such as RO or IT, still need to be further revised (Ciceu et al., 2019; Pilli et al., 2021), we can infer that the overall removals estimated at EU level are still partially underestimated. In these cases, ancillary information provided from remote sensing may integrate other data sources collected at country level (i.e. Ceccherini et al., 2020, 2022).

A further comparison of these data sources with the data used for calibrating the CBM highlights that the removals considered by CBM are well in line with the most recent data provided from FAOSTAT (and from NFAPs[51]), at least until 2015. Instead, the amount of fellings estimated by the model is generally higher than the fellings derived from the SoEF, except for 2015 when, according to both data sources, the fellings were around 4.5 - 4.7 m^3 ha^{-1} yr^{-1}.

Figure 75. Comparison between (i) fellings (FEL, including logging residues) estimated from SoEF (2020) and CBM and (ii) removals (REM, excluding logging residues) derived from FAOSTAT (FAOSTAT, 2022), from CBM and from the data reported within the National Forest Accounting Plans (NFAP) submitted in 2019 from EU Member States (see Korosuo et al., 2021). All values are reported in m^3 over bark (o.b.) ha^{-1} yr^{-1}, scaled against the FAWS area reported in SoEF 2020 (before 1990 the FAWS area is assumed as constant and equal to the value attributed to 1990), assuming an average bark's fraction equal to 12% to convert the volume under bark (u.b.) reported by FAOSTAT to o.b. For SoEF, the figures are only scaled against the area corresponding to the countries that report data. The share of FAWS covered from these countries is reported in the light-orange boxes.



Source: JRC own elaboration

6.5.5 Balancing growth and losses: the fellings rate

The ratio between the amount of fellings and the net increment represents the fellings rate, which is a key indicator because its long-term trend determines the evolution (increasing, stable or decreasing) of the biomass stock standing in the forest. Assessing the evolution of the annual fellings rate is challenging because the overall

[51] This is due to the fact that FAOSTAT data were preliminarily corrected, at country level, to account for possible unreported harvest, taking into account other ancillary information reported by literature (see Pilli et al., 2015).

uncertainty on fellings and removals obtained from various data sources adds up to the uncertainty on the increment data.

As expected, the fellings rate inferred from the SoEF increases in time, from 66% in 1990 to 79% in 2015[52] (Figure 76). However, these values refer only to part of the FAWS and they are estimated as the ratio between the total amount of fellings – including the merchantable wood components, the Other Wood Components (OWC) removed with harvest and the logging residues – and the NAI. Since the NAI, according to international definitions, is mostly referred to the merchantable standing stock (see Gschwantner et al., 2022), the fellings rate derived from the SoEF also includes a fraction of removals (i.e. OWC) not accounted within the definition of NAI.

When applying the same definition of the fellings rate to the data obtained from CBM, we estimated a fellings rate varying from 82% of the NAI in the year 2000 to 78% of the NAI in 2015, with this last value being in line with the rates derived from the SoEF. However, by using the CBM output, we could also estimate the ratio between the amount of fellings, including only the merchantable wood component and corresponding logging residues (i.e. excluding OWC), and the merchantable NAI. In this case, the fellings rate decreases to about 74% in 2000 and 69% in 2015.

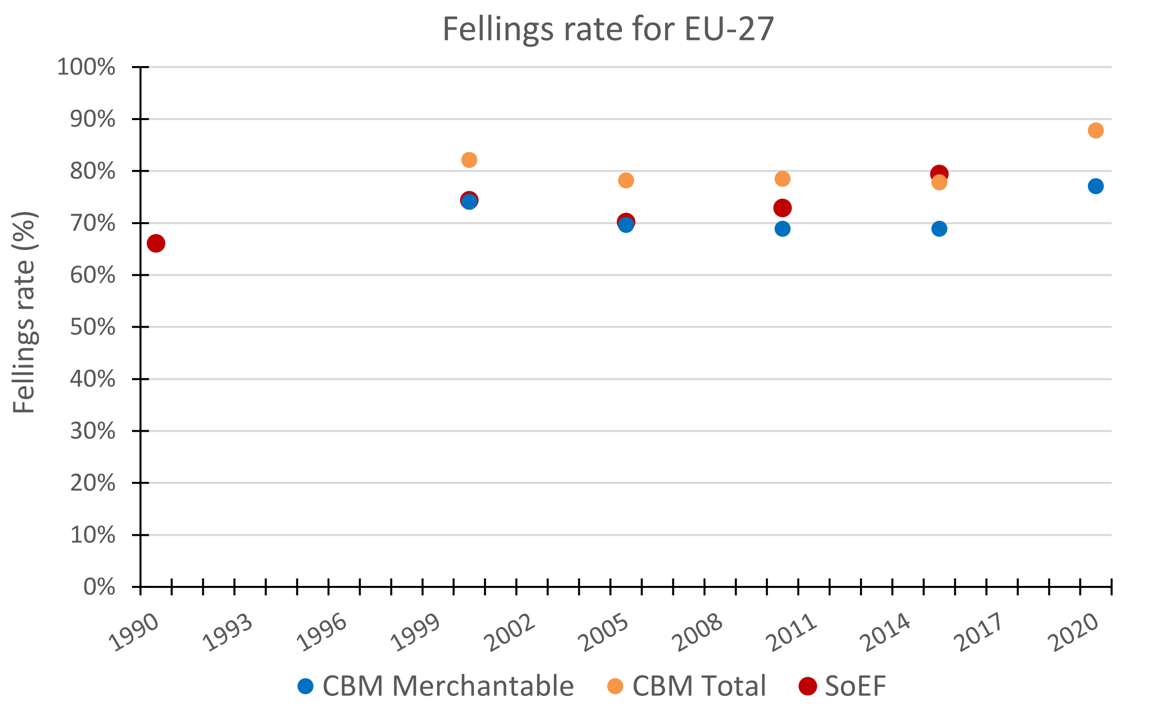
Based on the historical data series derived from CBM for the period 2000 - 2015 and taking into account that the absolute amount of removals reported by FAOSTAT increased to 4.3 m^3 ha^{-1} yr^{-1} in 2020[53], we estimated that the actual fellings rate in 2020 ranges between 77% (if calculated against the merchantable fellings rate) and 88% of the NAI (if calculated against the total fellings rate).

Based on this analysis, and despite the differences between various data sources, it is important to note that the overall fellings rate at EU level, even if it has been certainly increasing during the last decade, is still certainly below the current NAI. Of course, the increasing impact of natural disturbances on some countries during the last quinquennium, and the recent increase of the harvest demand, also determined from the international framework, may further reduce the marginal share of increment available for wood supply.

[52] Official statistics on the felling rate in 2020 are not yet available.

[53] This corresponds to +12% compared to the amount of removals reported by FAOSTAT for 2010. This share was used to calibrate the amount of fellings and merchantable removals derived from CBM for 2020, deriving the corresponding fellings rate. The NAI was already available from the CBM output for the period 2016-2100 (see Pilli et al., 2022, Korosuo et al., in prep).

Figure 76. Comparison between the fellings rate derived from SoEF and estimated from CBM, considering the total amount of fellings (CBM Total = NAI / (merchantable components + other wood components + logging residues) and the merchantable fellings' component (CBM Merchantable = NAI / (merchantable components + logging residues)).



Source: JRC own elaboration

6.5.6 Natural disturbances

6.5.6.1 Climate change and natural disturbances

Forest types and forest functioning are strongly determined by the interplay of climate and environmental factors, such as temperature, precipitation, vapor pressure deficit, and radiation. Therefore, changes in climate conditions and climate extremes can impact forest ecosystems (e.g. Hartmann et al., 2022).

In Europe, we are witnessing in the recent years an increase in climate variability. Extreme events such as droughts and/or heat waves are becoming more frequent and severe than in past decades (Trenberth et al., 2014; Spinoni et al., 2018), and they are spreading in wetter regions (Kornhuber et al., 2020), where vegetation is less adapted to cope with droughts and heat stress.

Recent climate extremes have impacted forests mainly through, first, an increase of tree mortality (e.g. Hartmann et al., 2022); second, an abrupt reduction of productivity (Reichstein et al., 2013), and finally, through potential carry over effects that impact forest productivity and functioning, as well as the probability of biotic disturbances, in the years after the climate extremes.

Recently, Salomon et al. (2022) evaluated the effect of the 2018 European heatwave on tree growth for 21 tree species in 53 locations in Europe. They found that the effects varied substantially by species and showed that conifer (particularly Norway spruce and Scots pine) are more vulnerable to extreme heat waves and droughts than deciduous species. This is a very relevant finding, considering that these two conifer species alone store about 40% of the total biomass of the EU forests (see section 6.1.2).

Moreover, drought and heatwave interplay with other natural disturbances such as fires and pest outbreaks that can lead to increase of tree mortality as shown in a recent literature review (Hartmann et al., 2022).

6.5.6.2 Natural disturbances in European forests

European forests are threatened by natural disturbances caused by abiotic and biotic agents such as windstorms, droughts, fires, insect outbreaks or a combination of these agents, which are exacerbated by climate change. Natural disturbances influence forest ecosystem services in different ways and there is evidence that such disturbances have dramatically increased in Europe in the last 40 years (Thom and Seidl, 2016).

The forest vulnerability to natural disturbances is determined by its structural properties, climate and landscape factors, and the agent of natural disturbances (Forzieri et al., 2020). Climate change will modify forest structure and dynamics through direct effects, such as precipitation, temperature and droughts, and indirect effects such as natural disturbance, which in turn will affect wood production, carbon storage and other ecosystem services (Lindner et al., 2014; Senf et al., 2020).

The rising intensity and frequency of natural disturbances are mainly due to the changing climate and a long history of human activities in the forests, and it is expected that these disturbances will be more frequent and intensive in the future due to climate change (Seidl et al., 2017). All these processes are expected to impact the forest growth, and their future dynamics will have substantial impacts on the forest increment in the coming years (Pilli et al., 2022).

It is estimated that the average amount of wood damaged by windstorms and bark beetles increased from about 35 million m^3 per year over the period 1950 - 2000 in Europe (Schelhaas et al., 2003) to over 100 million m^3 in 2018 only in 17 Member States (Camia et al., 2021), with large variations between years and among countries. When comparing the decade 1971 - 1980 with 2001 - 2010, in Europe insect outbreaks increased by 602%, wildfires by 231% and windstorms by 140% (Seidl et al., 2014).

6.5.6.3 Trend and causes of salvage logging

Natural disturbances in the EU are often followed by salvage logging, which can affect the primary wood supply in the forest-based sector. Salvage logging is a common and, in many EU countries, mandatory practice to remove damaged wood after a disturbance. Wood removal is performed to minimise losses and to prevent the spread of pests and disease to the remaining living trees. After wind or snowstorms, the damaged logs tend to degrade rapidly due to insects and other pathogens, therefore salvage logging is often performed in the weeks following the disturbance although, in case of large events, it may take years to be completed.

In the case of a large-scale disturbance, salvage logging introduces on the market a significant amount of wood of various qualities (damaged, infected, rotten, broken, split) within a very short time, which might distort the market by reducing wood prices and by increasing the woody biomass flows for energy (Holmes, 1991, Udali et al., 2021, Camia et al., 2021).

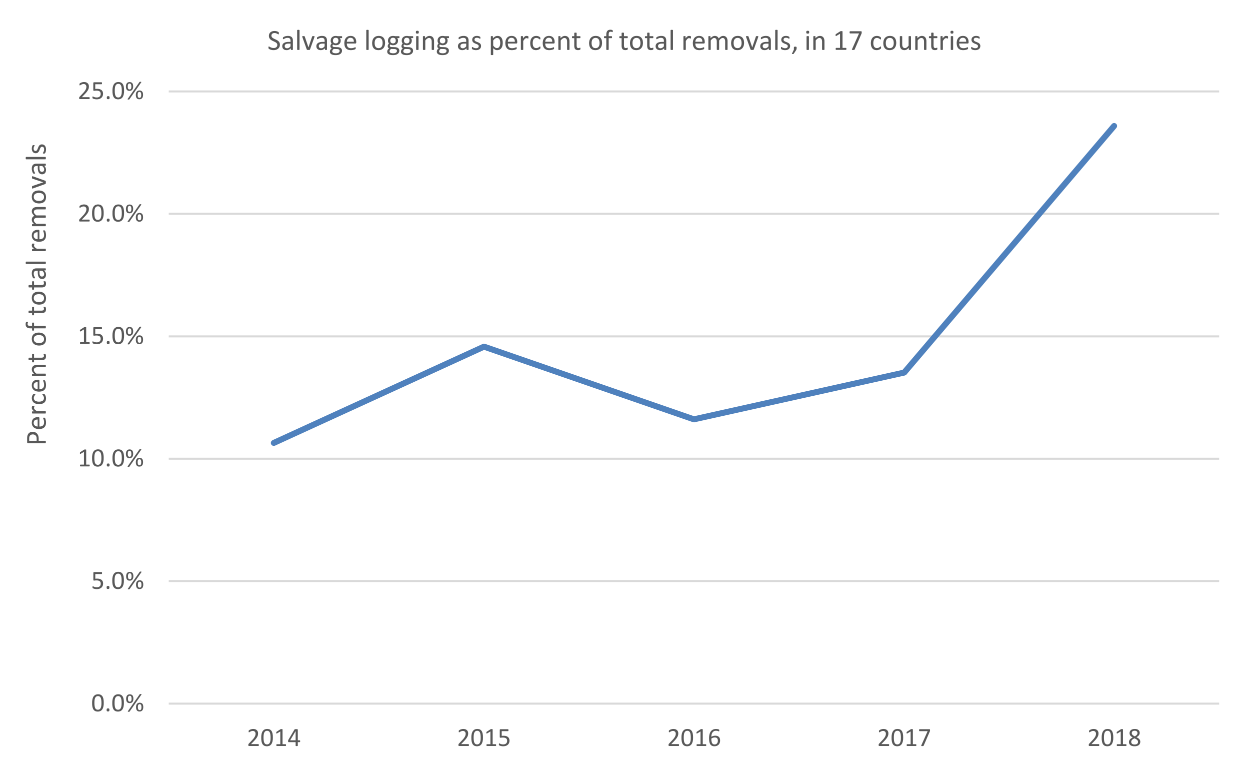
Currently there is no common European dataset on salvage logging that allows to estimate the effects of natural disturbances and to draw conclusions at EU scale. For this reason, the European Commission (DG AGRI), in collaboration with the JRC, has collected data for the period 2004 - 2019 on total harvest, salvage loggings and causes of salvage loggings in 17 Member States, representing 76% of the total EU-27 forest area. The data were extracted from publicly available national datasets, reports, Eurostat and/or consulting with national experts. Data on salvage loggings were found for the following Member States: AT, BG, CY, CZ, DE, EE, FI, FR, HR, HU, LT, LV, RO, PL, SE, SK and SI (see Camia et al, 2021).

The national data on salvage logging were harmonised to perform a meaningful comparison and integration. Since most countries report salvage loggings under bark, the countries reporting data over bark were converted to under bark by using forest product conversion factors (FAO, 2020). In PL, data on salvage loggings are collected only in the state forests that represent 80% of the national forest area and were upscaled to the country level.

The results of this study, first published in Camia et al. (2021), were recently revised using FAOSTAT data for the cases where the original dataset did not report sufficient information to attribute correctly the salvage loggings either to fellings or removals, or to volume under bark or over bark.

The revised time series with annual data on salvage loggings varies among Member States and data are available for all 17 Member States only for the period 2014 – 2018. According to this revised dataset, salvage loggings increased from 44.3 million m³ in 2014 to 103.5 million m³ in 2018, corresponding to an increase from 10.6% to 23.6% of total removals (Figure 77).

Figure 77. Evolution of the amounts of wood extracted from salvage logging as percentage of the total removals during the period 2014 – 2018 as reported by 17 EU countries.



Source: JRC 2022 (own data)

Data on the causes of salvage loggings for their respective time periods are available in 10 countries: AT, CY, CZ, FI, DE, LT, PL, SI, SK and SE. This dataset indicates that, for most countries, wind was the first cause of salvage logging, followed by insect outbreaks and then fires or other causes. However, the magnitude of the rise in salvage logging varies largely between countries, with central Europe showing a large pulse of bark beetle infestations. For example, in CZ in 2018, salvage loggings accounted for 90% of total removals, while in SE were negligible (Camia et al., 2021).

The increase in salvage loggings might be partly responsible for increased harvesting rates observed in the EU over recent years. For instance, CZ has experienced since 2015 the worst bark-beetle outbreak ever recorded, and their total removals doubled in 2019 compared to the harvest rate in 2014 (CSO, 2019).

This case illustrates that natural disturbances may force significant amounts of woody biomass into the market in a very short time. Even though it is likely that damaged wood is used for lower quality wood products and for bioenergy, it is difficult to assess the overall flow and the various uses of the wood obtained from salvage loggings due to limited data availability and the further work needed to characterise the woody biomass flows after salvage loggings.

6.6 Conclusions for Chapter 6

6.6.1 The status of biomass in European forests

This chapter presented an overview of harmonised and recent statistics and maps for the EU forests regarding the forest biomass stock, the share available for wood supply, the biomass growth (gross and net increment), and the losses due to harvest and natural disturbances. Most of the results presented here were derived by harmonising national statistics and published maps using common definitions, estimation methods and updating them to a common reference year.

According to our harmonised statistics, the aboveground biomass stock of the EU forests in the year 2020 is equal to 18.4 billion tonnes of dry matter, corresponding to an average biomass density of 117 tonnes per ha. The forests of central Europe store most of the biomass stock (10 billion tonnes) and present the highest biomass density (176 tonnes per ha), which gradually decreases moving towards southern (86 tonnes per ha) and northern (81 tonnes per ha) Europe. The EU forest biomass is almost equally stored between broadleaves and conifers, and about 40% is produced by two conifer species alone, *Picea sp.* and *Pinus sylvestris*.

In total, 89% of the forest area and 92% of the biomass stock of the EU is available for wood supply. The share of wood available decreases from northern (SE, FI) to southern (IT, PT) Europe, mostly because the relatively lower productivity of some area, makes harvesting not profitable, at least within a market still dominated by coniferous species' demand. The second main factor limiting wood availability is linked to orographic conditions (e.g. on the Apennines) which historically reduced the access to marginal lands, indirectly preserving ecosystems (e.g. old-growth forests with high biomass density) recently included within protected areas. Finally, socio-economic and historical reasons certainly played a key role. Until the 50s, southern and central European forests resources have been largely exploited, but after the second World War, the economic drivers have reduced the pressure on southern European forests (i.e. on coppices), increasing the demand on northern European forests.

In 2015, the EU forests produced 902 million m^3 of wood, of which 132 million m^3 were lost due mortality, resulting in a net annual increment of 770 million m^3 (85% of the gross increment). The average net annual increment is 4.9 m^3 per ha, but it varies largely across Europe reaching more than 8 m^3 per ha in central European forests and gradually decreasing towards Scandinavian and Mediterranean countries as a consequence of environmental constrains but also, in some areas, of the large natural losses.

The EU harvest level in 2015 was about 4.0 m^3 per ha (or likely higher, since fuelwood removals tend to be underestimated), meaning that 82% of the net annual increment was harvested. It is important to notice that the quality of the harvested wood is affected by the impacts of the natural disturbances. In 2015, about 15% of the wood harvested was obtained from salvage loggings, which is likely a damaged wood that can be used for lower quality wood products and for bioenergy, and this share has recently increased, especially in central Europe.

6.6.2 Upcoming challenges for biomass production in European forests

According to international reporting, the total area and the biomass stock of the EU forests have increased during the period 1990 – 2020 but their growth rate has slowed down significantly during the last 5 years. Instead, the forest area available for wood supply has increased since 1990 but it has become stable already since 2005.

This dynamic is reflected (and related) to the temporal evolution of the net annual increment. The average forest increment in the EU has increased from 1950 until 2005 but, between 2005 and 2015, it has remained quite stable and, according to the most recent data and modelling results, it is expected to decrease during the period 2020 – 2025, assuming the continuation of the current forest management practices. This evolution of the net annual increment is likely due to various factors, one of them being the ageing of the European forests, in particular of the broadleaves stands.

Contrastingly, the harvest level in EU was relatively stable between 1960 and 1985 but showed a clear upward trend between 1990 and 2015. This trend is related to the ageing of the forests, the increase wood demands from the market, and to the substantial increase in natural disturbances, and subsequent salvage loggings, observed during the last years, especially in central Europe. For instance, due to the worst bark-beetle outbreak ever recorded, CZ doubled its removals in 2019 compared to 2014.

The ratio between the fellings and the net increment (or, fellings rate) is a key variable because it determines the temporal evolution of the forest biomass stock and affects the future wood availability. The fellings rate slowly decreased from 82% to 78% of the NAI between 2000 and 2015, but it is estimated to grow and reach the 88% of the net annual increment in 2020.

The fellings rate has been thus increasing during the last decade as a result, on the one side, of the growing wood demand from the market, and on the other side, of the stable (or decreasing) net increment, but it is still below the current net annual increment. However, the increasing impact of natural disturbances may further reduce the marginal share of increment available for wood supply. In fact, Europe is witnessing an increase in climate variability and climate extremes that have caused a surge of tree mortality and a reduction of productivity. Moreover, drought and heatwave interplay with other natural disturbances such as fires and pest outbreaks, multiplying the negative impacts on the forest increment expected in the coming years.

This chapter focuses on the assessment of forest biomass production, without considering the companion land use category "other wooded land" (OWL). Harvest statistics often includes also the amount of wood coming from OWL, but this is generally just a minor fraction of the total amount of harvest that cannot be easily disentangle. This means that, the felling rate attributed to forest land may be slightly overestimated when harvest include also the wood harvested from OWL. However, while within the Mediterranean countries the OWL area is always > 20% of the area classified as forest land, within central and north European countries, this area, if reported, generally cover less than 5% of the forest land (Pilli et al., 2023). Moreover, within the Mediterranean countries, OWL are mostly marginal areas, not managed for wood production[54].

6.6.3 How to improve the monitoring of forest biomass

In Europe, the NFIs provide valuable reference statistics but they refer to different definitions, spatial scales, monitoring periods and temporal frequency. When integrating statistics from 27 countries, data harmonisation is essential to perform any meaningful pan-European assessment. Such task highlights the importance of a wide collaboration with NFI experts, as they provided key data for this study under the coordination of ENFIN. Moreover, harmonised data can support and facilitate a stronger integration among existing EU monitoring and reporting systems, such as the Forest Information System for Europe (FISE), the SoEF reports, the JRC Forest Observatory and the Copernicus maps.

The harmonised statistics presented in this chapter provide unbiased estimates at administrative level but they remain limited in their spatial resolution. For these reasons, we also produced EU-wide maps at 100 m resolution on forest area, forest biomass and forest available for wood supply that are consistent with the statistics.

However, such “static” database cannot always fulfil the multiplicity of applications increasingly requested from a forest monitoring system, which also needs to provide time-series information that are coherent, up-to-date and spatially detailed on a variety of forest variables. Such characteristics can only be achieved with a long-term acquisition and integration of ground and remote sensing data that are designed and acquired in a way to be highly compatible.

On one side, the ground surveys need to acquire reference data that can be used to calibrate and validate remote sensing maps as well as to estimate the forest properties that cannot be estimated by remote sensing. Considering the growing impacts of climate change on forest, it is becoming increasingly important to invest in repeated, consistent ground surveys of, e.g. forest growth, health, mortality, natural disturbances and management practices.

On the other side, Earth Observation can be used to integrate and support ground-based data with wall-to-wall forest monitoring over large areas with high spatial resolution in a timely, consistent and independent way. Remote sensing of forest can improve the monitoring of forest dynamics, facilitate early warnings and timely responses to forest disturbances, and support the implementation of forest policies and trade-off analysis.

[54] For an in deep analysis of the definition and assessment of the area classified as OWL at country and EU level, we refer to Pilli et al., 2023.

In the bioeconomy context, Earth Observation (see Box 1) allows a better assessment of the potential supply of forest biomass through the detailed mapping of the standing biomass stocks and the geospatial modelling of the restrictions to biomass availability, the harvesting costs, and the potential trade-offs between economic and ecological ecosystem services. In relation to climate policies, satellite data can be used to better measure and monitor the forest carbon sinks and sources from the forest sector.

Satellite and airborne data are also increasingly used within the NFI systems to improve the efficiency of the ground sampling (pre-stratification) and the estimation of the forest variables (post-stratification), or to provide an independent source of data to compare with sample-based statistics.

Moreover, the remote sensing of forest properties is rapidly evolving thanks to new, dedicated satellite missions and sensors, the increasing use of airborne laser sensors for sub-national monitoring, the promising results of the terrestrial laser sensors for high-quality ground reference data and a better understanding of how to collect and relate plot data with satellite data.

Certainly, the monitoring strategy depends on the scale of analysis (European, national, sub-national, local) and the forest characteristics, with substantial differences between the Mediterranean and boreal regions. Given the variability of the ground data availability, the different capabilities of the satellites among the ecoregions and the high diversity of European forests in terms of ecological conditions and dynamics, there will not be a single optimal data source for all forest types. Instead, the way towards a better monitoring will be through the skillful integration of the existing and upcoming satellite data with other geospatial data, with airborne and terrestrial lidar measurements, with ground plots and with local and expert knowledge.

For example, a cost-effective strategy may use a multi-layered approach and integrate satellite data, freely available over large areas with frequent wall-to-wall coverage, with airborne lidar flights, which are relatively costly but provide high-quality biomass estimates for mapping at sub-national scale and for satellite calibration at regional scale, and with forest plots and terrestrial lidar, which provide accurate reference data at local scale for the proper calibration and validation of airborne and satellite data. The synergic use of these data can allow the accurate, consistent, timely estimation of the biomass stocks and their changes in European forests, and ultimately support a better assessment of the forest resources and their potential role in the bioeconomy.

To this end, as announced in the EU Forest Strategy for 2030, the Commission will come forward with a legal instrument on EU Forest Monitoring and plans that look into long-term development of forests and the forest-based sector. Today, information about EU forests is patchy, derived by a range of methodologies for parameters with different definitions across Member States and provided too late for rapidly evolving situations. The above-mentioned legal proposal would stress the role of earth observation technologies in combination with ground-based data collection approaches to make available harmonised data layers and information about EU forests in a timely manner and at high spatial granularity, where appropriate. Such information will be essential not only to assess the high and increasing demands on forests but also to develop appropriate integrated policies, taking into account the growing stress of forests under a changing climate and combatting the loss of biodiversity.

6.7 References for Chapter 6

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7 Woody biomass sources, uses, flows and cascade use of wood

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Key messages

- The total use of woody biomass (primary wood, secondary wood, unreported and net-traded) for material (including the paper and paperboard sector) and energy in the EU-27 was 947 million cubic meters (Mm^3) in 2017. Of this total, 45% (424 Mm^3) was used for energy, while 55% (523 Mm^3) was used for material.
- The use of primary woody biomass has increased, mainly driven by the increased demand for primary woody biomass for material and energy. A slight trend towards an increase in the share of woody biomass used for energy is observed.
- The sources of primary woody biomass were mainly domestic removals from forests and other wooded lands within the EU-27. The overall net-import of primary and secondary wood to the EU-27 is less than 5% of the total sources. The net-import of primary wood has remained steady during the analysed period (2009-2017), while the net-import of secondary wood has slightly decreased.
- The increase in the domestic removals is attributed to the growing demand for woody biomass for material and energy uses, as well as an increase in salvage loggings due to natural disturbances.
- In 2017, secondary woody biomass (such as industrial by-products[55] and bark) accounted for 48% of the sources used for energy production, while 44% came from primary wood and 8% was uncategorised (origin not reported). Only a small amount of post-consumer wood was used for energy.
- For material production, primary wood is the most used source, followed by recovered woody biomass (mainly recovered paper).
- The sawmill industry plays a vital role in the wood-based sector in the EU-27, as it is the largest industrial user of primary woody biomass and the main supplier of industrial by-products.
- Woody biomass sources are underreported, while inconsistency among different datasets is increasing over time. Significant efforts to improve data quality are therefore required.
- The cascade use of by-products and post-consumer wood to materials has slightly decreased throughout the period (2009-2017) relative to the total woody biomass used. This decline is partly due to the increase in direct use of secondary woody biomass for energy.
- There is potential to increase the use of by-products and post-consumer wood for material use, particularly in the wood-based panel and wood pulp industries.

More than half a billion cubic meters of various wood assortments (sawnwood, pulp wood, fuelwood etc.) are harvested and placed on the EU-27 market yearly. Traditionally, primary wood (stemwood, treetops and branches) that is harvested from the forest and other wooded land is mainly used for wood products (sawnwood, pulp and paper, wood-based panels), and for energy. Secondary woody biomass (forest industry by-products, referring to secondary products made in the manufacture of sawnwood, wood-based panels and wood pulp, bark, and recovered post-consumer wood[56]) is mainly used for energy but is also used for materials (wood-based panels, pulp and paper). Analysing primary and secondary woody biomass flows, including circular flows and trade, is a complex task, because within the wood-based industries there are synergies as well as competition (see Cazzaniga et al., 2022).

[55] The term 'by-products' used throughout this chapter refer to secondary products made in the manufacture of sawnwood, wood-based panels and wood pulp.

[56] In this report, post-consumer wood is generally considered as secondary wood, but in some cases reported separately.

The typical supply chain of woody biomass starts with primary wood, which is processed either into materials or directly used for energy generation. If processed into materials, the final product may be further transformed for either material or energy purposes after its lifecycle. A quantification of woody biomass flows, including use of industrial by-products and the recycling of post-consumer wood or recovered paper and trends thereof, is important to support the implementation of the European Green Deal, and to the EU Forest Strategy for 2030, the EU 2018 Bioeconomy Strategy, and the Renewable Energy Directive.

An EU-level analysis of woody biomass sources, uses and flows is derived from different datasets to produce quantities for all the EU-27 Member States. Good quality and continuous data are an essential basis to support the analysis of woody biomass flows. Many scientific publications deal with the known open issues of data coverage and the methodologies to check and improve data quality, both for national and international analyses (Buongiorno, 2018; Kallio and Solberg, 2018; Jochem et al., 2021). For this reason, during the last years, international organizations (FAO, EUROSTAT, UNECE, etc.) have been working to gather more reliable and complete statistics on woody biomass. Nevertheless, for an in-depth analysis of the forest-based sectors, available reported data still needs a critical overview to identify the best data sources both for the specific sectors and for the different Member States. The EU-27-aggregates can be derived only after detailed data analysis for each Member State. In this respect, during the last years, the JRC has invested in building a reference database, which is published as the EU wood resource balances (Cazzaniga et al., 2021) and Sankey diagrams of biomass flows (Cazzaniga et al., 2022), both at Member States and at EU-27 levels. This effort has minimised the data inconsistencies and obtained, where possible, estimates of unreported amounts of woody biomass. This chapter will exploit the results of that work.

The results presented in the wood resource balances (WRB) and in the Sankey diagram have been derived from various official data sources (Table 6). All values in the wood resource balances and in the Sankey diagram have been converted to cubic meters of solid wood equivalents (SWE) using conversion factors to overcome the problem of different reported units.

Table 6. Data sources used for WRB and Sankey estimates in Cazzaniga et al. (2021) and in Cazzaniga et al. (2022).

Data source	Organization	Data
Joint Forest Sector Questionnaire (2021)	EUROSTAT, UNECE, FAO, ITTO	Production, imports and exports of forest products and removals
Eurostat database (2021)	EUROSTAT	Wood pellets production imports and exports
Input/output coefficients	(Mantau, 2010)	Input/output coefficients for wood products
Forest product conversion factors for the UNECE region (2010/2020)	UNECE, FAO	Bark correction factor, input coefficients
Joint Wood Energy Enquiry (2021)	UNECE/FAO Forestry and Timber Section, IEA, EUROSTAT	Use of wood for energy, input coefficients, conversion factors
National Renewable Energy Action Plans (NREAP) Progress Reports (2020)	European Commission, JRC	Use of wood for energy

Source: JRC own elaboration

7.1 Wood resource balance

The wood resource balance (Mantau, 2015) is a recognised tool to verify data quality and to compare and get an overview of woody biomass sources and uses. Some woody biomass is used more than once before reaching its final use (for instance, part of roundwood input to a sawmill is output as sawmill residues and afterwards used as input in wood-based panels, wood pulp production or energy). For this reason, in the balance table, some woody biomass is accounted for more than once, both in the sources and the uses side, according to the number of processes. The summary results of the wood resource balance are presented in Table 7 for the latest available year (2017). The Wood Resource Balance sheets for each Member State from 2009 to 2017 are published in the Knowledge Centre for Bioeconomy's platform as downloadable publications[57] and interactive diagrams[58] .

Table 7. Summary of wood resource balance for the year 2017 in the EU-27, derived from Cazzaniga et al., (2021)[59]. 'Primary' sources includes all woody biomass removed directly from forest and other wooded land (all components of the tree); 'Material' represents the feedstock needed for the material industries; 'H&P' means Heat and Power

Wood Resource Balance 2017 (all units in SWE)

	SOURCES	Mm^3	Mm^3	USES	
PRIMARY	Industrial roundwood removals	355.5	195.4	Sawmill industry	MATERIAL
PRIMARY	Fuel wood removals	118.1	100.6	Wood panels industry	MATERIAL
PRIMARY	Net-import roundwood	10.7	155.3	Wood pulp industry	MATERIAL
PRIMARY	Bark	67.1	187.8	Direct wood	H&P
SECONDARY	Domestic solid by-products	100.8	201.3	Indirect wood	H&P
SECONDARY	Black liquor	71.3	34.5	Unknown wood	H&P
SECONDARY	Net-import solid by-products	7.4			
SECONDARY	Net-import wood pellets	2.0			
	Post-consumer wood	38.1			
	Total sources	**771.1**	**874.8**	**Total uses**	

103.7
Unreported sources

Source: JRC 2022

Results of wood resource balance data analysis show that the declared amount of primary wood sources in 2017 in the EU-27 was 551.4 million cubic meters (Mm^3) (484.3 Mm^3 under bark), of which 97.8% are from domestic removals and only 2.2% are net-imports. This means that the EU-27 is almost self-sufficient in terms of primary wood supply. Industrial by-products, wood chips and particles together with black liquor, amount to 179.6 Mm^3 of which 95.9% is domestic and 4.1% are net-imported, again illustrating low dependency on wood supply from third countries.

More than half (451.3 Mm^3) of woody biomass sources were used for material (excluding the paper and paperboard sector). The sawmilling industry is the largest industrial user of woody biomass followed by the wood pulp industry and wood panel industry. Energy production is obtained by a mix of 44% of primary wood and 48% of secondary woody biomass and 8% of woody biomass of unknown category.

Ideally, the woody biomass sources and uses should be balanced. However, comparison between sources and uses reveal a non-negligible difference between the two. For all the analysed years (2009-2017), the total amount of woody biomass used in manufacturing of wood-based products and for producing H&P exceeds the total amount of reported sources (see last column "Balance" in Table 8). This gap has been increasing, and in 2017, amounted

[57] European Commission's Knowledge Centre for Bioeconomy: https://knowledge4policy.ec.europa.eu/publication/wood-resource-balances_en.

[58] European Commission's Knowledge Centre for Bioeconomy: https://knowledge4policy.ec.europa.eu/visualisation/bioeconomy-different-countries_en#wrb.

[59] In Cazzaniga et al. (2021), the wood pellets industry was included in the material sector too, following the approach of Mantau (2015), and consequently its domestic production is considered as secondary source too. This is important in terms of value added of production, which is out of scope of this report. For the sake of the following analyses, the production of domestic wood pellets has been accounted for just in the H&P sector.

to close to 104 Mm³ at the overall EU-27 level, with large differences among Member States (Table 9). This increase could, to some extent, be explained by the more complete reporting by the EU Member States on the uses side.

Table 8. Summary of wood resource balances 2009-2017, derived from Cazzaniga et al. (2021). Values are expressed in Mm³ SWE.

Year	Sources			Uses		Balance
	Primary	Secondary	Post-consumer wood	Material	Energy	(Uses - Sources)
2009	464	148	29	378	324	61
2010	524	165	31	408	357	45
2011	522	162	32	412	349	45
2012	520	170	34	407	373	56
2013	530	169	36	412	399	76
2014	533	171	35	419	397	77
2015	544	170	35	425	409	85
2016	551	176	37	440	421	97
2017	551	181	38	451	424	104

Source: JRC 2022

Table 9. Summary of wood resource balances of 2017 for all MS, derived from Cazzaniga et al. (2021). Values are expressed in thousand m³ SWE.

Member State	Sources			Uses		Balance
	Primary	Secondary	Post-consumer wood	Material	Energy	(Uses - Sources)
Austria	29,606	12,181	1,680	30,642	24,569	11,744
Belgium	8,456	6,158	1,546	8,843	5,660	-1,657
Bulgaria	6,794	1,109	0	4,650	4,565	1,312
Croatia	5,015	812	253	4,271	3,435	1,625
Cyprus	21	12	0	2	112	81
Czechia	16,509	5,935	296	14,024	13,544	4,827
Denmark	4,129	7,185	350	1,857	17,374	7,567
Estonia	10,119	1,969	337	8,543	5,420	1,538
Finland	76,356	37,504	1,047	71,791	41,492	-1,624
France	53,753	15,093	2,837	34,357	42,729	5,403
Germany	80,337	26,101	14,768	72,883	59,684	11,361
Greece	2,083	389	19	788	902	-802

Hungary	6,014	972	0	2,917	3,465	-604
Ireland	3,725	1,097	458	3,692	1,356	-232
Italy	18,978	8,650	4,733	11,245	44,811	23,695
Latvia	12,691	2,891	0	14,085	8,943	7,447
Lithuania	6,087	2,561	0	5,004	6,491	2,847
Luxembourg	748	300	67	873	421	180
Malta	1	5	0	0	4	-3
Netherlands	2,965	1,006	1,891	1,047	4,385	-431
Poland	50,136	11,247	1,272	35,895	22,888	-3,872
Portugal	17,162	10,051	210	17,756	19,459	9,793
Romania	18,382	7,418	2,250	20,908	27,192	20,051
Slovakia	9,404	3,084	130	8,368	4,478	229
Slovenia	2,641	592	0	2,347	2,696	1,810
Spain	18,281	6,909	729	19,980	11,865	5,925
Sweden	90,986	46,945	3,238	91,008	45,650	-4,510

Source: JRC 2022

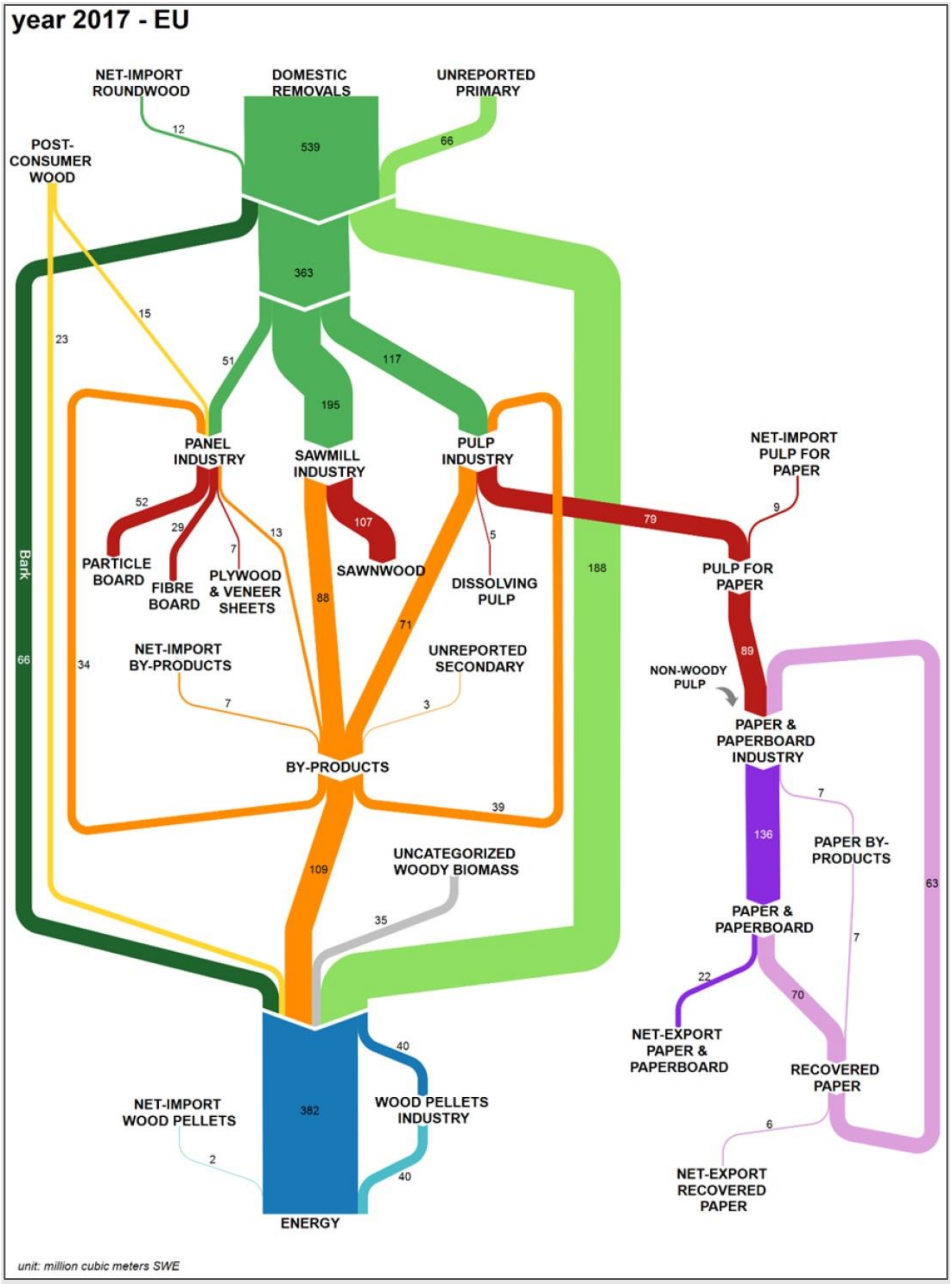
7.2 Woody biomass flows

The wood resource balance is a useful tool to point out inconsistencies in the data, but it is not suitable to identify where the major inconsistencies arise, nor to infer the unreported sources. In this respect, tracking the flow of woody biomass through the different sectors using a tool such as the Sankey diagram can be more helpful.

The Sankey diagrams are composed of arrows that represent the direction and quantity of the flows of woody biomass across the different sectors. The links among the different arrows are the nodes, which represent in some cases processes, while in other cases aggregate or disaggregate of the flows of the different categories of woody biomass. Each node should balance in terms of input and output, so it is possible to analyse the gaps in the nodes of the diagram, thus highlighting where there are gaps.

The methods used to derive woody biomass flows are published in Cazzaniga et al. (2022) and the values are reproduced in Figure 78 for the year 2017. This Sankey diagram also includes the paper and paperboard sector that is not included in the wood resource balance. The green arrows represent flows of roundwood over bark. The darkest green arrow represents bark, while the lightest green arrow are flows of roundwood under bark. Orange arrows represent the flows of all kinds of industrial by-products (both solid and liquid); dark purple arrows the paper and paperboard products; while light purple the recovered paper that is used in paper making industry. Yellow arrows represent post-consumer wood; red semifinished wood products; while the woody biomass flows for energy is shown in blue. The uncategorised woody biomass used for energy cannot be attributed to any major flows, therefore it is shown as a grey arrow. The Sankey diagrams for each Member State from 2009-2017 are published in the Knowledge Centre for Bioeconomy as interactive diagrams[60].

Figure 78. Sankey diagram of woody biomass flows in the EU-27 (year 2017). Values are expressed in Mm^3 SWE.



Source: JRC 2022

[60] European Commission's Knowledge Centre for Bioeconomy: https://knowledge4policy.ec.europa.eu/visualisation/interactive-sankey-diagrams-woody-biomass-flows-eu-member-states_en.

The Sankey diagram analysis reveals that domestic removals are the primary source of woody biomass in the EU-27. A large proportion of primary sources is used by the material industry (sawmill, wood pulp and wood-based panel industries); the remaining sources are used for energy. The sawmill industry is the largest industrial user of woody biomass and the main producer of secondary wood fibres. About half of the available industrial by-products are produced by the sawmill industry, namely high-quality secondary wood that are used by wood-based panel and wood pulp industries, as well as for energy. This means that the sawmill industry plays a crucial role in the wood-based sector, both as largest industrial user of primary woody biomass as well as an important supplier of industrial by-products. The wood pulp industry is the second largest industrial user of primary and secondary wood. The wood pulp industry mainly uses primary wood and industrial by-products. Black liquor is the result from the manufacturing wood pulp and it is primarily used for energy, often within the same pulp mill, to generate process energy. The wood-based panel industry is the third largest industrial user of woody biomass. The wood-based panel industry uses primary wood, by-products, and a small amount of post-consumer wood. It produces small amounts of industrial by-products, namely plywood and veneer sheets industries.

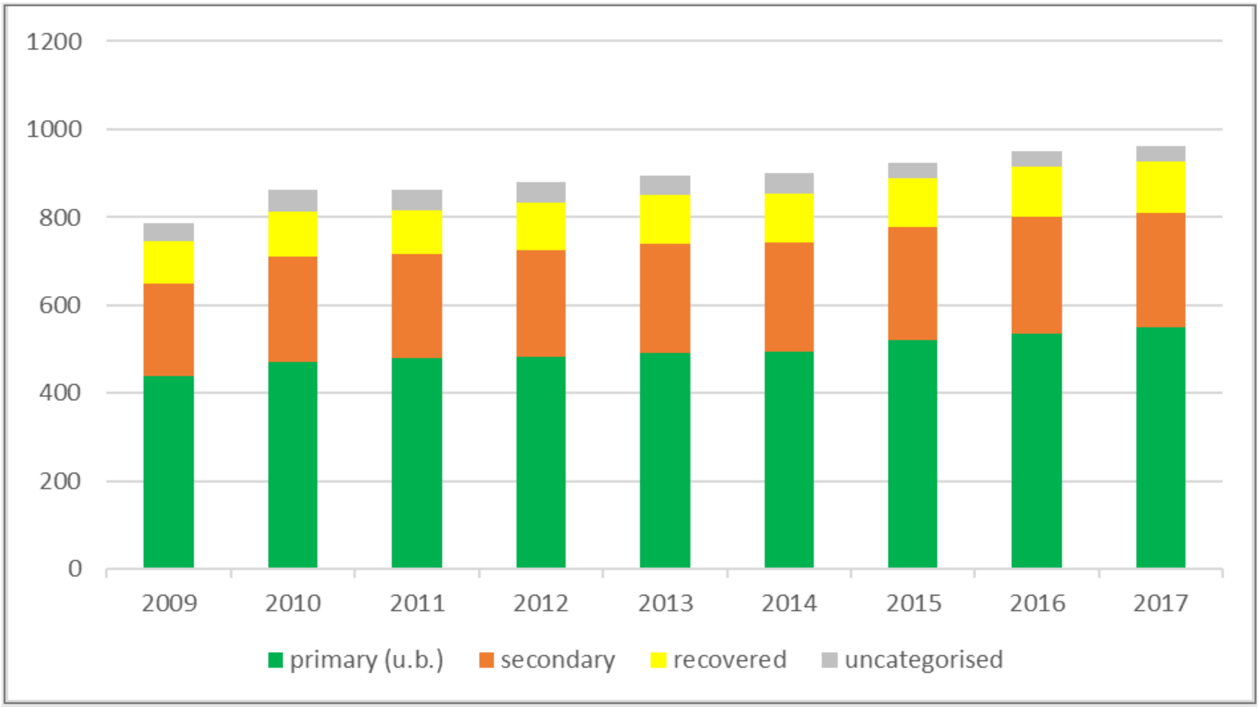
External factors, such as demand for wood, natural disturbances and policies, affect woody biomass sources and uses and they are changing over time. Therefore, in the following sections we analyse trends of woody biomass sources and uses.

7.3 Trends of woody biomass sources and uses

The time series analysed in this study covers the period from 2009 to 2017 and is too short to allow for the drawing of robust conclusions regarding trends. At the beginning of this time series, markets were still recovering from the effects of the 2008 global financial crisis, making it difficult to rely on this time period as a benchmark. Therefore, it is important to consider this event when interpreting the overall trend signals that emerge from the available time series.

In the EU-27, the sources of woody biomass have been increasing over time. The total sources increased from 786 Mm^3 in 2009 to 961 Mm^3 in 2017 (Figure 79). Primary wood is the most important source, followed by secondary woody biomass and finally by recovered wood (incl. post-consumer wood and recovered paper). Primary wood sources increased from 438 Mm^3 in 2009 to 551 Mm^3 in 2017. The uncategorised woody biomass for energy is decreasing, indicating a slight improvement of data quality in the energy sector.

Figure 79. Woody biomass sources in Mm^3 SWE in the EU-27 (2009-2017).

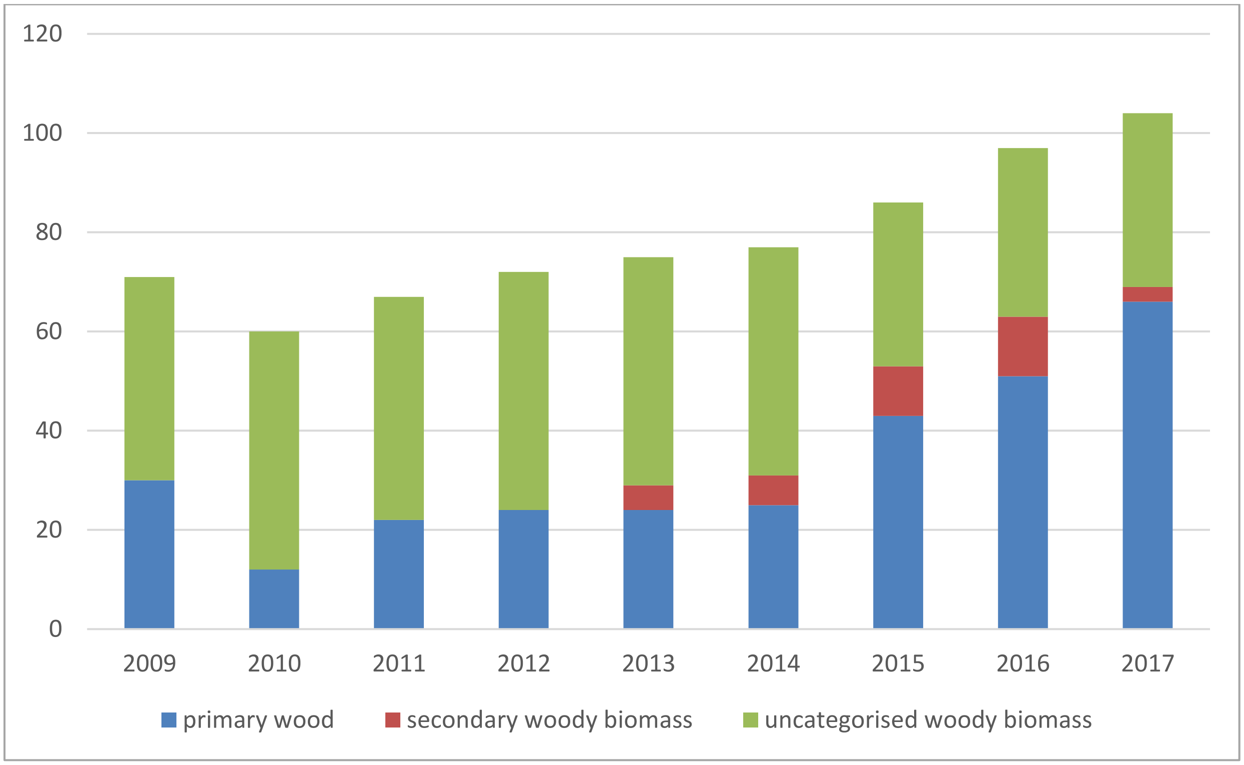


Source: JRC 2022

Primary wood is the most important source of woody biomass for both material and energy. The share of primary wood out of the total sources has increased throughout the timeframe monitored, from 56% in 2009 to 57% in 2017. The share of secondary wood is steady at around 27%, and the share of recovered wood remained at more or less 12% of the total woody biomass sources. Overall, the trend is of an increase in woody biomass sourcing, which concurs with an increase in wood removals from the forest (see Chapter 6), is due to an increase in demand for sawlogs and for woody biomass for energy (Camia et al., 2018). Natural disturbances such as windstorms, droughts, fires and insect outbreaks have also impacted EU-27 forest harvest and removals in the past years. Natural disturbances followed by salvage loggings have increased mainly in central Europe since 2014, bringing significant amounts of wood on the market (Chapter 6, section 6.5.6 and Camia et al., 2021).

The ''gap'' between sources and uses in the wood resource balance was allocated through the Sankey diagram approach, for the whole time series (2009-2017). We estimate that at EU-level, out of the total unreported sources, primary wood accounted on average for 53%, 42% was uncategorised wood and 5% was secondary wood. The share among these categories varies for each year depending on data availability (Figure 80). Large amounts of woody biomass of unknown sources (primary or secondary), is reported as uncategorised woody biomass used for energy.

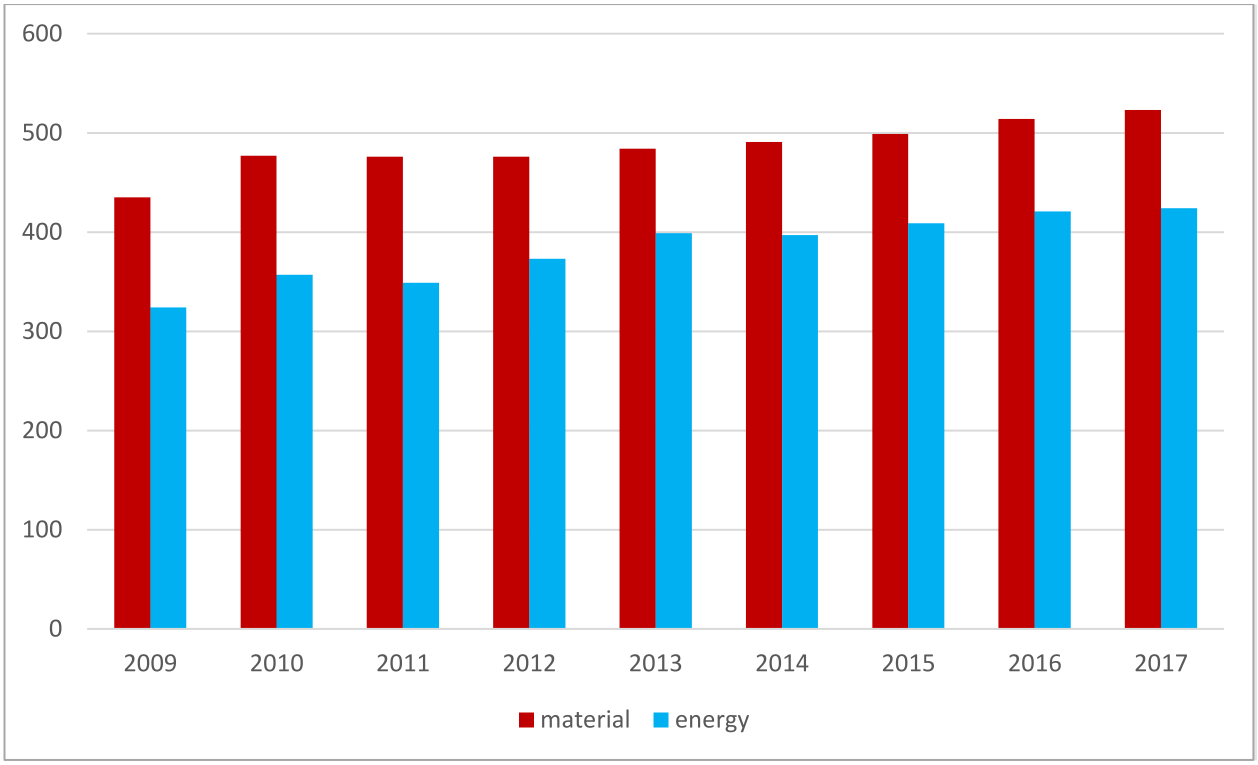
Figure 80. Allocation of the total unreported sources (in Mm^3 SWE) as calculated from the data available (2009-2017).



Source: JRC 2022

The total woody biomass uses for both material (including the paper and paperboard sector) and for energy increased from 759 to Mm^3 to 947 Mm^3 over the analysed period (2009-2017). This increase could be due to an actual increase in the uses, but also to a better reporting quality of energy data. The use of woody biomass for energy has increased at a higher rate with respect to the use for material, albeit this remained the dominant use of woody biomass (Figure 81). Wood used for energy increased from 324 Mm^3 in 2009 to 424 Mm^3 in 2017 while wood use for material increased from 435 Mm^3 SWE to 523 Mm^3 in the same time span.

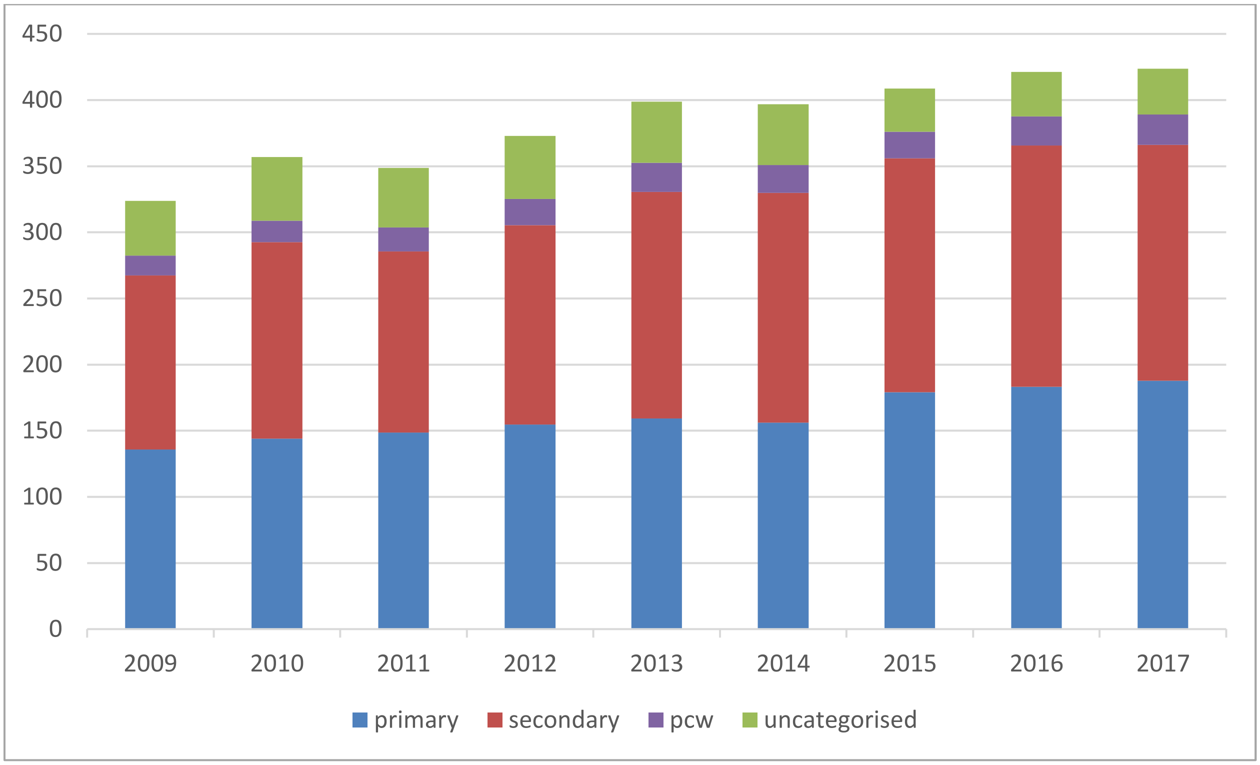
Figure 81. Use of woody biomass for material and energy (in Mm^3 SWE) in the EU-27 (2009-2017).



Source: JRC 2022

The quality of wood for energy use is unknown due to data constraints, but it is possible to analyse woody biomass by categories (primary, secondary, post-consumer and uncategorised wood, Figure 82 and Figure 83).

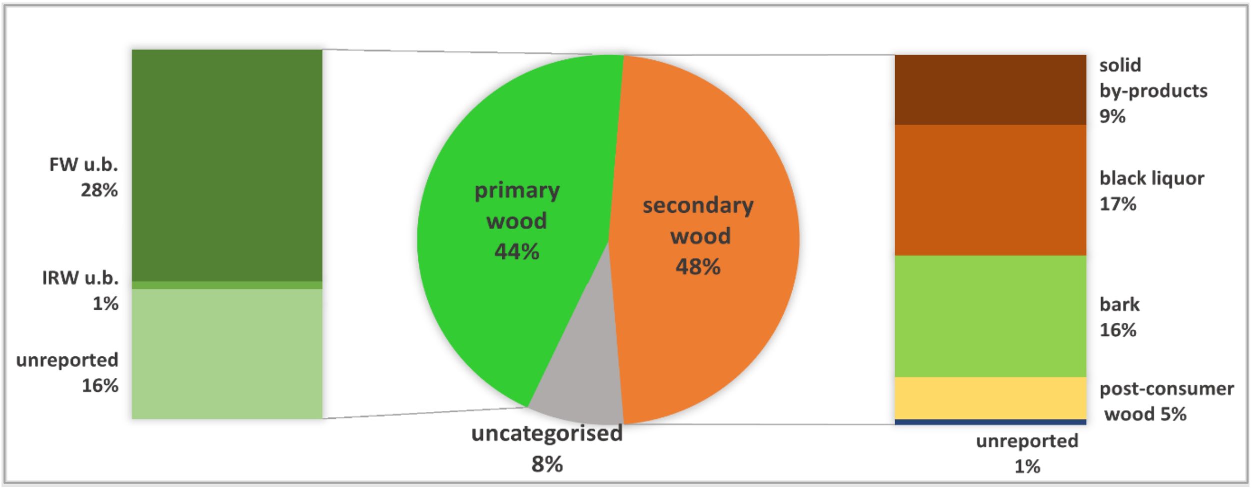
Figure 82. Woody biomass uses for energy (in Mm³ SWE) by sources (2009-2017).



Source: JRC 2022

In the EU-27, wood-based energy is produced from secondary wood (including post-consumer wood), primary wood, and uncategorised wood. Use of primary wood for energy increased from 136 Mm³ in 2009 to 188 Mm³ in 2017, the share of primary wood use for energy out of total woody biomass use for energy increased from 42% to 44%. The use of secondary wood for energy (including post-consumer wood) increased from 147 Mm³ in 2009 to 201 Mm³ in 2017 while the share of secondary wood use for energy out of the total woody biomass use for energy increased from 43% to 48%. The use of post-consumer wood for energy increased from 15 Mm³ in 2009 to 23 Mm³ in 2017. During the analysed period, the share of post-consumer wood use for energy out of total woody biomass use for energy ranged between 4.5% and 5.5%. Improved data reporting on woody biomass uses for energy reduced quantities of uncategorised woody biomass from 41 Mm^3 to 35 Mm^3 during the studied timespan.

Figure 83. Share (%) of sources of woody biomass used for energy in the EU-27 in 2017. (FW: fuelwood, IRW: industrial roundwood).



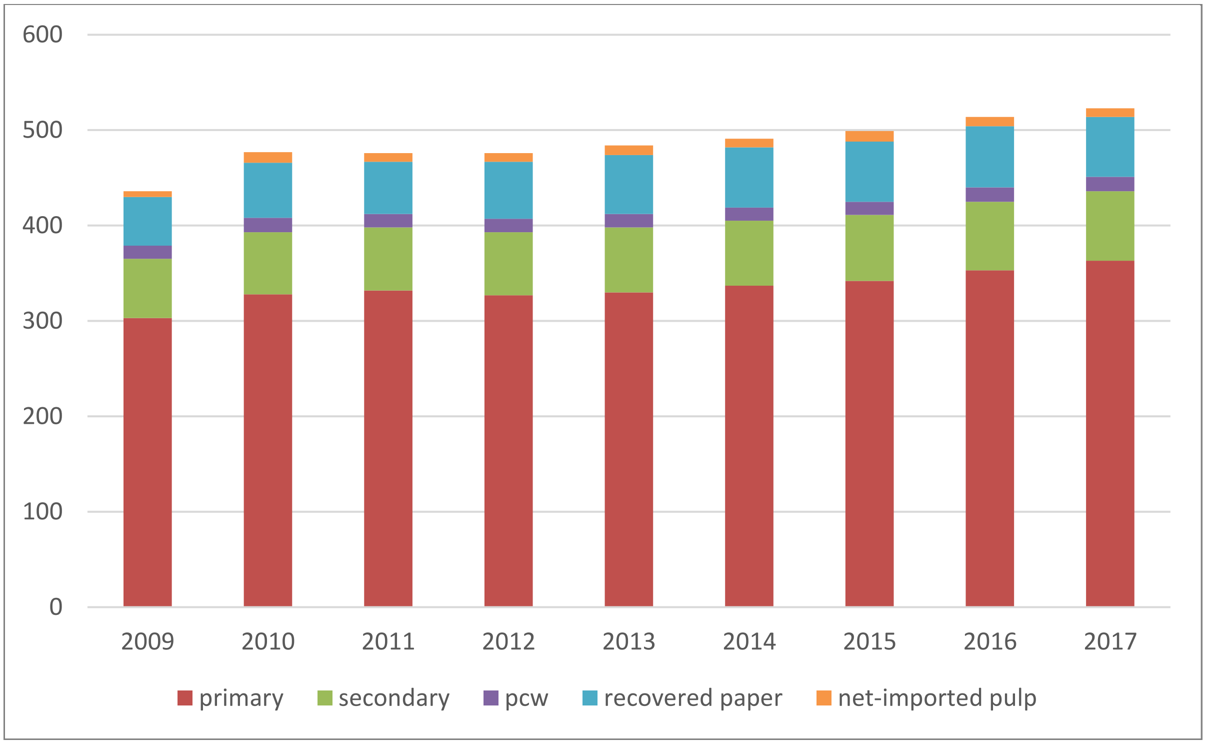
Source: JRC 2022

Primary wood contributed to 44% (188 Mm^3) of all wood used for energy. Within the primary sources, fuelwood[61] is the source most used for energy. This may consist in tree parts that do not fulfil the quality requirements for industrial roundwood, or wood that is either harvested to be used directly as fuel or to produce processed wood fuels such as wood pellets and briquettes. Unreported primary wood is largely used for energy. We assume that only small amounts of industrial roundwood are used for energy. It is unlikely that high-quality industrial roundwood, like sawlogs or veneer logs, would be used for energy because of its high market price. Secondary woody biomass, which comprises by-products from the wood processing industry, both solid (sawdust, chips, etc.) and liquid from the pulp industry (black liquor or tall oil), processed wood fuels, post-consumer recovered wood (from construction, renovation and demolition, packaging as well as old furniture), contributed to 48% (201 Mm^3) of the total woody biomass use for energy.

Within the secondary sources, black liquor and bark are the sources most used for energy. Black liquor and bark are traditionally used for energy within the same factory to generate process energy. Solid by-products are used by wood-based panels and wood pulp industries or innovative wood-based value chains in bioeconomy, as well as for energy. Using by-products for energy when there are higher value uses will negatively affect the indicator for the cascade use of wood (see Section 7.4). Post-consumer wood could be used by the wood-based panel industry, as well as for energy, however part of the post-consumer wood is not suitable for material or energy use due to contaminants and additives. Unreported and uncategorised wood is a large part of all the wood used for energy that remain unknown. Statistics report a certain amount of woody biomass used for energy whose origin, primary or secondary, is not known. This "uncategorised" woody biomass for energy accounted for 8% of total energy uses in 2017 (35 Mm3). Data reporting on woody biomass use for energy should be improved.

[61] Wood that is harvested to be used directly as fuel or to produce processed wood fuels such as wood pellets and briquettes is considered to be fuelwood.

Figure 84. Woody biomass uses for material (in Mm³ SWE) by sources in the EU-27 (2009-2017).

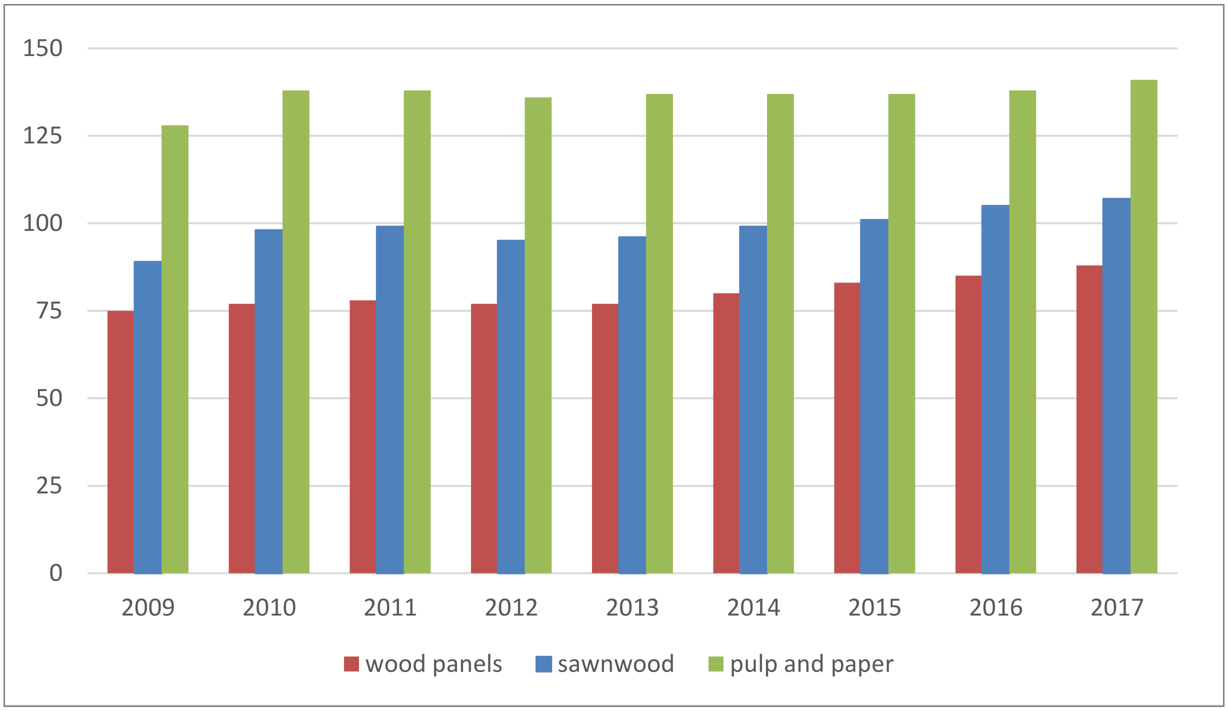


Source: JRC 2022

Materials (wood-based products) are mainly produced from primary sources (Figure 84). Uses of primary wood for material increased from 303 Mm³ in 2009 to 363 Mm³ in 2017. Secondary wood used for material production increased from 62 Mm³ in 2009 to 73 Mm³ in 2017. Its share on the total uses oscillates between 14.2% in 2009 and 13.6% in 2010. Recovered woody biomass (post-consumer wood and recovered paper) used for material purposes in 2009 amounted to 65 Mm³ and reached the quantity of 78 Mm³ by 2017. Total secondary woody biomass recovery for material uses had increased from 127 in 2009 to 151 Mm³ in 2017. The paper and paperboard industry uses a relatively small amount of wood pulp, on average 9 Mm³, that is net imported (less than 2.5% of the total uses), which is not possible to allocate to primary or secondary biomass and is therefore represented separately (in orange) in Figure 84.

Manufacturing of wood-based products in the EU-27 creates added value, supports bioeconomy development and mitigates climate change when biogenic carbon is locked in the long-lived wood products. The overall production of wood-based products increased from 292 Mm³ in 2009 to 336 Mm³ in 2017 (Figure 85).

Figure 85. Production of semifinished wood products (in Mm³ SWE) in the EU-27 (2009-2017).



Source: JRC 2022

In the EU-27, the production of sawnwood increased from 89 Mm³ in 2009 to 107 Mm³ in 2017. The sawmilling industry is the largest industrial user of primary woody biomass and the main producer of secondary wood fibres, meaning that increasing sawnwood production increases the availability of by-products for other industries such as wood-based panels, wood pulp industries, and for energy. Wood-based panel production increased from 75 Mm³ in 2009 to 88 Mm³ in 2017. Pulp and paper production increase from 128 Mm³ in 2009 to 141 Mm³ in 2017. The paper and paperboard production uses large quantities of recyclable materials, 41% of the feedstock is recovered paper. This said, the increase in production of paper and paperboard is rather low compared with other wood-based products. This might be explained by the decreasing demand for graphic paper due to the substitution of electronic information and communication technology. According to FAOSTAT data, the production of printing and writing papers in the EU-27 decreased by 33% from 29.4 Mt to 19.7 Mt in the period 2014-2020. At the same time, the production of packaging paper has increased, and this has partly compensated the decline in the production of printing and writing papers.

7.4 Cascade use of woody biomass in the EU

The cascade use of wood aims to maximise the carbon mitigation potential of forest-based bioeconomy by increasing biomass availability in the system, therefore potentially reducing harvest demand, thus contributing to maintain the carbon sink role[62] of the forest and to conserve biodiversity. It also implies higher value-added and employment benefits for the EU bioeconomy. One of the characteristics of woody biomass is that most of it can be used for a variety of purposes and products. Moreover, many wood-based products can be re-used or recycled.

[62] Although, as described in Grassi et al. (2021), a system-perspective is required to assess the climate benefits in reducing harvest to enhance the net sink.

In this dedicated section, we report the different concepts related to the cascade use of wood and we present two indicators, one at MS-level based on the Wood Resource Balance, and one at EU-27 level, which is based on the woody biomass flows data analysis as well as on additional data sources.

7.4.1 Cascade use of wood in EU policy

In recent years, the concept of cascade use of wood has received a lot of attention when debating EU policies on bioeconomy, circular economy and renewable energy. The cascading principle is highlighted in the EU 2018 Bioeconomy Strategy, the New EU Forest Strategy for 2030, and the Revision of the Renewable Energy Directive, and is seen as a measure to maximise resource efficiency, increase the availability of renewable materials and promote a higher economic added value when keeping biomass in the material cycle of use for as long as possible. In the Revision of the Renewable Energy Directive COM(2021) 557[63] the cascading principle is defined as follows: "*The cascading principle aims to achieve resource efficiency of biomass use through prioritising biomass material use to energy use wherever possible, increasing thus the amount of biomass available within the system. In line with the cascading principle, woody biomass should be used according to its highest economic and environmental added value in the following order of priorities: 1) wood-based products, 2) extending their service life, 3) re-use, 4) recycling, 5) bio-energy and 6) disposal*."

The EU 2018 Bioeconomy Strategy promotes the implementation of principles for cascading use of biomass, circularity, and resource efficiency. In the progress report of the EU Bioeconomy Strategy is noted that the cascading principle "*must apply to the use of all biomass*" (Key message, chapter 3), and in the case of the forest-based industries, there is room for improvement for the cascading use of the secondary woody biomass, by reinforcing the implementation of the cascading principle.

The New EU Forest Strategy highlights optimised use of wood in line with the cascading principle through market incentives. Wood should be used for long-lived products to substitute their carbon intensive and non-renewable counterparts. With due regard to the cascading principle and waste hierarchy, as set out in the EU Waste Framework Directive, Member States should take an action to minimise distortive effects of biomass use for energy.

In the revision of the Renewable Energy Directive, it is proposed to strengthen the obligation to minimise market distortions that result from support schemes, and to avoid supporting the use of certain raw materials for energy production. To be in line with the cascading principle and the concept of waste prevention, the re-use and recycling of waste for materials should be the priority use. Member States should avoid creating support schemes that would lead to an inefficient use of recyclable waste.

In 2019 the Commission published a guidance on cascading use of biomass with selected good practice examples on woody biomass. This non-binding guidance explains cascading and provides some principles and practices to inspire stakeholders when applying the cascading use of biomass. The practices presented in that document came from a range of stakeholders, EU research projects, studies and other sources.

7.4.2 Defining "cascade use of woody biomass"

The concept of resource cascading was first introduced in 1994 by Sirkin & Ten Houten. They specified that cascading is a way to increase resource efficiency and reduce negative environmental impacts. Woody biomass is a versatile material that, in many cases, can be recycled and re-used. However, wood "cascading" or ''cascade use" of wood does not have one universal definition. The terminology is fragmented in the literature, although a common understanding is that wood use for material should be prioritised over wood use for energy and wood should stay in the given system for as long as possible. A variety of cascade use definitions for woody biomass was found in the existing literature. As described by (Olsson et al., 2016) the cascading concept has three different forms/dimensions most prominently used when describing wood cascading.

<u>Cascading-in-time</u> meaning that wood should be recovered as many times as possible enabling resources to stay in the given system for as long as possible. Re-use and recycling of wood would reduce the pressure on forests

[63] Revision of the Renewable Energy Directive, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0557.

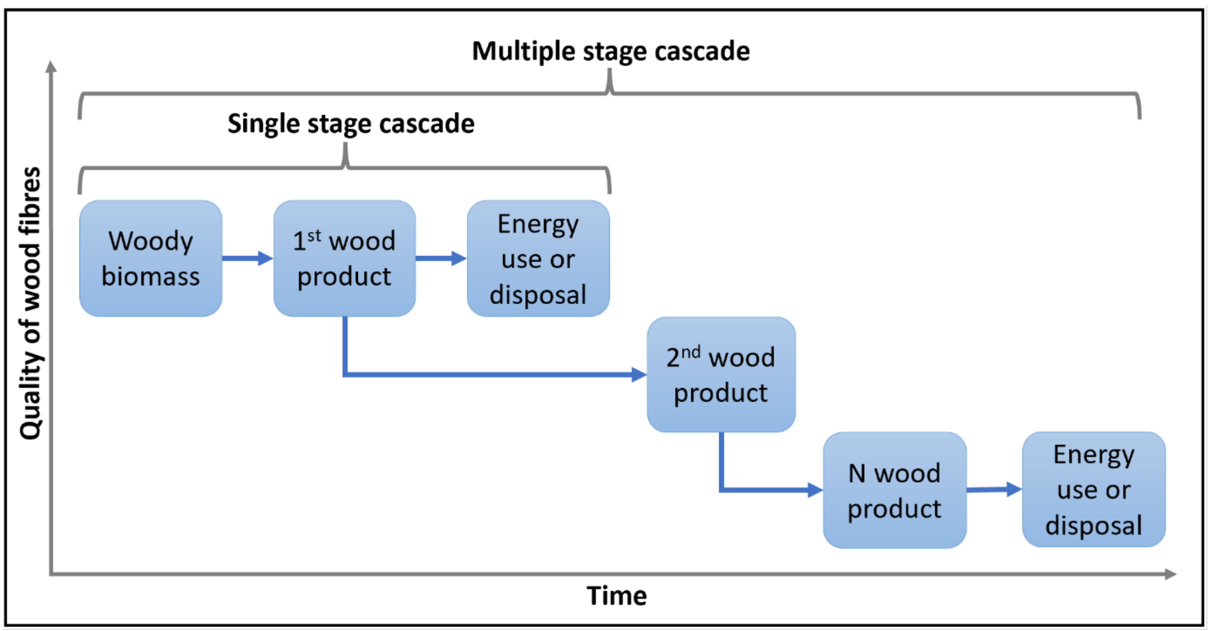
resources and positively would impact forest ecosystems and carbon sinks in the forest. Extended lifetime of wood fibres would have a positive effect on carbon storage in wood products.

Cascading-in-value meaning that resource shall be recovered with the aim to increase value within the cascade chain however, the meaning of increased value differs among different studies. Some studies refer to the economic added value (Carus et al., 2014) while other refer also to environmental added value (Keegan et al., 2013).

Cascading-in-function meaning that each woody component is used for an optimal purpose in a way that maximises value. For example, optimal feedstock for biorefinery would be by-products instead of roundwood, which should be used for sawnwood production.

Cascade use of wood can be of different stages (Essel et al., 2014): single and multiple stage cascade (Figure 86). In a single stage cascade, wood is processed into a final product and, after use, this product is used once more for energy purposes or disposed. Some definitions only accept less common multiple material uses as a cascade use where final products are recovered for manufacturing new products (for example post-consumer wood use for manufacturing wood-based panels). In a multistage cascade use, wood is processed into a final product and this product is used at least once more in material form before disposal or recovery for energy purposes. It should be noted that with each stage of cascade use, the quality of wood fibres decreases. For example, paper can typically be recycled an average of five times. After each cycle, the fibers become shorter until they reach a point where they can no longer be used for paper production anymore. In this chapter, we do not consider by-products as products, they are collateral products. For instance, the sawmill industry produces sawnwood as a semi-finished products, and the by-products are not a part of that product.

Figure 86. Distinction between the single and multiple stage cascade use of wood.



Source: JRC 2022

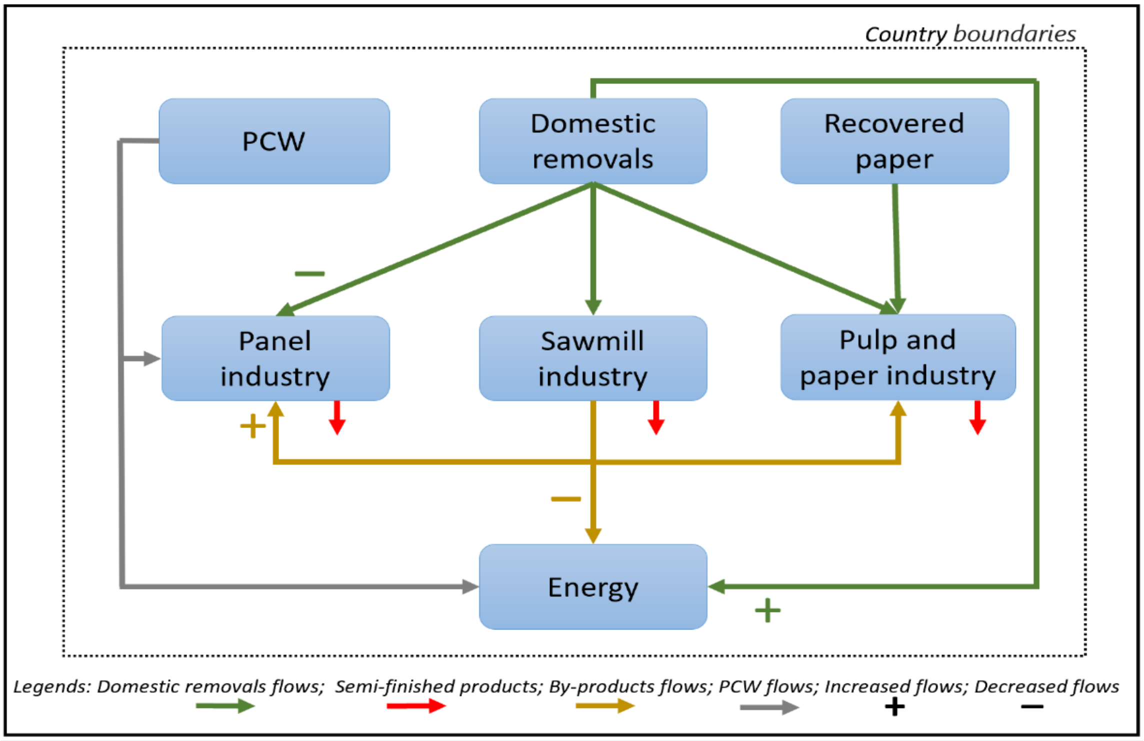
Furthermore, cascade use may be considered and analysed at different levels: at ‘product level’ (particular product or factory) and at ‘market level’ (particular sector or different sectors within the country or even between the countries).

A product level example: Particleboard is manufactured by using several inputs such as residues, recovered materials, primary wood and additives. The sum of the cascaded materials input rates for particleboard production determines how much primary wood has been replaced using cascaded wood. The higher the total input rate of cascaded woody, the higher the cascade use factor. Product level analysis does not include interrelations (flows of woody biomass) between the sectors.

A market level example: The sawnwood industry uses primary wood and produces secondary wood fibers that are used by the wood-based panel and wood pulp industries, as well as for energy. To estimate the cascade use at the market level, it is important to include the interrelations (flows of woody biomass) between the sectors.

When estimating cascade use, we consider the market level, hence the inclusion of the interrelation between the sectors is essential. This requires the inclusion of the interrelations between the sectors, which is essential for a comprehensive analysis. For instance, analysing and estimating the cascade use effect only at the wood-based panel industry level might suggest a great potential to increase sawmilling by-products utilisation for this same industry. However, these by-products are also used in other sectors (e.g. from energy or the pulp industry), thus increasing the by-products use for wood-based panel production would deviate feedstock from these and would have to be compensated, for example through imports or other sources. This would therefore result in a change or decrease in production quantity in other sectors. By-products that are redirected for the wood-based panel industry would have to be substituted by other means of woody biomass (e.g. domestic removals or imports) or by alternative energy sources, and this will influence whole system that is analysed (Figure 87).

Figure 87. Simplified schema of the interrelation between the wood-based panel industry, the energy sector and domestic removals where sawmilling by-products flows are redirected from energy use to panel industry to increase cascade use of wood in the panel industry.



Source: JRC 2022

7.4.3 Quantifying cascade use of woody biomass in the EU-27

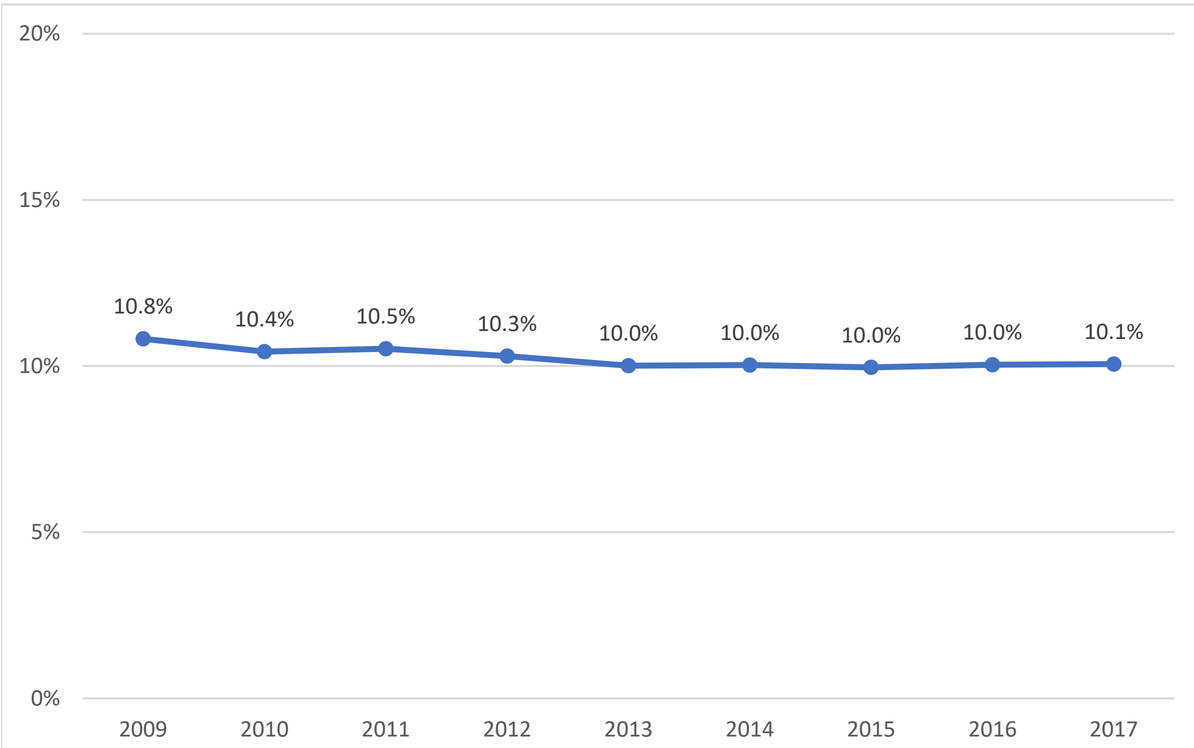
When attempting to quantify the cascade use of wood, we acknowledge the cascading principle highlighted in the EU policy documents as defined above, and for implementation of the indicator, we understand cascade use of wood as "*the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system*". From a technical perspective, the cascade use of wood takes place when wood is processed into a product and this product is used at least once more for material or energy purposes (Vis et al., 2016). For the purpose of this assessment, the production of by-productsis not accounted as material use in the wood-based industries. Thus, for the computation of the cascading indicator of this specific assessment, the energy use of industrial by-products is considered equivalent to the energy use of primary wood.

Quantifying the cascade use of woody biomass is not a new practice. Mantau (2015) proposed a set of cascade factors that indicate the level of the overall cascade use in the forest-based sector. The previous analysis was intended for a specific scope and temporal dimension. In this analysis, we are aiming to quantify the EU-27 market level cascade use of woody biomass (as described in Section 7.4.2) and to present the trends of cascade use that includes an interrelation between the main sectors and the EU Member States. The main limitation of this analysis is that it does not cover cascade use related with external EU-27 trade of woody biomass.

Box 2: Developing an indicator for the cascade use of wood at MS-level for the EU Bioeconomy Monitoring System

An indicator "cascade uses of wood resources" was developed and published on the EU Bioeconomy Monitoring System web portal for all the EU Member States and the EU-27[64]. This indicator is based on the wood resource balance data. The indicator is calculated as the share of by-products and post-consumer wood used for material production relative to the absolute woody biomass uses reported in the EU-27 (Figure 88). The share of secondary wood used for energy is also reported. The figures are presented per Member State for each year between 2009 and 2017 as shares (%) as well as in absolute numbers. The total uses of secondary woody biomass is also reported.

Figure 88. Share of by-products and PCW for material use, relative to the total uses of secondary woody biomass in the EU-27 (2009-2017)



Source: EU Bioeconomy Monitoring System, 2022

This indicator does not include the use of recovered paper by the paper and paperboard sector as it is not possible to estimate these at MS-level at this time.

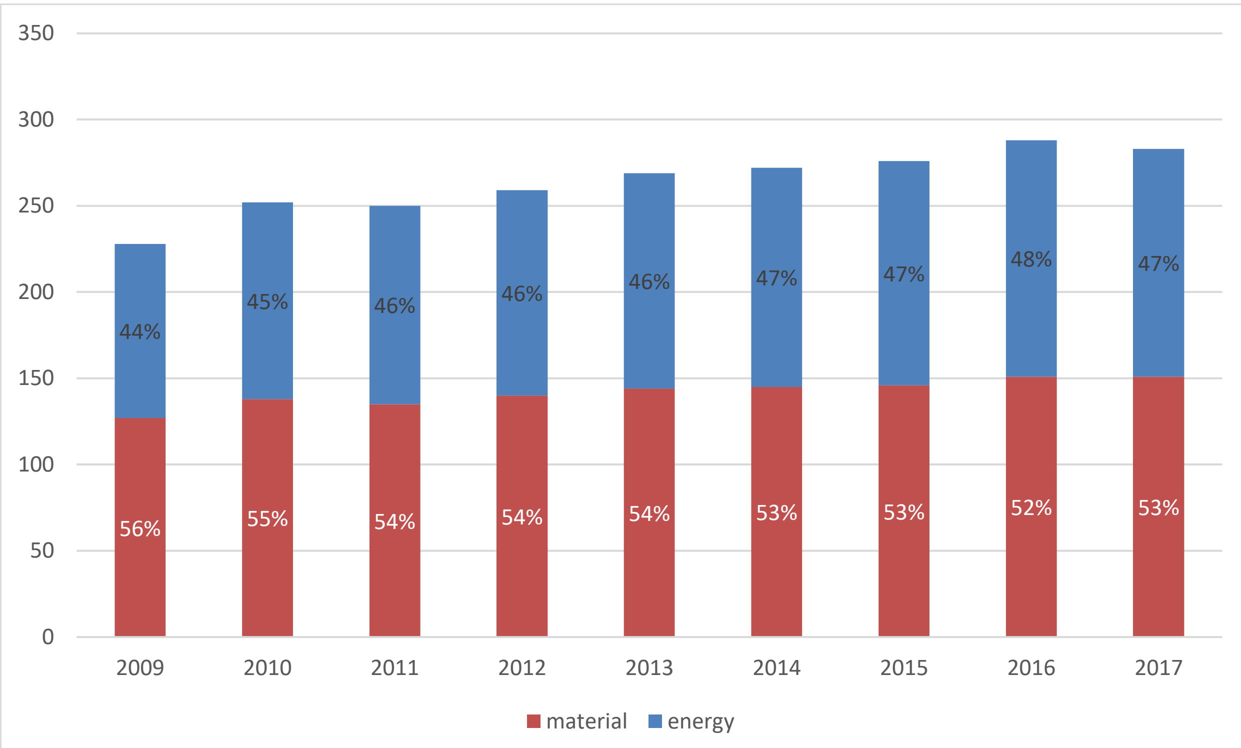
Sectors are interlinked within the wood-based industry. Energy and material-use (mainly wood-based panels but also wood pulp manufacturing) compete for the same secondary wood and recovered woody biomass sources (by-products, post-consumer wood) (see, e.g., Jonsson & Rinaldi, 2017). Sawmilling by-products are suitable feedstock for wood-based panel and pulp industries, because they are clean and dry. The same by-products are used by the energy sector. Post-consumer wood without contaminants and additives can be used for both wood-based panel production and energy. Recovered paper is a suitable feedstock for the paper and paperboard production and

[64] European Commission's Bioeconomy Monitoring System https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.1.

generally recovered paper is not used for energy generation. On the contrary, black liquor that is a by-product from chemical and semi-chemical wood pulp industry is primarily used for energy.

In the context of cascade uses, it is important to analyse the share of secondary wood and recovered woody biomass use for material and energy. This share provides insight into the extent to which secondary and recovered woody biomass is used for material or energy purposes. Between 2009-2017, woody biomass uses increased for both material and energy use but the share of secondary and recovered woody biomass use for material decreased, albeit it still occupied an overall larger share (Figure 89). It should be noted that in this analysis, by-products also include black liquor that is primarily used for energy; and post-consumer wood that includes contaminated biomass and therefore can only be used for energy.

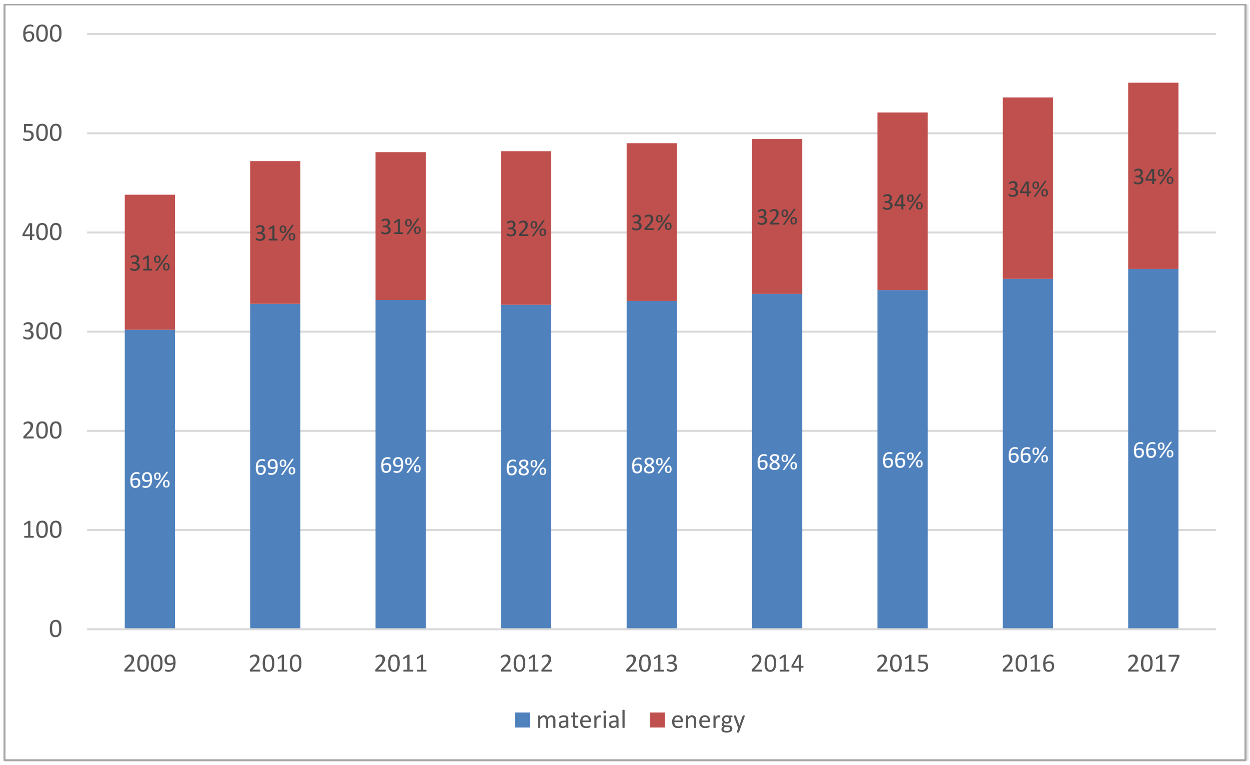
Figure 89. Use of secondary wood and recovered woody biomass for material and energy (in Mm^3 SWE) in the EU-27 (2009-2017).



Source: JRC 2022

Figure 90 shows that the uses of primary woody biomass have increased in the time span between 2009 and 2017, and that the additional primary woody biomass used over time was used for energy. The share of primary woody biomass uses for material decreased. It should be noted that not all primary wood is suitable for material use (because of the different qualities harvested). Data from the wood resource balance indicate that in 2017 approximately 24% of reported primary wood in the EU-27 was fuelwood primarily used for energy.

Figure 90. Uses of primary wood for material and energy (in Mm^3 SWE) in the EU-27 (2009-2017).



Source: JRC 2022

The decreasing share of secondary wood and post-consumer wood use for materials (Figure 88), combined with the increase in share of use of primary wood for energy (Figure 90), would indicate that the cascading principle is not being applied. These trends may be due to various reasons: Energy and material use (mainly wood-based panels but also wood pulp manufacturing, in most cases not sawmilling, as the price of saw logs is too high) compete for the same woody biomass sources (see, e.g., Jonsson & Rinaldi, 2017) and incentives for bioenergy most probably increased demand of woody biomass for bioenergy, thus increasing the use of woody biomass for energy. An increasing share of woody biomass used for energy limits wood-use for materials and thus the cascade use of wood. Another explanation for these trends may be an increase in sources of primary wood. In the EU countries where primary wood is scarce, the utilisation of recovered wood is generally higher compared to countries with abundant forest resources (Vis et al., 2016). In the EU-27, sources of primary woody biomass have increased, affected also by natural disturbances among other reasons (see Section 6.5.6), and as such, wood-based industries use primary sources instead of secondary and recovered wood.

7.5 Trends in cascade use of wood and its potential

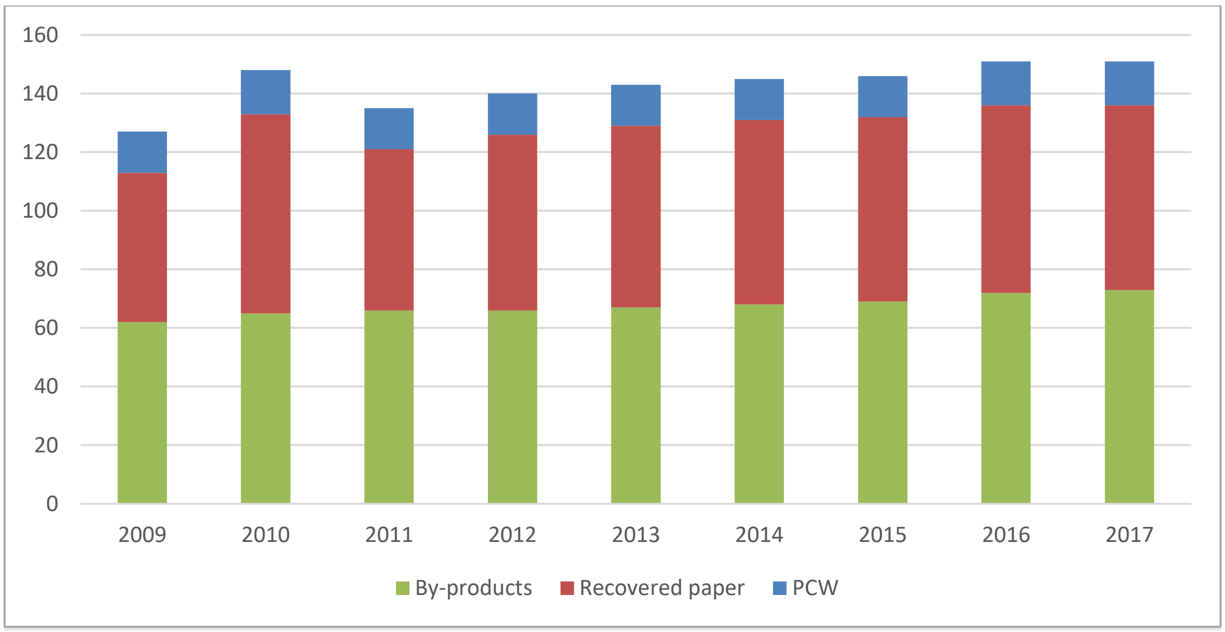
In this section, we investigate the trends in cascade use of wood according to the definition of cascade use: "the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system", whereby we do not consider by-products of the wood- based industries as "products" or material uses, to understand the cascading potential for different wood-based commodities (post-consumer wood, by-products and recovered paper) for material uses. In this section, we analyse trends in post-consumer wood and recovered paper recycling and by-products use for material products, which we refer to as "cascade use". We also examine the potential of various commodities to be used for material or to be recycled.

- Sawmilling by-products (chips and particles) are ideal input for wood-based panels or wood pulp manufacturing. By-products are also used to generate process energy primarily within the forest-based industries.

- Recovered paper can be used for manufacturing paper and paperboard. In the EU-27, almost half of paper and paperboard are made from recovered paper, 63 Mm^3 out of 152 Mm^3 total feedstock is recovered paper (Figure 78).
- Post-consumer wood is the wood-based component of wood-based products (demolition, packaging, furniture, etc.). These products have served at least one material use, and are therefore considered as "post-consumer", although this does not mean the wood cannot be recovered and recycled. After the product-use stage, post-consumer wood might be recycled to manufacture new wood-based products (e.g., particleboard), however, not all wood products can be recycled for material because of low wood quality, contamination and additives.

According to the analysis presented in Section 7.2 on woody biomass flows, total woody biomass recovery for material uses had increased from 127 to 151 Mm^3 in the period 2009-2017. The by-products contributed most to this increase in secondary woody biomass uses for materials, followed by recovered paper and post-consumer wood (Figure 91). The increase in use of by-products for material can principally be explained by its increased availability: an increase in sawnwood production (Figure 85) resulted in higher production of sawmilling by-products that are used for wood-based panels and wood pulp production.

Figure 91. Secondary woody biomass used for materials (in Mm^3 SWE) in the EU-27 (2009-2017)



Source: JRC 2022

In terms of trade, by-products that were imported to the EU-27 between 2009 and 2017 varied from 7 to 13 Mm^3. The EU-27 was a net-exporter of recovered paper, where the net-export of recovered paper varied from 6 to 11 Mm^3. Data on post-consumer wood trade is not available at the EU level (Table 10).

Table 10. EU-27 trade of by-products and recovered materials (in Mm^3 SWE).

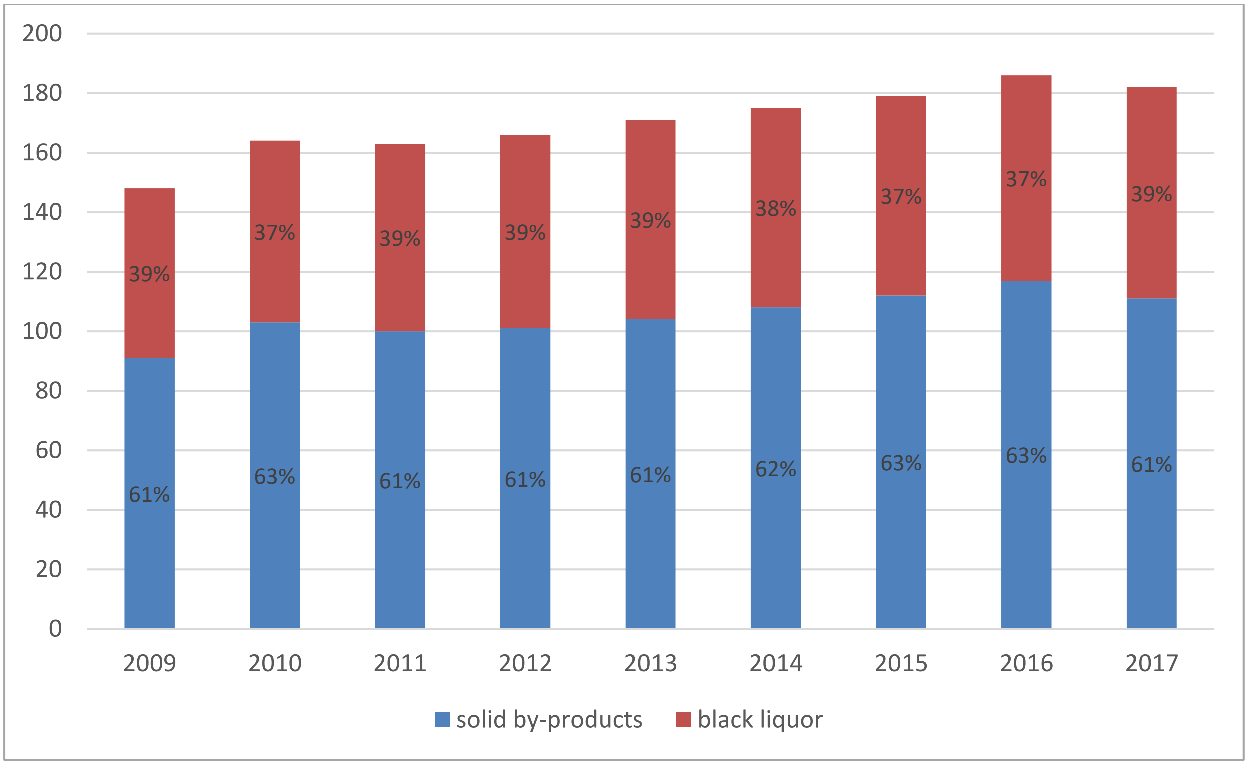
Trade	2009	2010	2011	2012	2013	2014	2015	2016	2017
Net-import of by-products	9	13	9	12	9	9	7	7	7
Net-export of recovered paper	11	6	8	7	6	6	7	6	6

Trade of post-consumer wood	NA	NA	NA	NA	NA	NA	NA	NA	NA

7.5.1 By-products

By-products are secondary products from the manufacture of sawnwood, wood-based panels and wood pulp. By-products include black liquor, sawmill residues, wood chips and particles. Sawmill residues, wood chips and particles are suitable for use as a fuel or for production of wood-based panels and wood pulp. A large share of by-products in the EU-27 is black liquor (Figure 92). Black liquor is a by-product from the chemical and semi-chemical wood pulp industry that is primarily used for energy. A small share of black liquor is used for production of innovative wood products, like bioplastics (see Chapter 11).

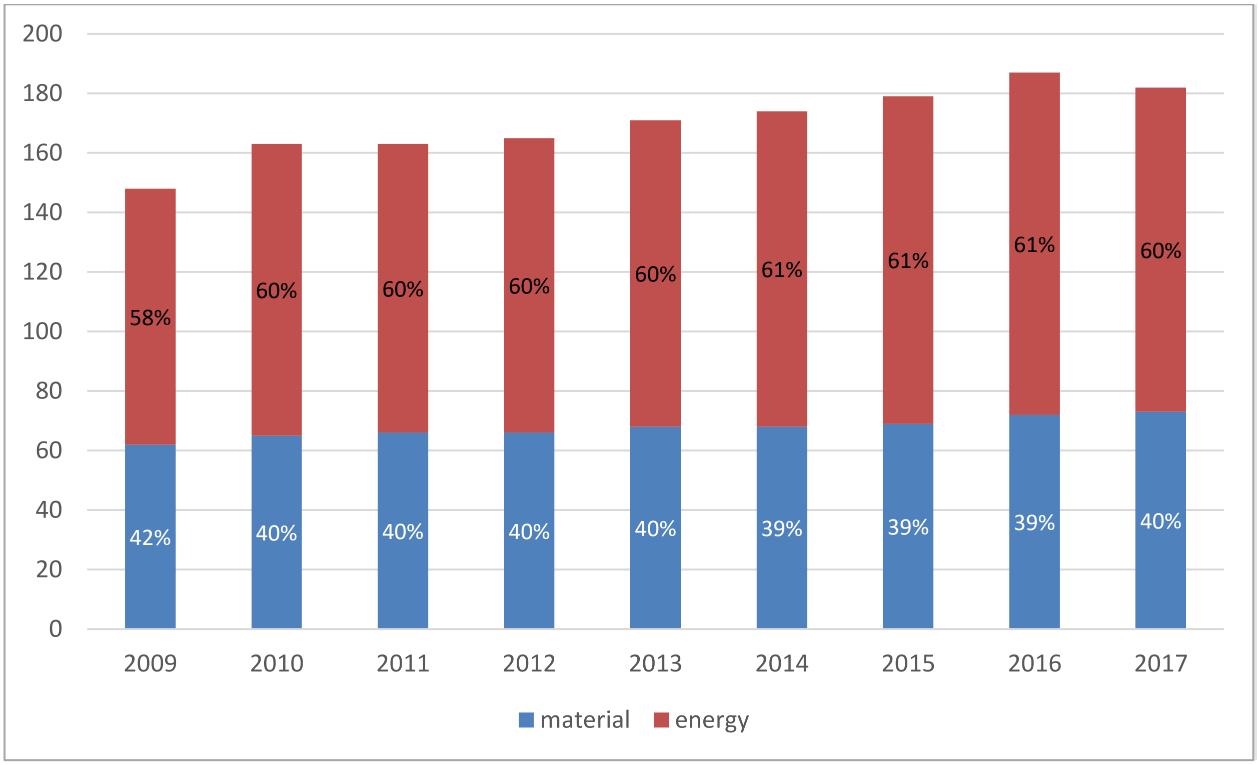
Figure 92. Black liquor and other by-products (in Mm^3 SWE) in the EU-27 (2009-2017).



Source: JRC 2022

The total use of by-products increased from 148 to 182 Mm^3 in the period 2009-2017 (Figure 93). On average, 40% of by-products were used for material and 60% were used for energy. The use of by-products for material increased from 62 Mm^3 in 2009 to 73 Mm^3 in 2017, and in the same period, the use of by-products for energy increased from 86 Mm^3 to 109 Mm^3.

Figure 93. Uses of by-products for material and energy (in Mm^3 SWE) in the EU-27 (2009-2017).



Source: JRC 2022

In order to estimate the cascade-use potential of by-products and their actual use-ratio in the EU-27, we analysed the total potential of by-products that could be used for manufacturing semi-finished wood products, which are mainly wood-based panels and wood pulp. In the total potential of by-products, we include sawmilling, plywood and veneer sheets residues and its net-trade and unreported secondary wood. The Sankey diagram in Figure 78 shows that the potential of by-products that could be used for manufacturing semi-finished wood products mainly come from the sawmilling industry, and small amounts from the plywood and veneer sheets industries, as well from net-imports and unreported secondary wood. To illustrate cascade use of by-products out of total potential, we determine a "by-products use rate" where the use of by-products for material is divided by the total potential. This rate does not include specific characteristics of by-products and the needs of the different industries nor the geographical dimension such as transport distances, cost of by-products etc. Further analysis at the country or value chain level would be needed. Nevertheless, this indicator provides an order to magnitude, or "potential".

The cascade use rate (K) is defined as the actual use of by-products for material production divided by total potential of the available by-products:

$$K = \frac{use}{potential} = \frac{Pa + Pu}{Sa + Pl + Im + Us}$$

where:

K is by-products cascade use rate out of total potential;

use is the total use of industrial by-products for material production;

potential is the total potential given by the available by-products;

Pa is by-products use in the wood panel industry;

Pu is by-products use in the wood pulp industry;

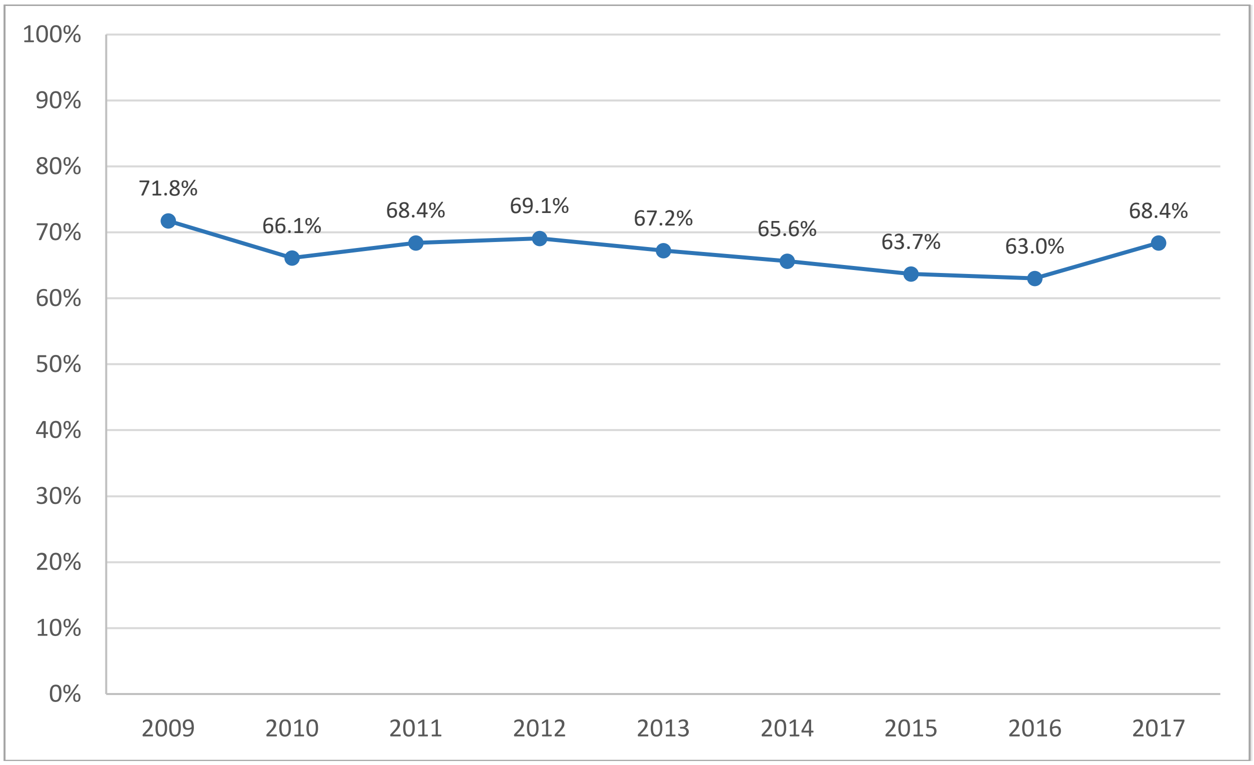
Sa is the amount of by-products generated in the sawmilling industry;

Pl is the amount of by-products generated in the plywood and veneer sheets industry;

Im is net-trade of by-products;

Us is unreported secondary wood.

Figure 94. By-products cascade use rate (K) out of total potential in the EU-27 (2009-2017).



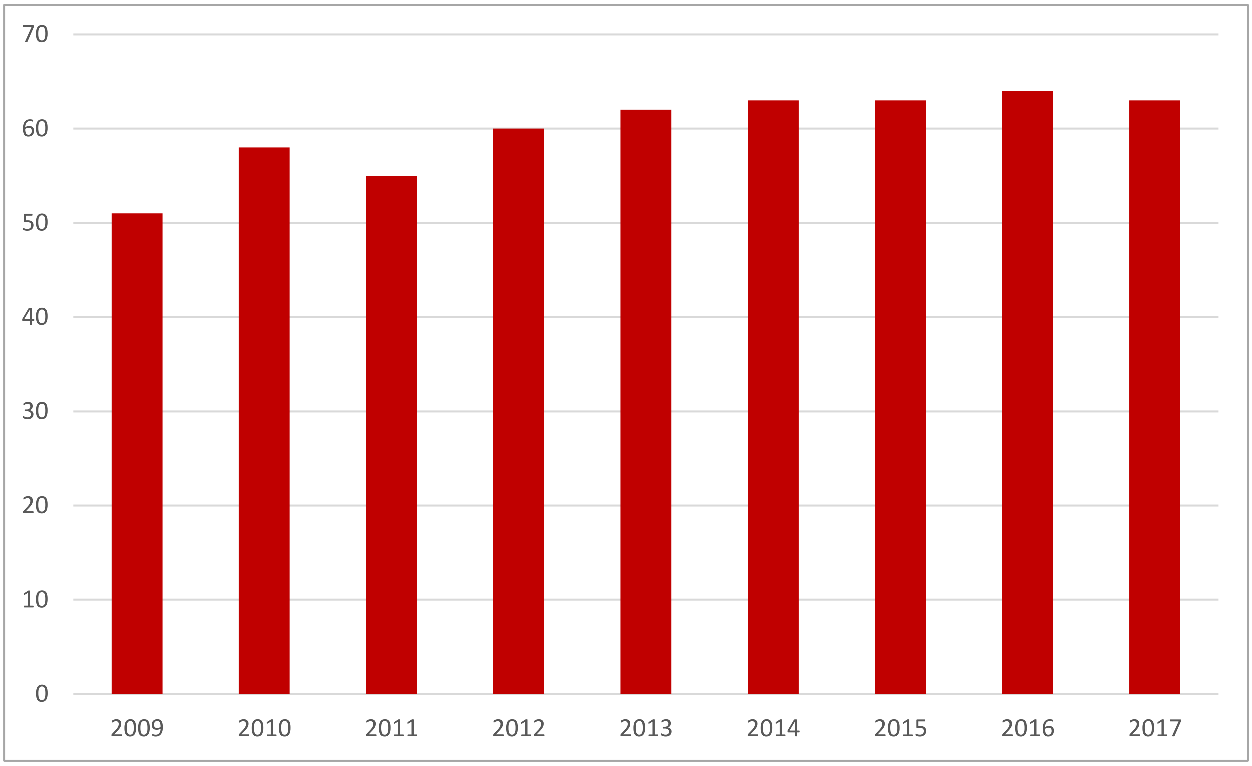
Source: JRC 2022

The results of this analysis show that the cascade-use rate fluctuates throughout the time frame assessed (Figure 94). There is potential to use more by-products for material, although it should be acknowledged that to quantify exactly how much, the technological, physical and geographical considerations should also be assessed. Nevertheless, the fluctuation over time indicates that there is a decline in recovery of by-products. This means that if at one point in time, a higher recovery of woody biomass had been possible, the barriers, or constraints, were not an issue.

7.5.2 Recovered paper

Recovered paper is waste and scraps of paper or paperboard that have been collected for re-use, recycling or trade. It includes paper and paperboard that has been used for its original purpose, as well as residues from the paper and paperboard production. Recovered paper is suitable as a raw material for the papermaking process. Based on the woody biomass flows data analysis, the use of recovered paper increased from 51 to 63 Mm^3 in the period 2009-2017 (Figure 95). However, it is observed that from 2014 the increase of recovered paper use in the paper and paperboard industry stabilised and reached a plateau. In the recent years, although paper production has decreased, the production of packaging paper has increased. According to FAOSTAT, production of printing and writing papers in the EU-27 decreased by 33%, from 29.4 M tonnes to 19.7 million tonnes in the period 2014-2020. Furthermore, net-export of recovered paper (Table 10) reduces the potential for cascade use of recovered paper in the EU-27. A possible explanation of this trend may be the quality of wood fibre in the recovered paper. A recent study (Scott, 2019) concluded that fibre strength in the recycled paper, will continue to be the greatest impediment to further increased recycling.

Figure 95. Uses of recovered paper (in Mm^3 SWE) in the EU-27 (2009-2017).



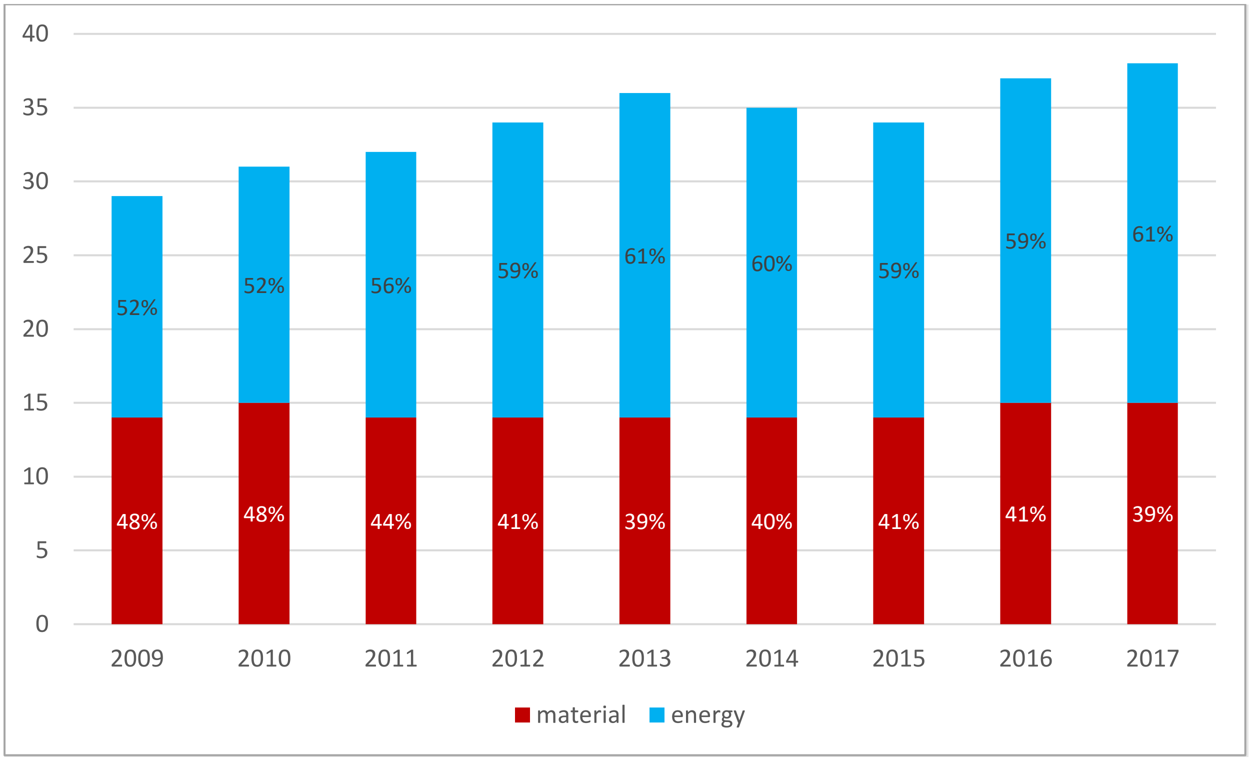
Source: JRC 2022

7.5.3 Post-consumer wood

Post-consumer wood is a waste wood fibre after at least one life cycle. It comprises wood from construction, renovation and demolition, packaging as well as used furniture. Post-consumer wood is suitable for use as a fuel or for particle board production. The wood resource balance and woody biomass flows data analysis show that the total use of post-consumer wood increased from 29 to 38 Mm^3 in the period 2009-2017. Post-consumer wood was mainly used for energy. On average, 42% of post-consumer wood was used for material and 58% was used for energy (Figure 96). Post-consumer wood use for energy increased from 15 to 23 Mm^3 while use for material increased from 14 to 15 Mm^3 from 2009 to 2017.

It should be noted that in the wood resource balance and woody biomass flows analysis data on post-consumer wood might be underestimated, especially for energy use, because in the progress reports from the National Renewable Energy Action Plans (NREAP), this category cannot be disaggregated from others reported uses. Therefore, data on post-consumer wood use is uncertain in some Member States. However, it is certain that the overall use of post-consumer wood is increasing, and that post-consumer wood is mainly used for energy. Staring from 2017, FAOSTAT reports data on production quantities of post-consumer wood. In 2017 production quantity was 21.5 M tonnes and 23.5 million tonnes in 2020 showing an increase of 9% within three years period. For overlapping years, values reported by FAOSTAT are similar to values in the wood resource balance when tonnes are converted to cubic meters.

Figure 96. Uses of post-consumer wood for energy and material (in Mm³ SWE) in the EU-27 (2009-2017).



Source: JRC 2022

For material use, the main user of post-consumer wood in the EU-27 is the wood-based panel industry. In 2017, 15% of wood input to the panel industry was post-consumer wood. Other feedstocks were sawmilling by-products (34%) and primary wood (51%). Particleboard production uses most of the post-consumer wood. Other types of wood-based panels, such as fibreboard, are mainly produced from primary wood and sawmilling by-products. Technically, particleboard might be produced mainly from the post-consumer wood and sawmilling by-products (Vis et al., 2016), however a significant share of input is still primary wood. This might be due to the limited availability of quality post-consumer wood in the market, the high costs of processing post-consumer wood, or oversupply of primary wood.

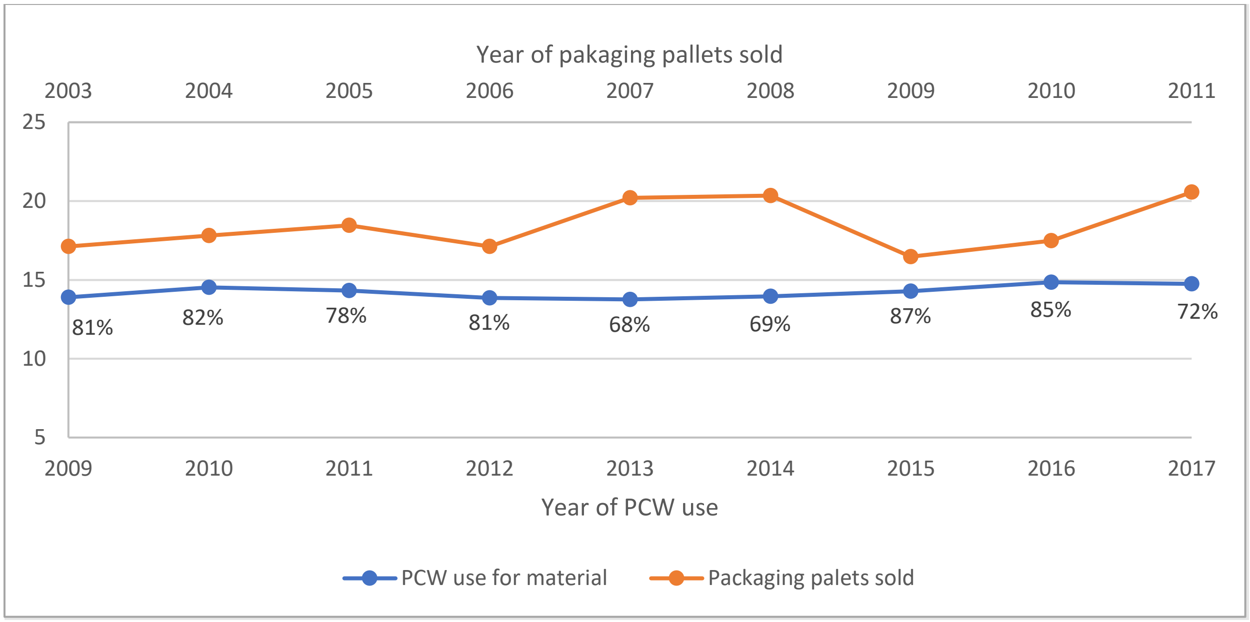
To estimate the cascade use potential of post-consumer wood, we analysed data on the wooden packaging pallets that are often used as an input for particle board production. At the end of their lifecycle, the wooden packaging pallets are ideal input for particleboard manufacturing because they are generally clean and dry. The wooden packaging pallets usually contain sawnwood and are manufactured from lower quality roundwood and cuttings from wood sawmilling (Madison, 1971). There are other packaging items made of wood, like boxes, cable drums and barrels that are used as an input for particleboard manufacturing, however quantities are relatively small compared to the wooden packaging pallets (Saal et al. 2022) and data on other packaging items than wooden pallets are limited.

Data on the wooden packaging pallets in the EU-27 market and trade data are reported by EUROSTAT (wooden packaging pallets sold in pieces). To convert pieces of pallets to tonnes we used the average weight of standardised Euro pallets and JWEE[65] conversion factor to convert tonnes of waste wood to cubic meters. The average lifespan of the packaging pallet is 6 years (FEFPEB, 2022)[66], meaning that packaging pallets produced in 2011 could be utilised as a post-consumer wood in 2017. Based on the wood resource balance and woody biomass flows data

[65] JWEE https://unece.org/forests/joint-wood-energy-enquiry.
[66] FEFPEB https://www.fefpeb.eu/cms/files/Factsheets/facts-figures.pdf.

analysis, on average 14 Mm^3 of post-consumer wood was used in the wood-based panel industry in the period 2009-2017, while amount of packaging pallets placed on the market on average was 18 Mm^3 (Figure 97).

Figure 97. The packaging pallets sold in the EU-27 market including net-trade (2003-2011) in Mm^3 SWE and the share (%) of post-consumer wood used for material out of packaging pallets sold in the EU-27 market (2009-2017).



Source: JRC 2022

These rough estimates imply that from 2009 to 2017, where only packaging pallets are considered, 22% of this potential was on average not utilised. Moreover, adding other packaging products that were excluded from this analysis would increase the cascade use potential of the wood-based packaging products. Therefore, we assume that there is still unexploited potential to utilise more of post-consumer wood in the wood-based panels and other sectors.

The quality of wood-based packaging products is rather homogeneous and suitable for recycling, while the quality and reusability of other waste wood products, like construction and demolition wood, furniture and panel boards are limited. In most cases these products contain contaminants and additives that are technologically difficult and costly to remove therefore, demolition wood, furniture and panel boards are rarely recycled for material. Cascade use barriers were studied and extensively reported in (Vis et al., 2016; De Jesus and Mendonça, 2018; Kirchherr et al., 2018; Jarre et al., 2020). These studies identified various cascade use barriers such as technological, market and policy barriers. Currently research and experimental studies are on-going to lift the barriers of cascade use of wood.

7.6 Conclusions for Chapter 7

The data on woody biomass sources and uses at the EU level are inconsistent, resulting in significant gaps between reported sources and uses (reported sources are smaller than reported uses). This gap has been growing over time. On the contrary, there are smaller amounts of uncategorised woody biomass reported for energy, which indicates an improving situation with respect to reporting.

The wood resource balances show that in 2017 the unreported sources are estimated at 104 Mm^3.

The estimates obtained from the woody biomass flow (the paper and paperboard sector included) show that in 2017 the total use of woody biomass (primary, secondary, recovered, unreported, both domestic and net-traded) for material and energy in the EU-27 was 947 Mm^3, woody biomass was mainly used for material (523 Mm^3) and for energy (424 Mm^3).

Estimates based on available data indicate increasing uses of woody biomass in the EU-27. The increased use of woody biomass was mainly driven by the increased demand for primary woody biomass for material and energy and resulted in an increase in the reported domestic removals, which were also impacted in recent years by salvage loggings because of increased natural disturbances since 2014. Cascade use of wood is seen as a measure to increase resource-use efficiency and climate mitigation potential while potentially reducing harvest demand. Although the cascade use of wood has received a lot of attention when debating EU policies on bioeconomy, circular economy and renewable energy.

Cascade use of wood is seen as a measure to increase resource-use efficiency and climate mitigation potential while potentially reducing harvest demand. The cascade use of wood has received a lot of attention when debating EU policies on bioeconomy, circular economy and renewable energy. Wood "cascading" or ''cascade use" of wood does not have one universal definition, however in this study we consider that wood use for material should be prioritised over wood use for energy and wood should stay in the given system for as long as possible. In the computation of our indicator for the cascade use of wood, we do not include the direct use of primary wood or industrial by-products that is used for energy. This, according to the definition applied, which is *the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system.*

The proportion of the cascade use of wood is declining within the total uses of wood. Thus, while the total amount of recovered woody biomass (post-consumer wood and recovered paper) and by-products for material uses has increased from 127 to 151 Mm3 over the period 2009-2017, when assessed alongside total consumption, its share has in fact declined. The share of both primary and secondary woody biomass for energy, with respect to total uses, has been rising slightly. Once wood is burned it cannot be recovered and the cascade use potential is fully terminated for material use at that point[67].

Our analysis indicates that there is a potential to increase post-consumer wood and by-products cascade use for material. The sawmilling industry produces large quantities of by-products (small amounts comes from plywood and veneer sheets industry) that potentially could be used for wood-based panels and wood pulp production. Estimates suggest that the potential use of by-products for material was under-exploited (2009-2017). Moreover, for the same period, the by-products cascade use rate out of total potential slightly decreased.

In order to estimate potential of post-consumer wood, we analysed data on the wooden packaging pallets that are mainly used as an input for particle board production. Other packaging items like wooden boxes, cable drums and barrels are also used for particleboard manufacturing, however, were excluded from these analyses due to relatively small quantities and limited data available. The results show that on average, 22% of potential (only wooden packaging pallets considered) was unexploited (2009-2017). Moreover, adding the other packaging products that had been excluded from this analysis would increase the cascade use potential of the packaging sector. Reusability of other waste wood products, like construction and demolition wood, furniture and wood-based panel boards are limited due to contaminants and additives in these products.

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[67] Acknowledging that there are non-material uses such as ashes, CO2 and biochar.

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8 Drivers of wood price volatility following the COVID pandemic

Paul Rougieux & Ragnar Jonsson

Key messages:

- During the COVID-pandemic, lock down and related government stimulus measures, such as subsidies for home renovation and insulation, led to an increased demand for wood.
- Lock downs at the same time constrained the supply of wood products.
- Resulting wood products price increases have been more pronounced for processed products than for primary forest products.
- Apparent imperfect transmission of price signals from processed wood products markets to roundwood markets could increase price volatility.
- Due to geopolitical issues, the price volatility events are still ongoing at the end of 2022 and drive wood demand for energy use.

Price movement is an indicator of changing market conditions, or expectations thereof, on the demand side, supply side, or both. For example, during a construction and home renovation boom, more consumers accept to pay more for construction materials. On the supply side of the market, a storm or a very harsh winter would lead suppliers to require higher prices to cover increased logistic costs. Some price changes are temporary, i.e. they return to the original level after the situation has gone back to normal, while other price changes, reflecting structural market changes, are likely to be permanent. The purpose of this chapter is to disentangle the drivers of price volatility in the forest sector following the COVID pandemic in the period 2020-2022, and to shed some light on other events and interactions at play between different stages of the global forest products markets. With price we here refer to trade unit value, i.e. the value of trade divided by the quantity traded.

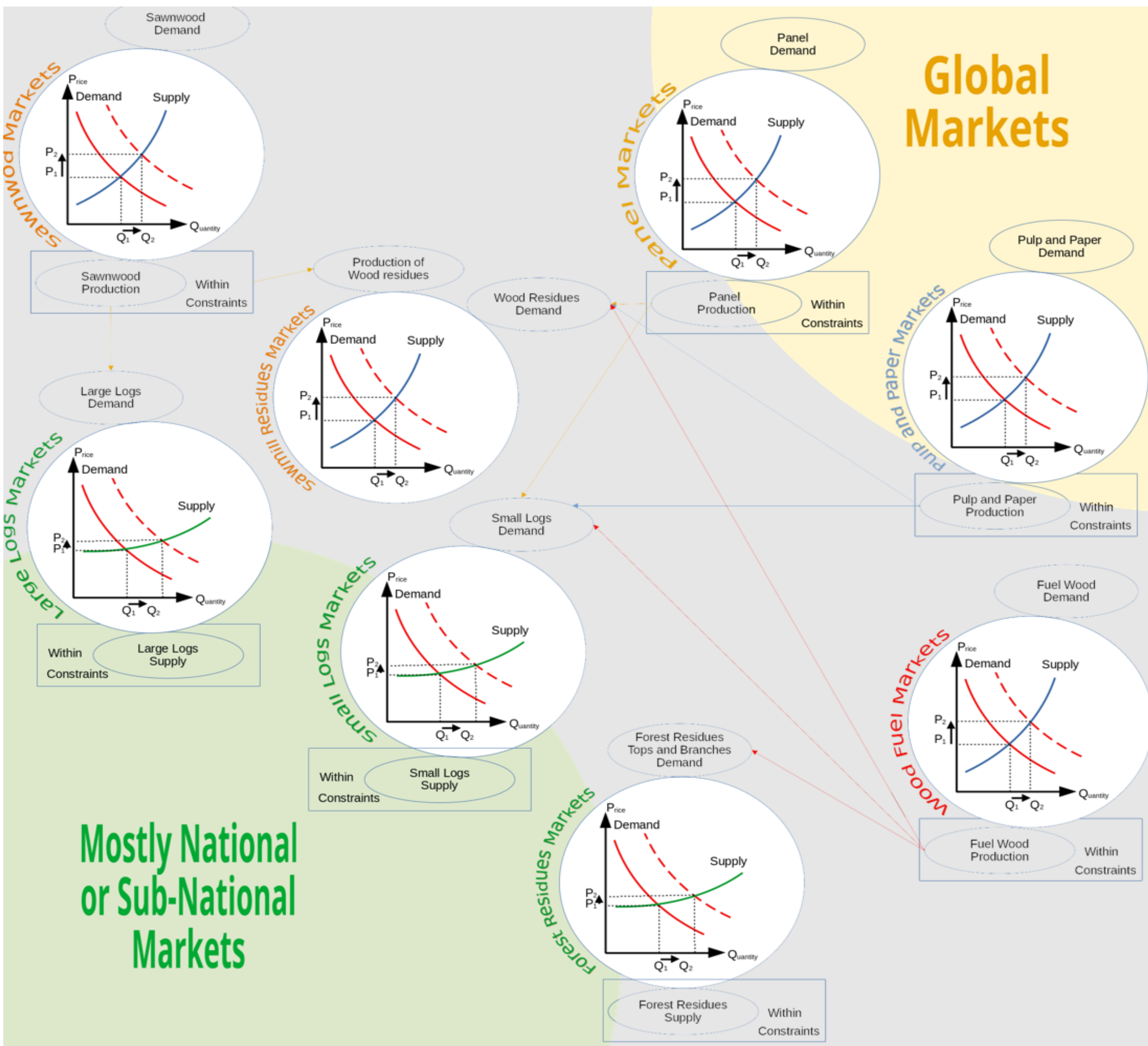
8.1 Forest sector price change drivers

Price movement reflects changing market conditions, or expectations thereof. For example, expectations from the sawmill industry, such as (1) pre-2020 predictions that demand would be lower (Zhang and Stottlemyer 2021) and (2) a smaller 2022 decrease of lumber imports from Russia than anticipated (Ekstrom 2022), can lead to underestimation of future demand in the first case – leading to future price increases – or to overestimation of future demand in the second case and ensuing future price decreases. As investment in industrial capacity is planned over the long term – in the order of decades – the production capacity is inevitably constrained in the short term. Moreover, the industry can only reply within its capacity limit to short term monthly and yearly demand fluctuations. Even in the presence of sufficient industrial capacity, shortage of skilled labour or logistic issues can impose further constraints on industrial production as illustrated in the bottom part of Figure 99. As logistical costs increase with road transport distance, in the longer term, the sawmill industry tends to be adapted to the local roundwood supply capacity, except in regions where it chiefly processes imported timber. Similarly, the pulp and paper industry tends to rely mainly on the local supply of primary forest products. However, there are many areas around the world–notably China, Japan, but also some mills in Scandinavia – that largely depend on imported logs.

The price of secondary processed products has increased more than that of primary forest products, which could be an indication of imperfect vertical price transmission. Market participants adapt their behaviour in anticipation of future developments, hence, this lack of price transmission between secondary and primary products could lead forest owners to delay fellings in expectation of higher prices (Gan et al. 2022), restricting the supply of roundwood and the production of processed wood products. The presence of a strong demand for processed wood products would lead to price hikes. Hence, the behaviour of stakeholders described previously constitutes an endogenous feature of forest products markets that can exacerbate price volatility.

Bark beetle attacks in central Europe intensified after 2017 and led to extensive salvage logging, particularly in Germany and Czechia. The latter country experienced salvage logging volumes two to four times the normal harvest level in 2019 and 2020 (Hlásny et al. 2021; Fernandez-Carrillo et al. 2020). This resulted in increased sawmill production in Czechia and Germany, increasing domestic supply as well as increased log exports, within the EU but also, notably, to China. Increased overall supply exerted downward pressure on prices. Another consequence was increased production of sawmilling residues, which are in turn used by the panel and paper industry as well as by the energy sector (see Figure 98). As sawmill production returns to normal levels, reduced availability of sawmilling residues is expected to create tensions on the market for feedstock of the panel, pulp and energy industries (Ekstrom 2022), leading to an upward pressure on prices.

Figure 98. Flow chart of forest products markets. Green curves represent the supply of primary product and blue curves the supply of secondary products P=price; Q=quantity.



Source: JRC 2022

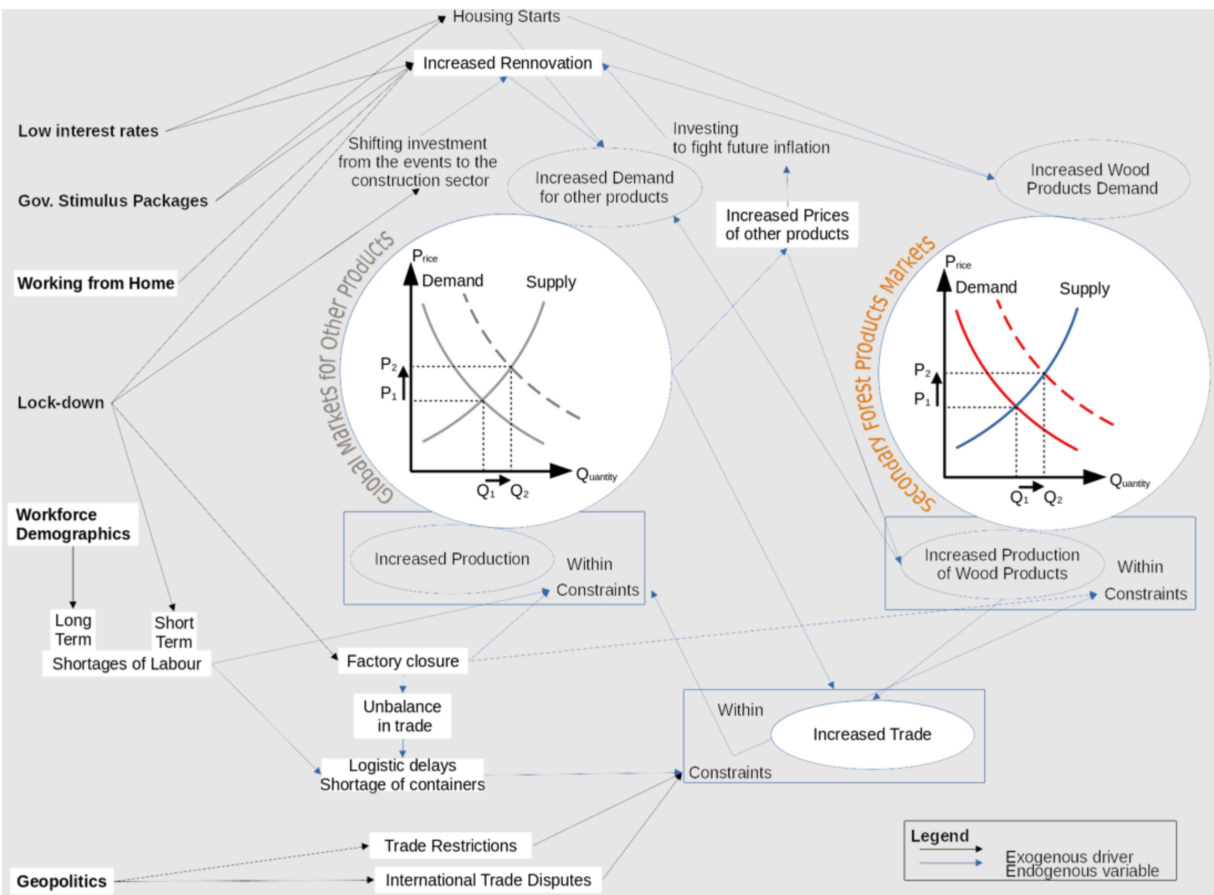
8.2 Price change drivers related to the COVID-19 Pandemic

Lockdown measures to slow the spread of the COVID-19 pandemic led to loss of revenue in economic sectors affected by the restrictions. Governments put stimulus measures in place to compensate and prevent an immediate economic crisis. Among them were, notably, measures related to home improvements, such as, e.g. insulation to increase energy efficiency. Over 2020 and 2021, bank interest rates remained below 2% for households (ECB 2022), which favoured investment, further bolstered by the desire of home buyers to invest their savings to fight future inflation. All these factors led to increases in renovation and housing starts, as illustrated in the upper part of Figure 99. In addition, the closing of restaurants and cafés and the cancellation of events, led to another push for renovation and a shifting of investments from the events to the construction sectors (Kooten and Schmitz 2022).

During the COVID-19 pandemic, country measures related to the workplace targeted teleworking and work place closures (cite EDCD dataset). Firstly, a mass switch to teleworking for all work where it was possible affected the demand side of the market, through an increase of renovation for home offices. Secondly, some countries put in place workplace closures, shutdowns. This led to a short-term, acute, shortage of labour, on top of the shortage due to the long-term trend of an aging workforce in the forest sector (Blombäck et al. 2003), and temporarily reduced industrial production (Gan et al. 2022; Franco 2021) illustrated on the left side of Figure 99.

From 2020 to 2022, COVID-19 related measures on the demand as well as on the supply side of forest products markets combined to exert upwards pressure on prices for secondary wood products, in particular sawnwood and wood-based panels.

Figure 99. Drivers of price volatility during the COVID pandemic



Source: JRC 2022

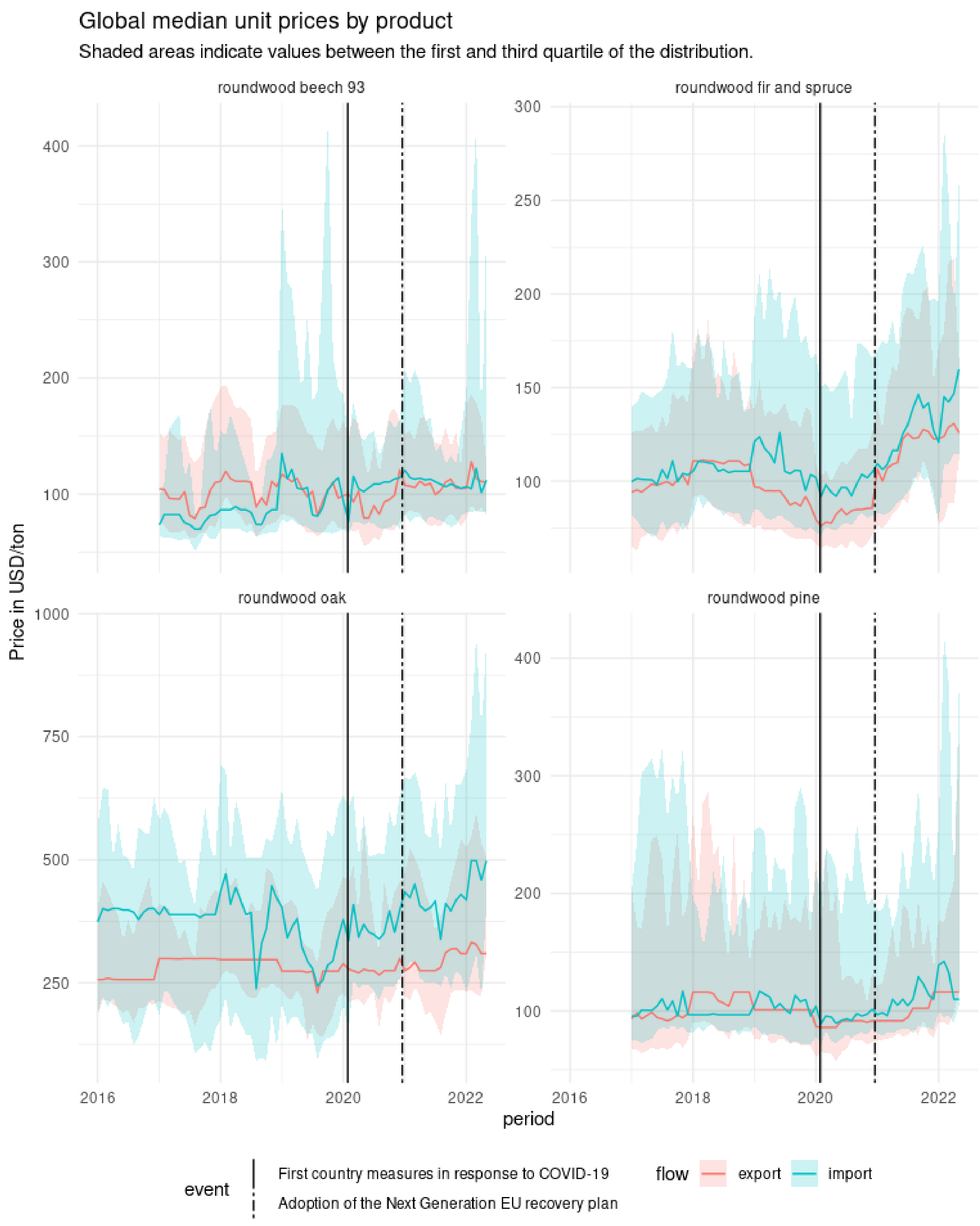
8.3 Price developments

Global price increases in roundwood (log) markets (Figure 100) have been smaller than in sawn timber markets (Figure 101). These figures illustrate the median unit price of trade, which means that half of the trade flows had prices above the line and half had prices below the line. The color band represents the first and the third quartile i.e. half of the observed unit prices are within the band.

The global plots show nominal price proxies (trade unit values) in US dollars. Converting to euros and compensating for inflation, we get a clearer picture. For example, comparing pine logs (Figure 102) with pine lumber prices (Figure 103), it becomes clear that raw material prices remained unchanged in real value terms during the pandemic, while the price of processed products increased. This suggests lacking vertical price transmission. However, the situation should be reassessed over the coming years, as it could be that prices visible in the international trade in roundwood reflect past contracts and that they are, therefore, slower to react to price changes.

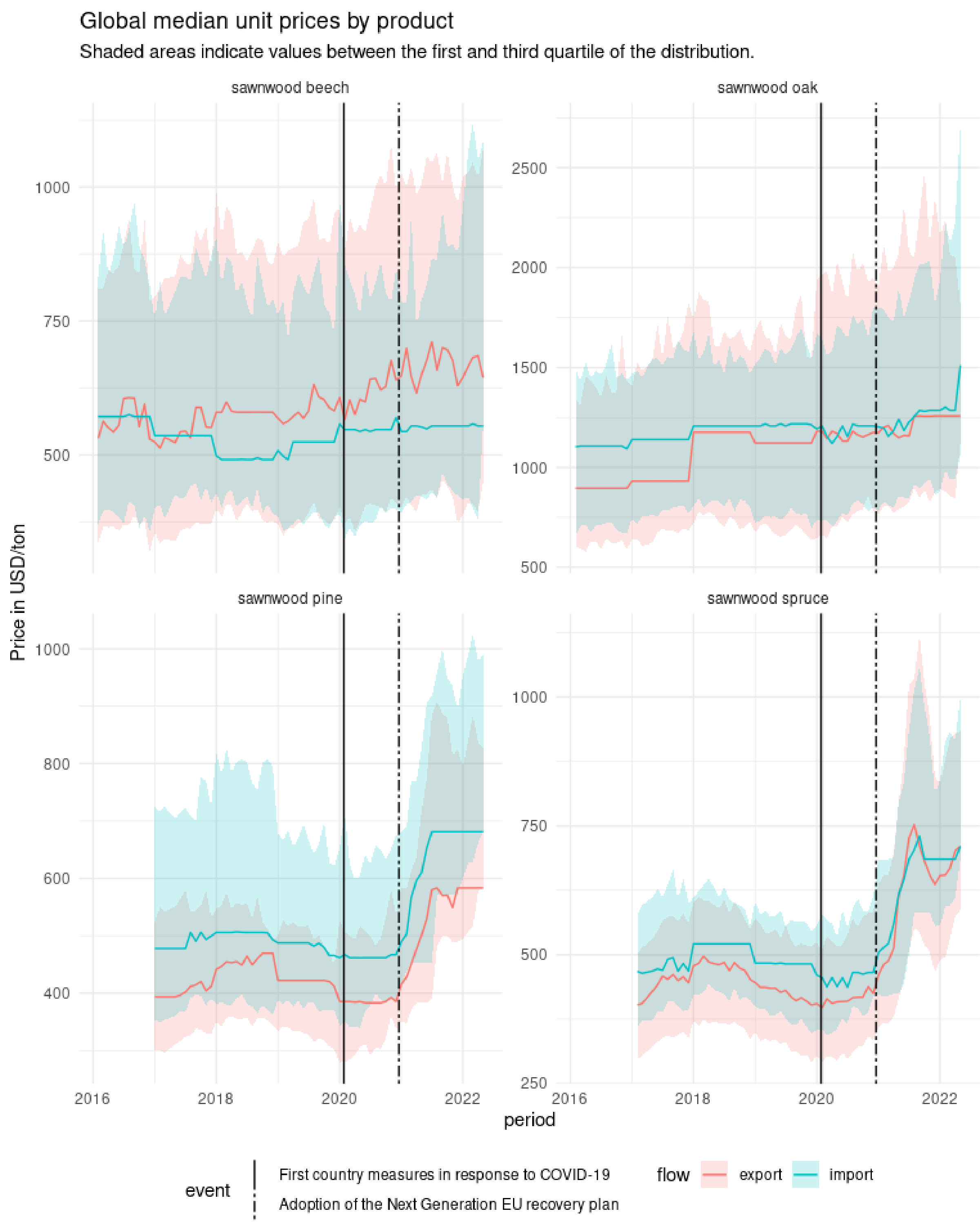
Prices expressed in real value (2015 euros) of non-coniferous plywood (Annex 8.2), coniferous plywood (Annex 8.3) and particle board (Annex 8.4) have increased over 2021 and the first quarter of 2022. Before the pandemic, Oriented Strand Board (OSB) prices (Annex 8.5) had shown a much tighter dispersion that any other product previously mentioned, as well as a better agreement between the intra EU and the global price. In 2021, OSB prices increased, and the dispersion increased as well, before decreasing at the end of 2021 and rebounding in 2022, showing high volatility. Pellet prices also increased globally during 2021 and the first quarter of 2022 (Annex 8.6). In turn, wood energy price increases are likely to persist as the energy crisis continues to develop.

Figure 100. Global roundwood price.



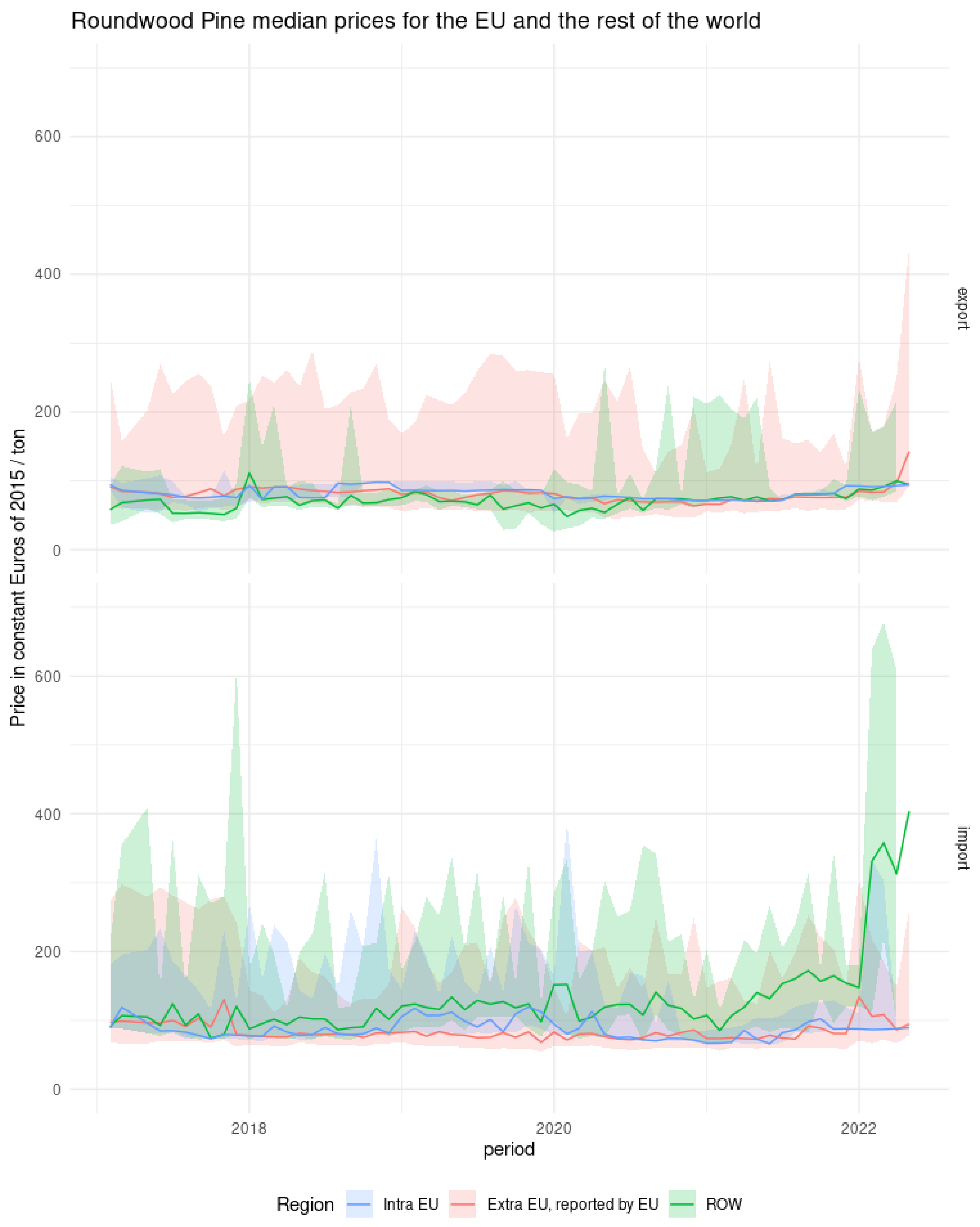
Source: JRC 2022 based on UN Comtrade data.

Figure 101. Global sawnwood price.



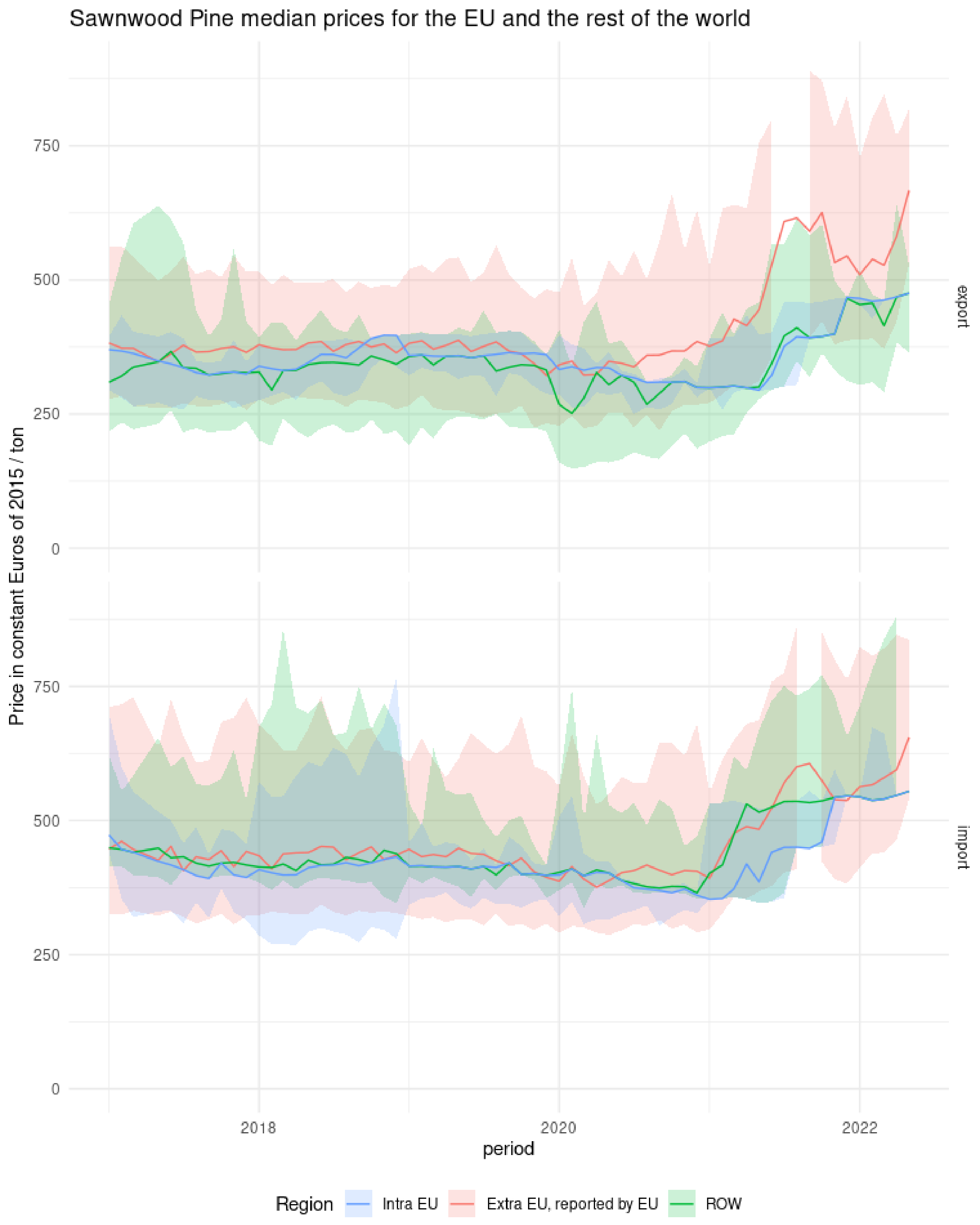
Source: JRC 2022 based on UN Comtrade data.

Figure 102. Intra and extra EU Pine log prices.



Source: JRC 2022 based on UN Comtrade data

Figure 103. Intra and extra EU Pine lumber prices.



Source: JRC 2022 based on UN Comtrade data

8.4 Conclusion for Chapter 8

Forest products are traded on the global market, and price developments in all markets reflect global changes. As observed in most plots, the price level tends to follow a long-term equilibrium path, becoming more unstable one year after the COVID-19 pandemic. As the pandemic ends, one would expect that prices reverted to a lower long-term level without geo-politics events and other shocks. However, as things were about to return to normality, the Ukraine crisis and the associated sanctions on the Russian Federation erupted. This has led to rapidly increasing energy and food prices in Europe and worldwide, exacerbating inflation and causing reduced economic activity due to reduced household income and increased production costs in most manufacturing industries. There is also the more direct effect of EU sanctions on Russian exports of wood products and the Russian log export ban reducing the overall supply in the EU. Hence, within the EU, the demand for wood products and the supply thereof is falling, which leads to a decrease in prices towards the end of 2022, although prices remain at a higher level compared to before the pandemic. However, due to its recent nature and evolving character, it is not possible at this point to conclude what the outcome of the Ukraine crisis in terms of real price levels (corrected for inflation) of wood products within the EU will be.

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9 Waste biomass availability: food waste and other biowaste streams

Carla Caldeira, Valeria De Laurentiis, Serenella Sala

Key messages

- Around 17 million tonnes wet weight (Mtww) of biomass waste was, on average between 2014-2017, incinerated or landfilled on an annual basis, showing potential for improvements towards a circular economy.
- JRC estimates EU Food waste in 2018 amounts to 84 Mtww, representing roughly 13% of the food produced in the EU is wasted across the whole food supply chain.
- Consumption is the stage of the food supply chain with the highest share of food waste ranging between 56% and 80% in EU countries.
- EU MSs are obliged to report food waste generated and binding reduction targets will be defined towards achieving SDG target 12.3 on food waste.
- The JRC food waste quantification model can be coupled with life cycle-based indicators of environmental impacts in order to assess environmental benefits of food waste reduction by compliance with targets to be defined.
- Food waste reduction strategies focused on food waste prevention and valorisation are key to the achievement of a circular economy.

Waste biomass has a significant role in the transition to circular economy and contributes to the sustainable use of natural resources (EEA, 2020; European Commission, 2018). The Waste Framework Directive (WFD) defines bio-waste as "*biodegradable garden and park waste; food and kitchen waste from households, restaurants, caterers and retail premises; and comparable waste from food-processing plants*" (European Parliament and of the Council, 2018).

A particular stream of waste biomass that has been gaining attention in past years is food waste. Since the establishment of Sustainable Development Goal (SDG) target 12.3 "*By 2030 halve per capita global food waste at the retail and consumer levels, and reduce food losses along production and supply chains including post-harvest losses*", several initiatives have been developed towards food waste reduction. Food waste has been identified as one of the priority areas of the European Commission with its Circular Economy Action Plan (European Commission, 2020), the Bioeconomy Strategy (European Commission, 2018) and with the Farm to Fork Strategy (European Commission, 2020), all important components of the European Green Deal (European Commission, 2019). The EC is highly committed to fight food waste. In the Farm to Fork strategy, the EC commits to halving per capita food waste at retail and consumer levels by 2030 (SDG Target 12.3) and foresees the definition of a baseline and binding targets to reduce food waste across the EU (European Commission, 2020).

The amendment to Directive 2008/98/EC on waste obliges the European Union (EU) Member States (MSs) to monitor the generation of food waste along the food supply chain (FSC) and to take measures to limit its generation (European Parliament and of the Council, 2018). 2022 was the first reporting year, during which MSs reported food waste data referring to the year 2020. The quantities reported were published by Eurostat in October 2022 (Eurostat, 2022) and will be used for the definition of the targets. In this context, the JRC has developed a model for the estimation of food waste in the EU at MS level, based on data currently available, adopting a consistent approach across countries, and enabling the assessment of temporal trends (De Laurentiis et al., 2021). A summary of this model is presented in Section 9.2. The food waste estimations were used to perform plausibility checks of the values reported by MSs in the framework of the Waste Framework Directive (2008/98/EC) reporting obligation. In addition, these estimations are being used in the Impact Assessment of food waste targets, to complement food waste data reported by MSs. The outcomes of the JRC food waste quantification model can be coupled with life cycle-based indicators for environmental impacts in order to assess environmental benefits of food waste reduction by compliance with targets to be defined (Sinkko et al. 2019).

In parallel, the JRC developed a model to quantify biowaste (including food waste) based on EU waste statistics. A summary of this approach is presented in Section 9.3. Some concluding remarks are presented in Section 9.4.

9.1 Food waste quantification and uses

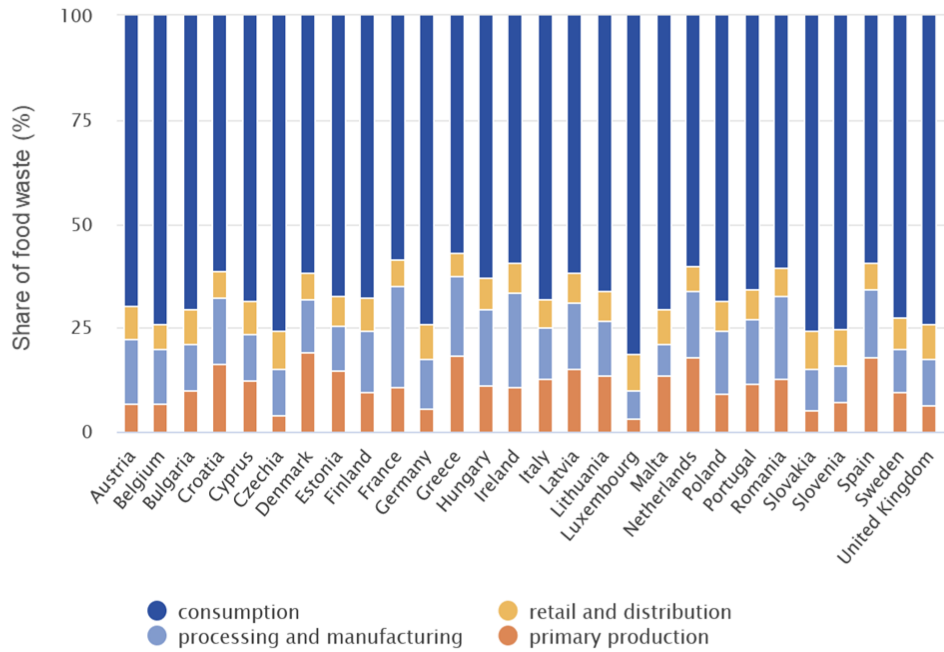
The food waste quantification model calculated that, in 2018, roughly 13% of the food produced in the EU was wasted across the food supply chain, equal to 84 million tonnes (in wet weight - Mtww) of food. This food waste generation is associated with greenhouse gas (GHG) emissions that contribute to 7% of the EU consumption based GHG emissions[68]. Results of the food waste quantification model are provided for each country, both per stage of the food supply chain and for different food groups. The results identified the consumption stage as the major contributor to the total amount of food waste generated in all countries (Figure 104), stressing the relevance of putting in place food waste prevention initiatives that target consumers and promote behavioural change. The most contributing food group varies among MSs and food supply chain stages.

When looking at food waste generation at consumption level, perishable food groups such as fruit, vegetables and dairy tend to be the largest contributors, however there are significant variations across countries (Figure 105). The estimations do not present significant yearly variability over the time range, nevertheless this can be attributed to a limited ability of the model to capture changes in rates of food waste generation, due to a lack of data that could enable to better model this aspect.

Regarding the destination of food waste, Figure 106 illustrates that more than half of the food waste generated is disposed of via landfill, sewage or incineration. Composting and anaerobic digestion are the other two main destinations of food waste (19% and 18% respectively). Finally, 8% of the waste is used in other ways such as home composting or food for pets. This shows a significant potential for increasing the rate of food waste used for composting and anaerobic digestion, bearing in mind that food waste prevention must always be given priority. As there will always be a certain level of food waste generation, in particular at the processing stage (De Laurentiis et al., 2018), it is important to prioritise the direction of such food waste to destinations higher in the food waste hierarchy such as its valorisation into added-value products. In particular, food waste generated at processing and manufacturing can be valorised in a variety of added-value products (Caldeira et al., 2020). The destination of food waste was obtained from EU waste statistics, as described in Corrado et al. (2020).

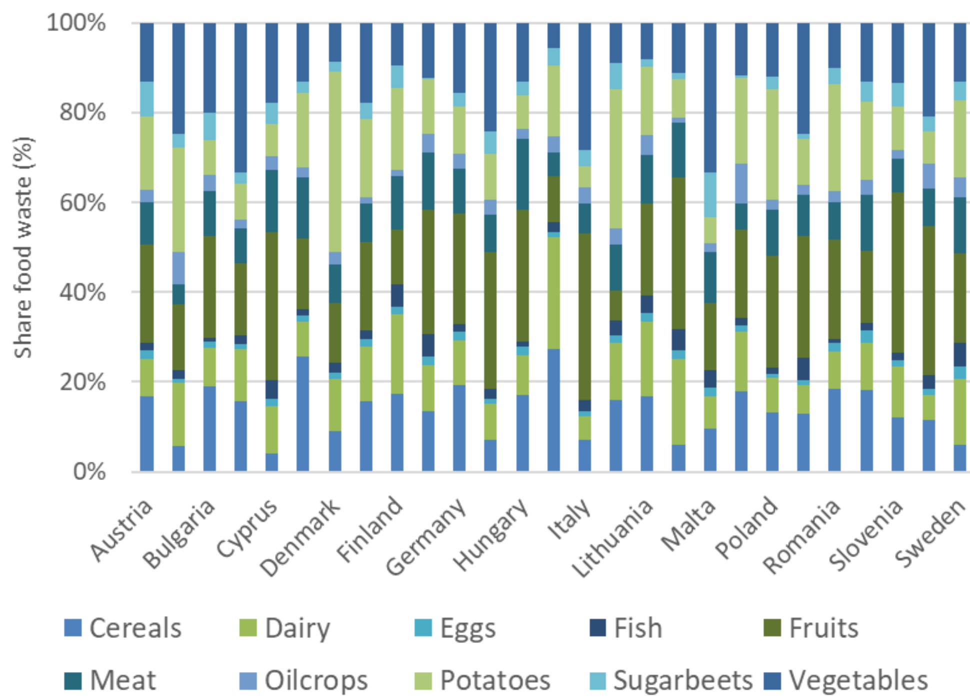
[68] Calculated by comparing the GHG emissions linked to producing and distributing the food that is wasted with the overall emissions of EU consumption derived from the Consumer Footprint Platform, available at: https://eplca.jrc.ec.europa.eu/ConsumptionFootprintPlatform.html.

Figure 104. Share (%) of food waste per stage of the food supply chain for each Member State in 2018.



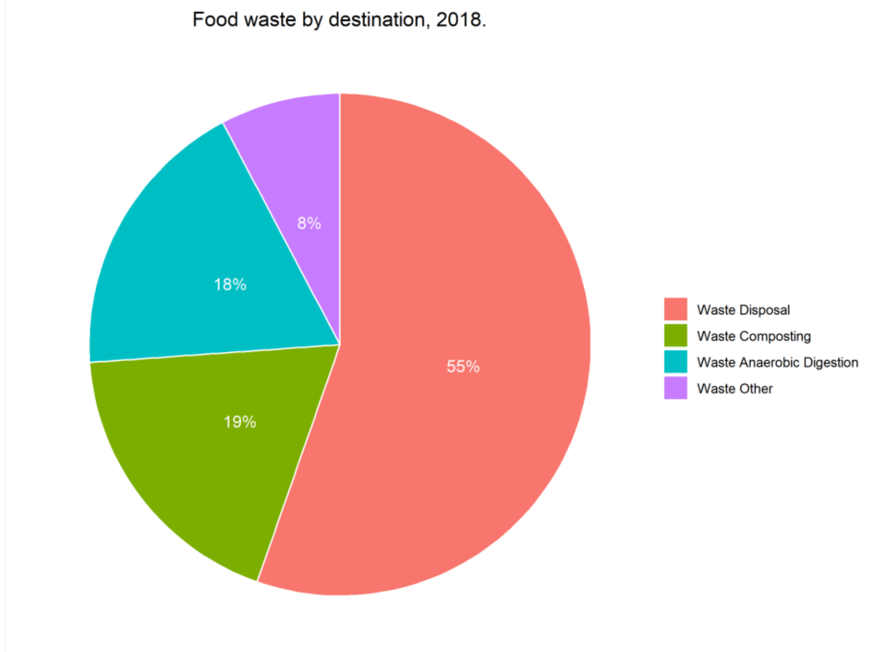
Source: JRC, own elaboration

Figure 105. Share (%) of food waste per food group at consumption for each Member State in 2018.



Source: JRC, own elaboration

Figure 106. Destinations of food waste in EU in 2018



Source: JRC, own elaboration

9.2 Material Flow Analysis (MFA)

The food waste quantification model applies the EU legislation definition of food waste which includes *"all food [...] that has become waste"* (European Parliament and of the Council, 2018). Regulation (EC) No 178/2002 defines food as a whole, encompassing the entire Food Supply Chain (FSC) from production to consumption. Food, and hence food waste, is composed also by inedible parts, where those were not separated from the edible parts during food production, such as bones attached to meat. 'Waste' means any substance or object which the holder discards or intends or is required to discard (European Parliament and Council, 2008).

The model combines a mass balance approach with data from official statistics (e.g. FAOSTAT and PRODCOM) and waste coefficients from scientific literature. The model was initially developed to quantify food waste at EU level (Caldeira et al., 2019) and was further refined to provide data at Member State level (Caldeira et al., 2021; De Laurentiis et al., 2021), providing a harmonised approach for food waste quantification for 10 food groups (sugar beet, cereals, fruit, vegetables, potatoes, oilseeds, meat, fish, eggs, and dairy) at each stage of the food supply chain:

i) primary production, modelled using crops and livestock production values from FAOSTAT (Commodity Balance Sheet for 2000-2013, and Food Balance Sheet for 2014 onwards) which reports data in commodity primary equivalent (i.e. the amount of primary commodity input that would be required to produce a given amount of derived product output (GSARS, 2017)) Additionally, live animals slaughtered in the EU are extracted from FAOSTAT livestock primary database;

ii) processing and manufacturing, modelled differently for each food group, with cereals and meat presenting the higher level of detail and complexity. The main inputs come from several databases from FAOSTAT and Eurostat (i.e. FAO CBS, FAO trade, PRODCOM, COMEXT, APRO, EUMOFA);

iii) retail and distribution, modelled by means of waste coefficients and mass balance, and

iv) consumption in food services and household, modelled as well using waste coefficients and mass balance.

In addition to food waste, the model estimates food losses (i.e. not harvested or ploughed in crops, and animal mortality during transport to slaughterhouse and rejected at slaughter[69]); by-products (i.e. surplus food used as animal feed and for non-food uses); and food consumed. Food waste and food consumed at retail and distribution and consumption phases are provided both in absolute and per capita terms.

The modelling details for each FSC stage and food group are described in detail in De Laurentiis et al. (2021).

The FW MFA model is implemented in R and it generates results for all MSs and in the time range 2000-2019. The results at EU and MS level for the time series are presented in the EU Bioeconomy Monitoring System and will be periodically updated there[70,71].

The sensitivity of the model was analysed by comparing the estimated amount of food consumed with food consumption data from surveys. Despite the limitations that prevent full comparability of results (e.g. data availability limited to few years and countries), many food groups showed values within the expected range of variability. Additional plausibility checks were performed by comparing model outcomes with food waste values voluntarily reported by MSs and with values obtained from statistics. In both situations, the distribution of food waste generation across the food supply chain stages appeared to be well captured by the model.

The model and its results are affected by uncertainty mostly related to the data gaps, to the inherent uncertainty of the underlying statistical data used, and to the assumptions made in the modelling stages to overcome missing data on food waste percentages for different MSs.

The model is being further developed to reduce these sources of uncertainty by e.g. broadening the coverage of country-specific coefficients (when data is available) and improving the modelling of food waste and by-products generated at the processing stage by obtaining data from food processing industries (e.g. via manufacturing associations). An updated version of the model is expected to be published by Q2 2023.

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[69] Although an official definition of food losses is lacking in EU legislation, according to Article 2 of Regulation (EC) No 178/2002 of the European Parliament and of the Council "the loss of potential food prior to the harvest of crops or animal products shall not be considered as food waste". Therefore, crops ploughed in or left on field and mortality of animals ready for slaughter are considered as food losses.

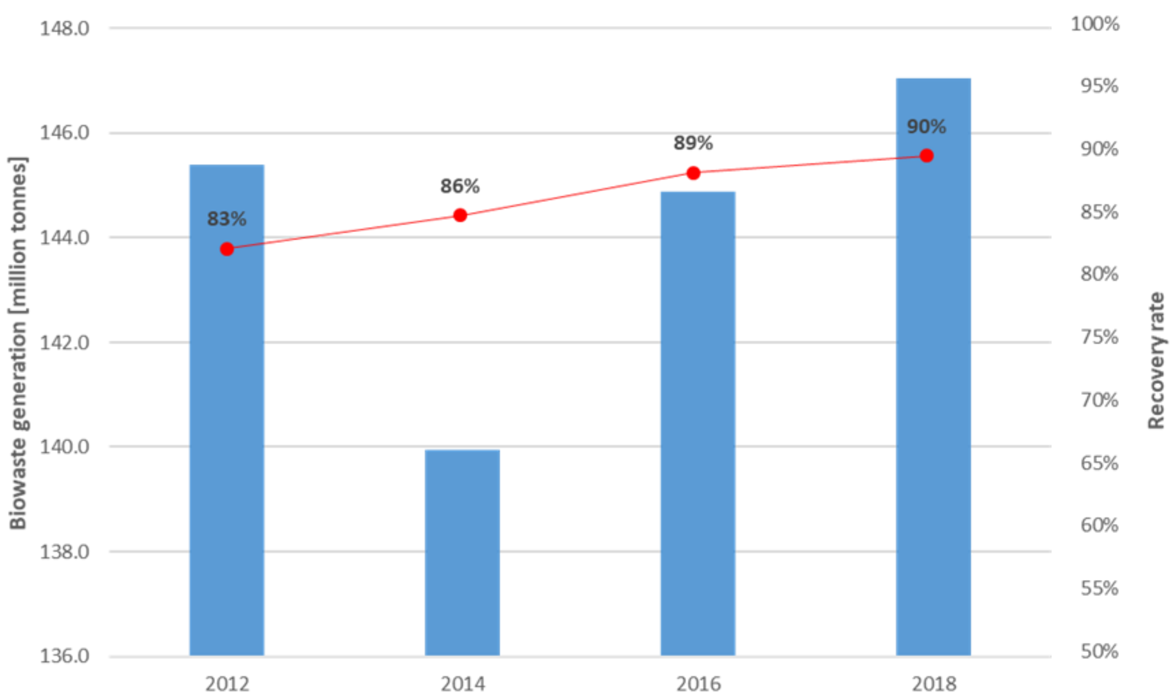
[70] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.1

[71] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.2.a.2

9.3 Biowaste quantification and uses

The analysis of the biowaste generation in the EU, based on waste statistics, showed how the generation of biowaste has been increasing since 2014, although no clear trend can be detected for the timeframe 2012-2018 (Figure 107). The recovery rate, corresponding to the share of biowaste recycled or used for energy recovery, has been steadily increasing during this timeframe, and, as a consequence, the share of biowaste disposed of via landfill and incineration without energy recovery has been decreasing (Figure 107). There is, however, still potential to further increase the recovery rate.

Figure 107. Biowaste generation (blue bars) and recovery rates (red line) (shares used for recycling and energy recovery) in EU 2012-2018.



Source: JRC 2022, https://knowledge4policy.ec.europa.eu/publication/infographics-biomass-sources-uses-eu-27-2017-data_en.

9.4 Biowaste from waste statistics

We implemented the calculation of biowaste generated by industry and households derived from waste statistics at EU and MS level. According to information received from DG ESTAT, significant changes in the classification used by the waste statistics took place after 2010, entailing that results obtained up to 2010 are not comparable with those from 2012 onwards. Therefore, results were calculated for the years 2012, 2014, and 2016 for the EU and for each MS.

Data on waste generation is collected from EU Member States in a framework set up by the Waste Statistics Regulation and published by Eurostat based on Regulation (EC) No 2150/2002 on waste statistics. This data includes a mix of organic and inorganic wastes generated from various economic activities (including households). Nevertheless, it does not distinguish the biodegradable component in the different waste categories. For example, certain waste categories such as textile or rubber waste contain a mix of biodegradable and synthetic wastes, and the two components are not reported separately. Similarly, the biodegradable fraction in generic categories such as "household and similar waste" is not estimated. In fact, some studies in EU MSs have tried to estimate the share of biodegradable waste in municipal solid waste using empirical evidence (Edjabou et al., 2015; Horttanainen et al., 2013). The present study builds on the existing statistics and empirical evidence available to estimate the quantities of biodegradable waste generated in the EU and in each MS. Details of how this is computed are provided in the Annex to this Chapter.

The amount of biowaste that is recovered (recycling or energy recovery) and the amounts disposed (landfill or incinerated) were computed, building on EU statistics on waste treatment. Industrial biowaste that is used in integrated processes is not included as the data on waste generation is obtained from waste statistics, therefore not capturing biowaste that is utilised in the industry.

The amount of each type of biowaste (e.g. paper and cardboard waste) differentiated by waste treatment option (e.g. landfill, incineration, recycling) is provided in the database *"Treatment of waste by waste category, hazardousness and waste management operations [env_wastrt]"* (Eurostat, 2014). These data were retrieved for the EU and each MS for each year.

The resulting amounts of biowaste generated and recovered have been published in the EU Bioeconomy Monitoring System and will be periodically updated there[72,73].

As biowaste estimated from waste statistics included food waste as well, we compared the estimations of food waste obtained using the material flow approach (as described in Section 9.2) and from waste statistics. Food waste estimates obtained with the MFA approach are generally higher than those obtained using the waste statistics approach. These differences are more significant for early stages of the food chain, i.e. primary production and food processing. Such discrepancies are very likely caused by an underreporting of waste collected by waste statistics as waste flows generated in these stages can be treated on site (e.g. incineration of residues for energy production, anaerobic digestion) and might, therefore, not be reported. The reader is referred to Caldeira et al. (2021) for more details on this exercise.

9.5 Conclusions for Chapter 9

Waste biomass estimation in EU show potential for improvement towards a circular (bio)economy and cascading use of biomass, especially in extracting bioactive compounds and nutrients and bioenergy use (Pivac-Zeko et al., 2022). Estimations obtained from EU statistics, show that, on average from 2014 to 2017, around 17 Mtww of biomass waste was disposed in landfills or incinerated.

Regarding food waste, 13% of food available was being wasted in 2018 which reveals the inefficiency of the EU food system, representing significant costs and environmental impacts. With the mandatory reporting of MSs and the definition of binding targets for food waste reduction in the coming years, this situation is expected to improve. However, MSs need to implement food waste prevention strategies and monitoring systems that allow to measure progress towards the reduction of food waste and achievement of the SDG target 12.3.

9.6 References for Chapter 9

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[72] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.5
[73] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=3.1.c.6

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10 Biomass uses in biorefineries

Edoardo Baldoni, Patricia Gurría, Robert M'barek

Key messages

- Biomass processing facilities, including biorefineries, may contribute to the environmental ambitions of the EU while creating jobs and growth in rural areas.
- Data on production activities and territorial distribution of biomass processing facilities are still scarce.
- The JRC publishes spatially explicit data on biomass processing facilities in the EU and in selected non EU countries, which help understand their role in the EU and global bioeconomies and assess their direct and indirect impacts on local economies.
- Forestry and agriculture are the main feedstock sources for biomass processing facilities in the EU.
- Agricultural feedstock used by chemical and material biorefineries is mostly of primary origin (90.7%) while forestry feedstock for a relatively large share is of secondary origin (42.9%).
- The share of secondary biomass used by the chemical and material biorefineries is higher in the EU-27 (22.7%) than outside the EU (15.8%).

Facilities that convert biomass into bio-based products are a structural component of the bioeconomy. Some of these facilities fall under the definition of biorefineries, depending on the chosen focus (Parisi, 2020). Some sources (US DOE 1997) define a biorefinery as "*an overall concept of a processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products*". Others provide more details and include sustainability aspects into the definition. For instance, a biorefinery is defined by de Jong et al. (2012) and BIC (2017) as "*a facility that performs the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat), using a wide variety of conversion technologies in an integrated manner*".

As outlined in the Bioeconomy Progress report (European Commission, 2022), biorefineries at scale could play an important role in transforming industrial facilities towards the environmental ambitions of the EU, while creating jobs and growth in rural areas.

Despite their central role as transformers of biomass, data on production activities and the territorial distribution of biomass processing facilities and of biorefineries are still scarce. To partly fill these data gaps, the European Commission's Joint Research Centre (JRC) compiled three databases with corresponding dashboards on these facilities across the EU and in selected non-EU countries, allowing the user to explore the underlying data and to download specific visualisations that are publicly available in two platforms, DataM[74] and the EC's Knowledge Centre for Bioeconomy[75].

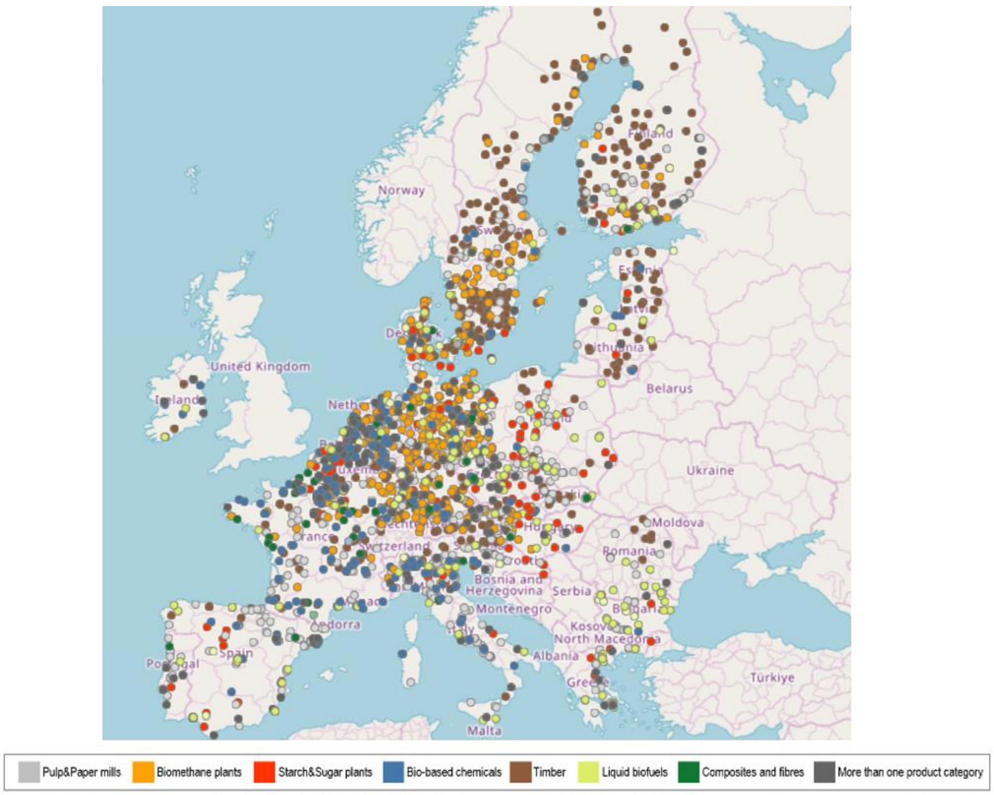
[74] https://datam.jrc.ec.europa.eu/.
[75] https://knowledge4policy.ec.europa.eu/bioeconomy_en.

10.1 Biomass processing facilities in the EU

According to the latest available data[76] about 2,362 biomass processing facilities across the EU are involved in the production of bio-based chemicals, liquid biofuels, composites and fibres, biomethane, pulp and paper, sugar, starch and timber. The spatially explicit information includes data on feedstock and type of bio-based products produced as well as on other characteristics such as the Technology Readiness Level (TRL) and the presence of products-energy integrated processes. At facility level, only qualitative information on feedstock and product types is presented.

Figure 108 presents the territorial distribution of the production activities of these facilities across the EU-27. It is visible that biorefinery uptake is not equally distributed across Member States (MS) and it does not reflect the biomass availability in the territory, especially in the eastern parts of the EU-27.

Figure 108. Territorial distribution of bio-based industries and biorefineries in the EU-27.



Dots in lighter colour in each category indicate facilities that are currently inactive (but not necessarily as a permanent status)

Source: *DataM and Parisi et al., 2020.*

The majority of the facilities of the database are involved in the production of pulp and paper (21.4%), followed by bio-based chemicals (19.9%), timber (18.5%), biomethane (14.3%), liquid biofuels (12.8%), starch and sugar (7.6%) and composites and fibres (5.5%). The major feedstock sources are coming from forestry and agriculture. Overall, 1,202 facilities use feedstock sources from forestry (47.9%) while 845 employ feedstock sourced from agriculture

[76] https://datam.jrc.ec.europa.eu/datam/mashup/BIOBASED_INDUSTRY/.

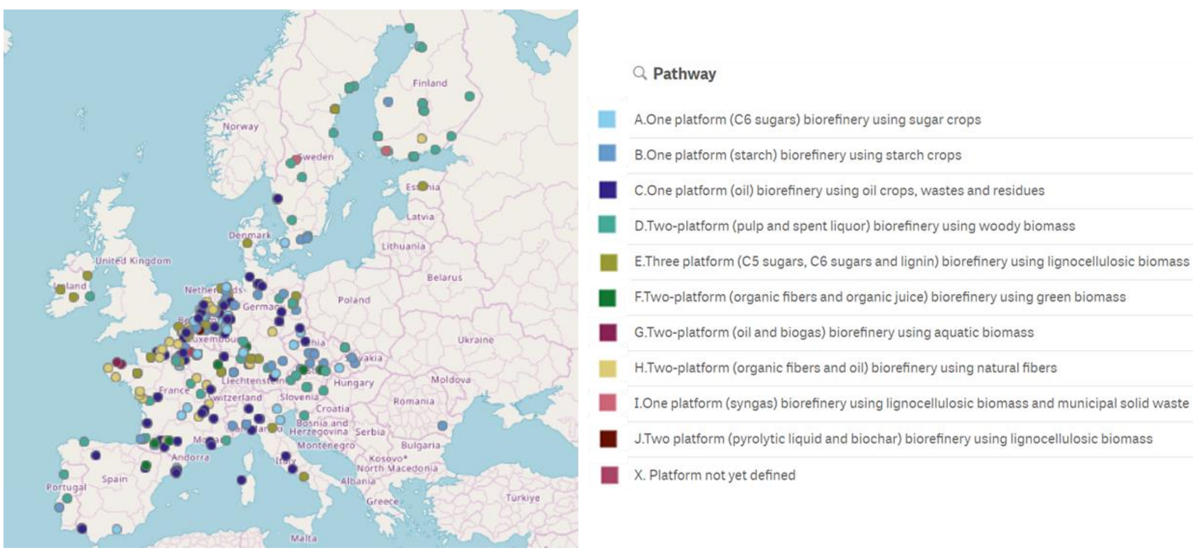
(33.7%). Other feedstock sources accounted for in the database are grasses and short-rotation coppices (9% of the total number of facilities), waste (8%), marine (1.4%), and other types of feedstock (0.1%).

Hereafter, we describe the biomass processing facilities that fall under the definition of biorefineries and specifically on chemical and material driven biorefineries[77]. These include integrated biorefineries that produce chemical and materials as major products, but could also co-produce food and feed as well as bioenergy (Baldoni et al., 2021a; European Commission et al., 2021). Bio-based chemicals and materials range from high-value added chemicals and materials such as cosmetics, pharmaceuticals, food additives and others, to high volume chemicals and materials such as general bio-based polymers or chemical feedstock (i.e. building blocks). These products have the potential to contribute substantially to the environmental ambitions of the EU because of their structural role in the manufacturing sector (Baldoni et al., 2021b).

Figure 109 presents the data on territorial distribution, feedstock, conversion processes, platforms, and detailed products of 298 biorefineries in the EU. A high level of detail is provided for products, feedstock, conversion process and platforms to allow the classification of the biorefineries by their pathway. As for the bio-based industries, only qualitative information at facility-level is available.

Figure 109 illustrates uneven and concentrated biorefinery development in the EU-27 that might signal non-technical barriers in MS with much biomass availability but lacking biorefineries (e.g. the 11 central and eastern European MS organised in the BIOEAST Initiative). These non-technical barriers are mainly represented by the lack of economic viability, overlaps and conflicts between existing strategies and policies, the high level of investment required in plants, the lack of evidence on the life-cycle benefits of bio-based products, and the low level of development of biomass supply chains (European Commission et al., 2021).

Figure 109. Territorial distribution of chemical and material driven biorefineries in the EU-27.



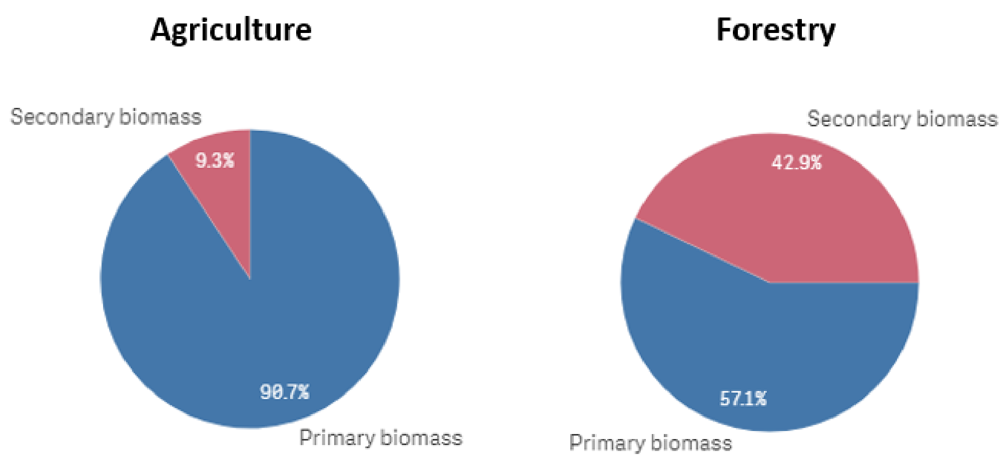
Source: DataM and Baldoni et al., 2021c.

In the EU-27, the majority of facilities produce chemicals (43.0%) and other types of products, such as pharmaceuticals, nutraceuticals, food, and others (30.4%), and, to a lesser extent, composites and fibres (20.9%) and liquid biofuels (5.7%). The major source of feedstock of chemical and material driven biorefineries is agriculture (63.9%). In particular, oil crops, sugar and starch crops and lignocellulosic crops are the most used types of agricultural feedstock. Residues from agriculture are still less used instead. Overall, in terms of composition of agricultural biomass by type, around 91% of agricultural feedstock used by chemical and material biorefineries is

[77] https://datam.jrc.ec.europa.eu/datam/mashup/CHEMICAL_BIOREFINERIES_EU/; https://datam.jrc.ec.europa.eu/datam/mashup/CHEMICAL_BIOREFINERIES_NON_EU/. Due to data availability, sustainability criteria are not considered in the definition of biorefinery in these databases.

of primary origin. In contrast, residues from agriculture account only for a 9.3% share of the types of feedstock. The second type of feedstock used by chemical and material driven biorefineries is forestry which accounts for the 23.8% share. Unlike agricultural feedstock, the share of secondary biomass from forestry accounts for a relatively large share of the overall types of feedstock used (43%). Figure 110 shows that only 9.3% of agricultural feedstock is of secondary type while for the forestry feedstock approximately 43% is of secondary type.

Figure 110. Chemical and material biorefineries in the EU-27 by biomass type.

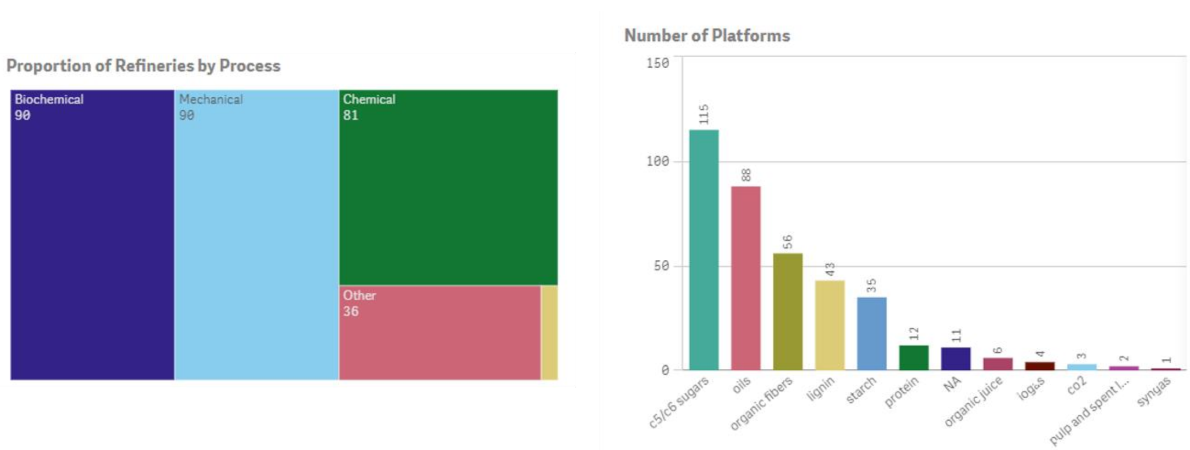


Source: *DataM and Baldoni et al., 2021c.*

Other types of feedstock used by these facilities are waste (8.9%), marine (3.2%) and other types (0.3%). Overall, approximately 77.3% of the types of biomass used by these facilities is of primary origin while 22.7% is of secondary origin. From a sustainability perspective, the share of secondary biomass used in biorefineries can be considered as a proxy of the degree of adoption of the cascading principle in the use of biomass (European Commission, 2022) and thus, it allows monitoring one dimension of the environmental performance of the sector.

In addition to the information on feedstock and products, the distribution of platforms and conversion processes is also available for chemical and material biorefineries. These data allow to better qualify the production processes of these facilities. Figure 111 presents the visualisation that includes the distribution of feedstock types, conversion processes, platforms and products (page "Bio Refineries Uses").

Figure 111. Chemical and material biorefineries in the EU-27.

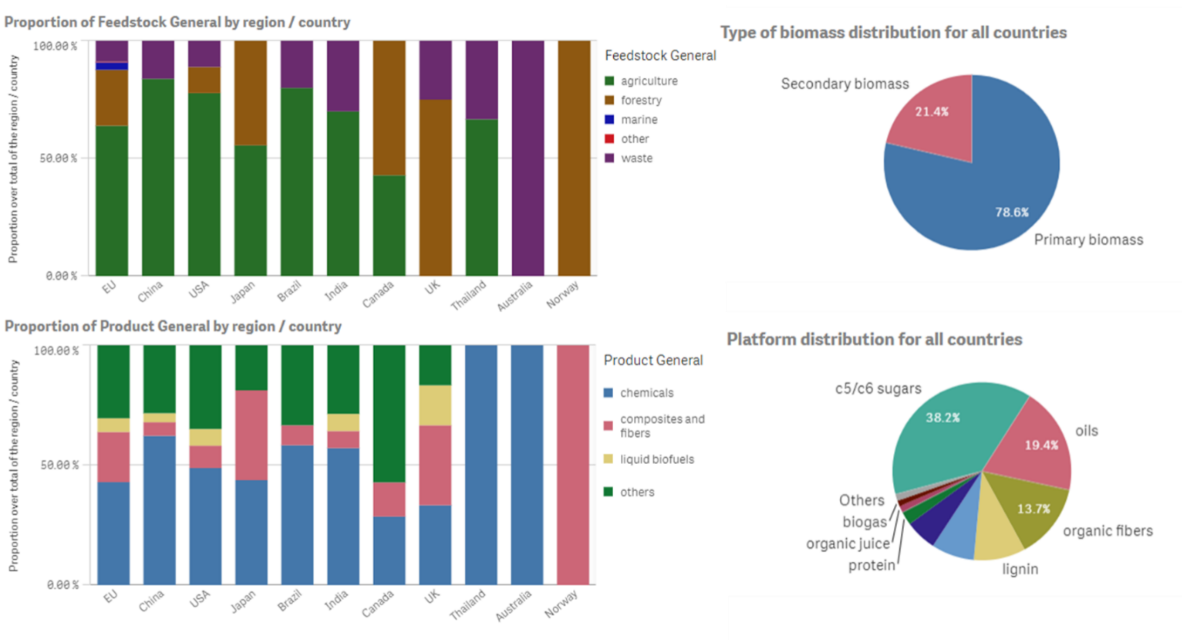


Source: *DataM (page "Bio Refineries Uses") and Baldoni et al., 2021c.*

10.2 Biomass processing facilities (chemical and material biorefineries) in selected non-EU countries and comparison with the EU

Information on chemical and material biorefineries is also available for selected non-EU countries as shown in Figure 112. To get all information available, the reader can access the full dashboard[78] which has the same structure of the one for the EU-27 (Figure 112) but includes information on 110 biorefineries for Australia, Brazil, Canada, China, India, Japan, Norway, Thailand, UK and the USA. The biorefineries included do not represent a complete list of the chemical and material driven biorefineries present in the selected countries, but only a limited number of biorefineries whose data was more accessible. Therefore, we believe that the coverage level for these countries is lower than that of the EU. Nevertheless, these data are used to make some comparisons between biorefineries in the EU and in these countries. These comparisons are provided in terms of number of facilities as well as in terms of composition of feedstock sources, products produced, platforms, pathways and type of biomass used.

Figure 112. Chemical and material biorefineries outside the EU.



Source: *DataM (page "Comparisons") and Baldoni et al., 2021d.*

Focusing on the type of biomass, the comparison using the current data shows that the share of secondary biomass used by the chemical and material biorefineries is higher in the EU (22.7%) than outside the EU (15.8%).

10.3 Conclusions for Chapter 10

According to the latest available figures, the bio-based share of the EU's chemical market, estimated at around 3%, is rather limited (Spekreijse et al., 2019). Investments in private and public partnerships have been contributing to the development of the supply side of the market and to overcome some of the technical barriers. For example, the Bio-based Industry Joint Undertaking (BBI-JU) was a public-private partnership between the European Union and the Bio-based Industries Consortium (BIC) to fund projects in the bio-based industries sector from 2014 to 2020. This initiative has been relaunched as the Circular Bio-based Europe Joint Undertaking in 2021 (European Commission, 2022). Both, the currently low bio-based share in the EU chemical market and the fact that the EU's

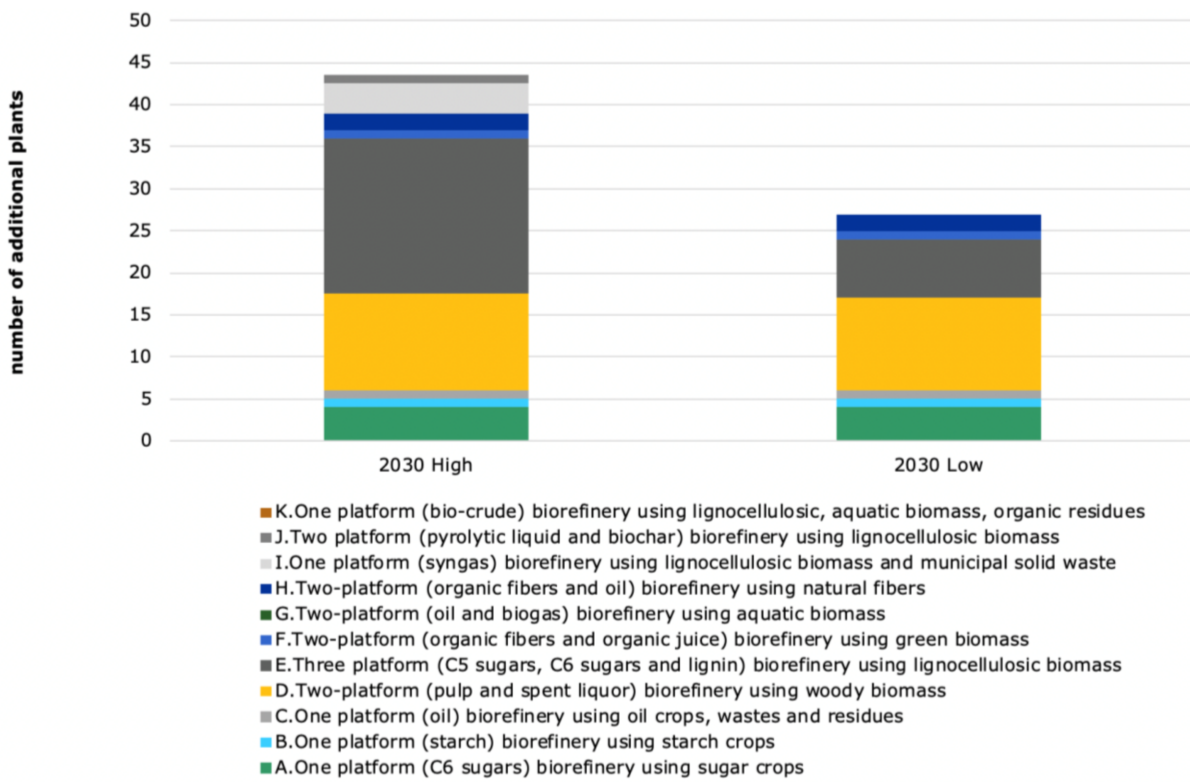
[78] https://datam.jrc.ec.europa.eu/datam/mashup/CHEMICAL_BIOREFINERIES_NON_EU/.

global market share for bio-based chemicals and materials is approximately twice the size of the fossil-based sector, point to an important growth potential of the sector (Spekreijse et al., 2019; Spekreijse et al., 2021).

According to European Commission et al. (2021), between 27 and 44 new chemical and material driven biorefineries could be developed by 2030 depending on scenarios assumptions. All pathways currently at advanced TRL levels (8 and above) are expected to see an increase in their number by 2030. Biorefineries fed with woody biomass and lignocellulosic biomass (pathway D and E) are estimated to have the highest growth potential (Figure 113). This potential could be realised in Nordic countries where there are large sources of feedstock, more developed biomass supply chains as well as already existing pulp and paper industries. BIOEAST countries may also represent an important location for future development thanks to their relative abundance of biomass. However, developments in infrastructure and supply chains may be required for this potential to be realised (European Commission et al., 2021).

Policy is expected to play an important role also in overcoming non-technical barriers. For example, setting standards may contribute to increasing awareness and willingness to pay of final consumers for bio-based products. Moreover, the introduction of specific measures (such as a carbon tax) could help level the playing field between bio-based and conventional products (European Commission et al., 2021).

Figure 113. Ramp-up of additional plants by 2030, high and low scenario.



Source: *European Commission et al., 2021.*

Adequate information systems will be another essential component for the development of the sector. The available information on biomass processing facilities and the focus on chemical and material driven biorefineries in the EU and in selected non-EU countries can help shedding light on the features and on the territorial distribution of these critical segments of the bioeconomy and a better understanding of its role at the global level. Moreover, the spatially-explicit nature of the information may be useful in assessing the role of these biomass converting facilities in terms of direct and indirect impacts on local economies and in supporting policy-making.

Indeed, the Bioeconomy Progress Report (European Commission, 2022) states with regard to the Activity 1.3.1 (Report on enablers and bottlenecks to unlock bio-based innovation potential: research needs, market uptake), that "*it remains crucial to stay abreast those opportunities, but also the bottlenecks and enablers. For any future mapping or foresight close cooperation with JRC – (e.g. Knowledge Centre for Bioeconomy, Biorefinery database etc.) can be recommended.*"

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11 Innovative wood-based products

Gediminas Jasinevičius, Mariana Hassegawa, Pieter Johannes Verkerk

Key messages

- Statistical data on production quantities of innovative wood-based products in the EU are limited and scattered.
- Some innovative wood-based products whose quantities are most significant or have the potential to increase market share are cross-laminated timber, man-made cellulosic fibres (lyocell), bioplastics and wood-based composites.
- Global production capacity of cross-laminated timber in 2020 is estimated at 2.8 million cubic metres, of which 48% is produced in Europe. The global production is expected to double by 2025.
- Lyocell is an innovative man-made cellulosic fibre that is produced with less harsh chemicals compared to conventional man-made cellulosic fibres such as viscose and acetate. However, the market share of this fibre is relatively small compared to other fibres.
- The estimated production of crude tall oil, which can be used in the production of biodiesel and bioplastics, is around 650 thousand tonnes in Europe, and production is expected to increase to 2.3 million tonnes by 2030.
- In Europe there are roughly 30 major wood-based composite producers in nine different countries. In 2018, the production was nearly 470 thousand tonnes of bio-based composites.

The need to achieve EU climate mitigation goals and to increase resources use efficiency is driving innovation across various industries. The wood-based industry is looking for innovative and resource-efficient products portfolios. There is an increasing production of innovative wood-based products, such as bioplastics, wood-based composites and cross-laminated timber, which indicates that technologies are improving. Moreover, the use of wood products instead of functionally equivalent non-renewable products might create a positive substitution effect in some cases (Leskinen et al. 2018).

Based on findings from the EU-funded BIOMONITOR project (Hassegawa et al., 2022), a recent report by Verkerk et al. (2022) and additional literature and data sources, this chapter presents four innovative wood-based product types: Cross-Laminated Timber (CLT), man-made cellulosic fibres (in this chapter we focus on lyocell as a novel fibre), bioplastics and wood-based composites. These products use feedstock derived from woody biomass, they represent an improvement to older technologies, and are either at an industrial scale or entering mature markets. These products are also chosen because Europe is the largest producer of CLT and lyocell fibres thus they are important for the European economy. Some of the selected wood-based innovative products can be produced from industrial side-streams. For instance, bioplastics and wood-based composites that have the potential to their increase market share are mainly originating from by-products such as sawdust, chips and particles and black liquor; therefore, a higher added value is created. However, the same feedstocks are currently used for energy generation, thus increasing competition and limiting the feedstocks available for innovative wood-based products.

Innovative wood-based products have the potential to replace fossil-based materials and are therefore positively affecting EU bioeconomy development and climate change mitigation. In this chapter, we aim to present some alternative uses of woody biomass to conventional products or energy; however, this is not meant to be a comprehensive analysis of innovative wood uses.

The statistical data on production quantities of innovative wood-based products in the EU are limited (e.g. due to confidentiality) and scattered. Therefore, this chapter reports on production of innovative wood-based products in Europe based on data from various sources, including grey literature. Table 11 summarises the main uses, the woody feedstock and the estimated production quantities of innovative wood-based products.

Table 11. Summary table on review of innovative wood-based products.

Product name	Main use	Woody feedstock	Annual Global production (2018-2020)	Annual production in Europe (2018-2020)
Cross-Laminated Timber	wood-based construction	solid sawn wood	*2.8 million cubic metres	*1.3 million cubic metres
Man-made cellulosic fibres (lyocell)	textile	pulpwood and by-products	0.3 million tonnes	NA
Bioplastics	packaging	by-products of pulping process (tall oil)	2.1 million tonnes	*0.5 million tonnes
Wood-based composites	construction, packaging	solid wood, wood chips, sawdust, wood flour	NA	*0.47 million tonnes

*Estimated

Source: JRC own estimations

11.1 Cross-Laminated Timber

CLT is defined as a prefabricated, solid, engineered wood product made of at least three orthogonally bonded layers of solid sawn wood that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber intended for roof, floor, or wall applications (Karacabeyli, 2013) (Figure 114). Although CLT is a product that was developed in Austria more than 20 years ago, only recently has its versatility been fully recognised and used in the construction sector. CLT panels are typically prefabricated and then transported to a construction site and integrated into the building construction. The use of CLT reduces construction time, produces less waste and results in lighter buildings with higher comfort and building performance compared to traditional building materials (Carvalho, 2019). CLT is an innovative wood-based construction product with apparent economic and ecological advantages over conventional building materials such as concrete or steel. In Europe, CLT competes in selected market segments such as apartment buildings with bricks and concrete. The prefabricated nature of the product enables an effective and efficient construction with minimal impact on the construction site and the environment (Espinoza et al., 2016).

Figure 114. CLT construction

Source: ©iStock

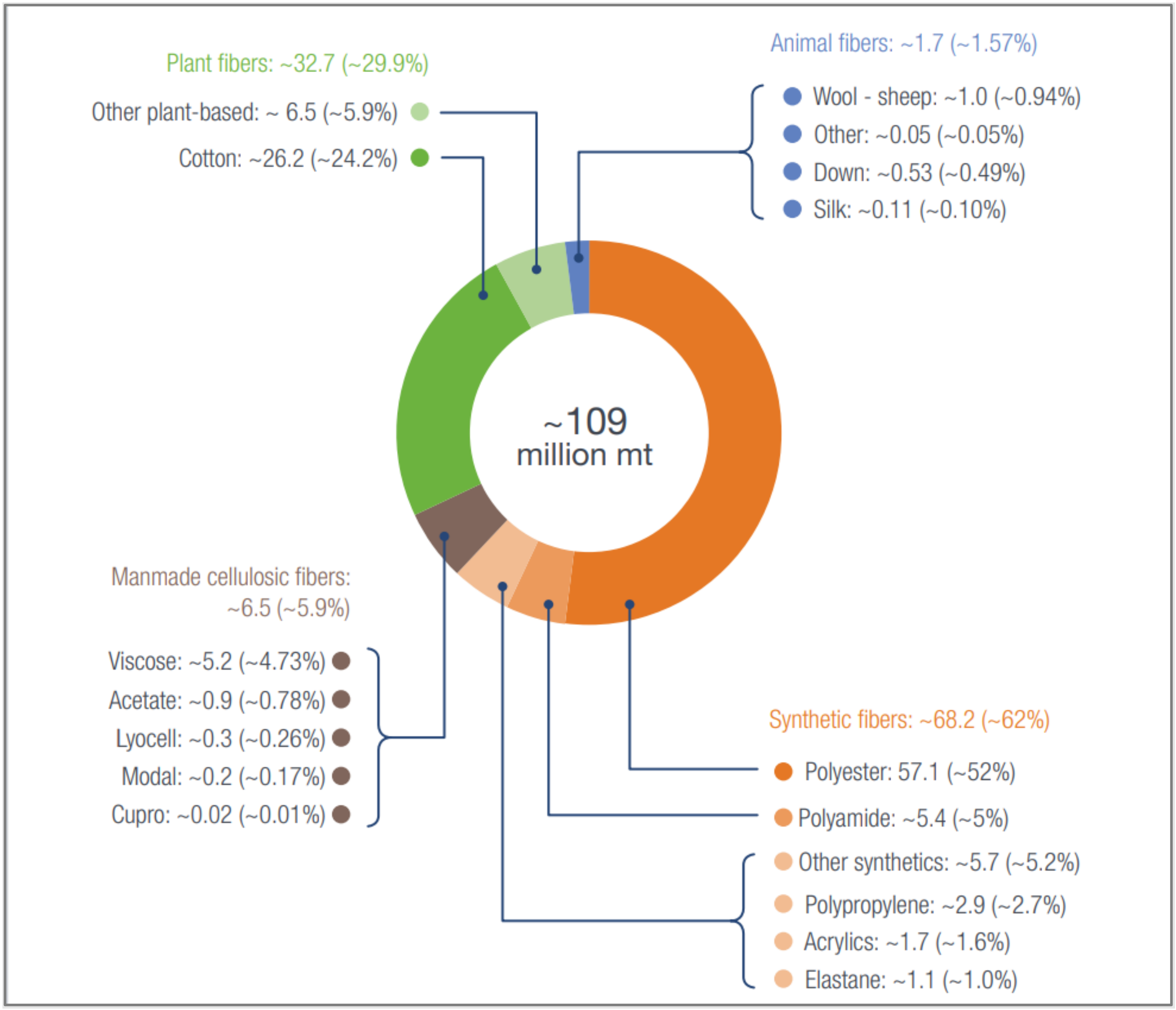
CLT has become popular in Europe, Japan, North America and Oceania. It is foreseen that global CLT production will double by 2025 (Jauk, 2019). The global production capacity of CLT in 2020 is estimated at 2.8 million cubic meters, of which 48% is in Europe, 43% is in North America, 6% is in Oceania and 3% is in Asia (UN, 2021). Austria, Czechia, Germany, Italy and Switzerland continue to form the epicentre of global CLT production; these five countries have produced slightly more than 1 million cubic metres of CLT in 2020 (UN, 2021). New developments in this sector have also been taking shape across North America. At the end of 2019, 14 plants were producing mass timber panels in North America, and 3 new facilities were under construction. While the current capacity of these plants is roughly 910,000 cubic meters, industrial matting applications constitute more than half of the total (UN, 2021). CLT production is also increasing dramatically in northern Europe, with Norway (50,000 cubic meters in 2019) and Sweden both increasing production faster than the central European CLT cluster countries; Sweden is increasing its production capacity from 25,000 in 2018 to 400,000 cubic meters in the near future (Jauk, 2019). Most of the CLT production nowadays is made with softwood. However, existing studies suggest that the utilisation of hardwood is technically feasible, and the resulting product offers perspectives for specific applications (Espinoza et al., 2016).

11.2 Man-made cellulosic fibres (lyocell)

Man-made cellulosic fibres (i.e. viscose, acetate, lyocell, viscose modal, and cupro) are primarily produced from wood; however, among these, only lyocell is considered an innovative fibre. Because most man-made cellulosic fibres are produced using methods developed about 100 years ago, in this section we focus on lyocell. The production process of lyocell is usually based on dissolving wood pulp and wet spinning. The main consumer of these fibres is the textile industry.

Global annual production of man-made cellulosic fibres in 2020 was around 6.5 million tonnes. Global production of lyocell was around 0.3 million tonnes corresponding to 0.3 percent of the total fibre production volume (PFMMR, 2021) (Figure 115). Lyocell is considered the most environmentally friendly textile fibre compared to other man-made cellulosic fibres, synthetics and even cotton (Shen et al., 2010). Even though lyocell is apparently the most environmentally friendly and innovative fibre, the market share of this fibre is relatively small. This is partially due to the fibre properties, which are still inferior to the counterparts. Also, the production costs for lyocell are higher than for other man-made cellulosic fibres, synthetics and cotton. Around 57% of uptake volume has no information on country of origin. When reported, China is the main country of origin of man-made cellulosic fibres uptake (22%) followed by European countries (9%), South Africa (3%) and other countries (MCIR, 2019).

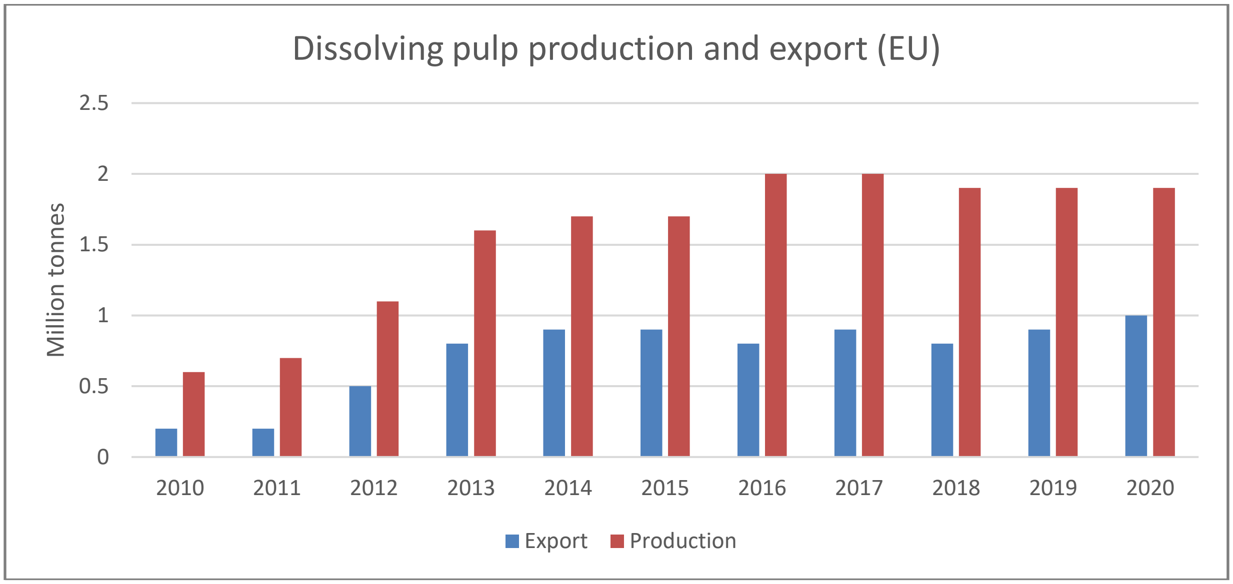
Figure 115. Global fibre production in million tonnes in 2020.



Source: PFMMR, 2021

During the last decade, production of dissolving pulp in the EU, which is a feedstock for man-made cellulosic fibres, increased by more than three times, reaching 1.9 million tonnes in 2020 (FAOSTAT, 2022). More than half of this production was exported for further processing (COMTRADE, 2022), meaning that some production of the final innovative products occurred, outside of the EU (Figure 116). It should be noted that dissolving pulp is also used for other products than lyocell e.g., viscose and acetate however, data on dissolving pulp use are not available.

Figure 116. Dissolving pulp production and export 2010-2020.



Source: FAOSTAT and COMTRADE data

11.3 Bioplastics

In 2020, the global production of plastics was 367 million tonnes, while the production in Europe was 55 million tonnes (Plastics Europe, 2021). Plastics are mainly manufactured from fossil fuels and only 25% of all plastics is recycled (Geyer et al., 2017). Bioplastics (Figure 117) are seen as a more environmentally friendly alternative to fossil-based plastics however, production quantities of bioplastics are relatively small compared to the production of fossil-based plastics. Global production capacity of bioplastics in 2018–2019 was only 2.1 million tonnes. About a fifth of the global volume of bioplastics is produced in Europe and it is expected that by 2023, the share of bioplastics manufactured in Europe will reach 27 % due to recently approved policies in Italy and France (European Bioplastics, 2020). Bioplastics can be produced from woody and agricultural biomass (Carus et al., 2020; Hassegawa et al. 2022). They can substitute some fossil-based plastics and reduce GHG emissions during the production process (Mozaffarian, 2015). Some of these bioplastics are biodegradable and can be used in various sectors (Figure 118). However, biodegradable bioplastics release carbon that is stored in the product faster than non-biodegradable plastics.

Bioplastics can be produced from various bio-based sources such as carbohydrate-rich agricultural crops (e.g., potato and sugar beet), woody biomass and even from algae. Bioplastics from woody biomass might be produced by using two intermediate products: bio-ethylene (from industrial sugars such as glucose) and tall oil (from black liquor – a residue of the pulping process). However, currently bioethanol from woody biomass is rarely used to produce bio-ethylene because the manufacturing processes are not optimised. The conversion of lignocellulosic biomass to bio-ethylene involves pre-treatment, enzymatic hydrolysis of carbohydrates, the fermentation of sugars to ethanol, ethanol recovery by distillation, and ethanol dehydration to ethylene (Mendieta et al., 2021). Therefore, in this section we focus on bioplastics produced from tall oil.

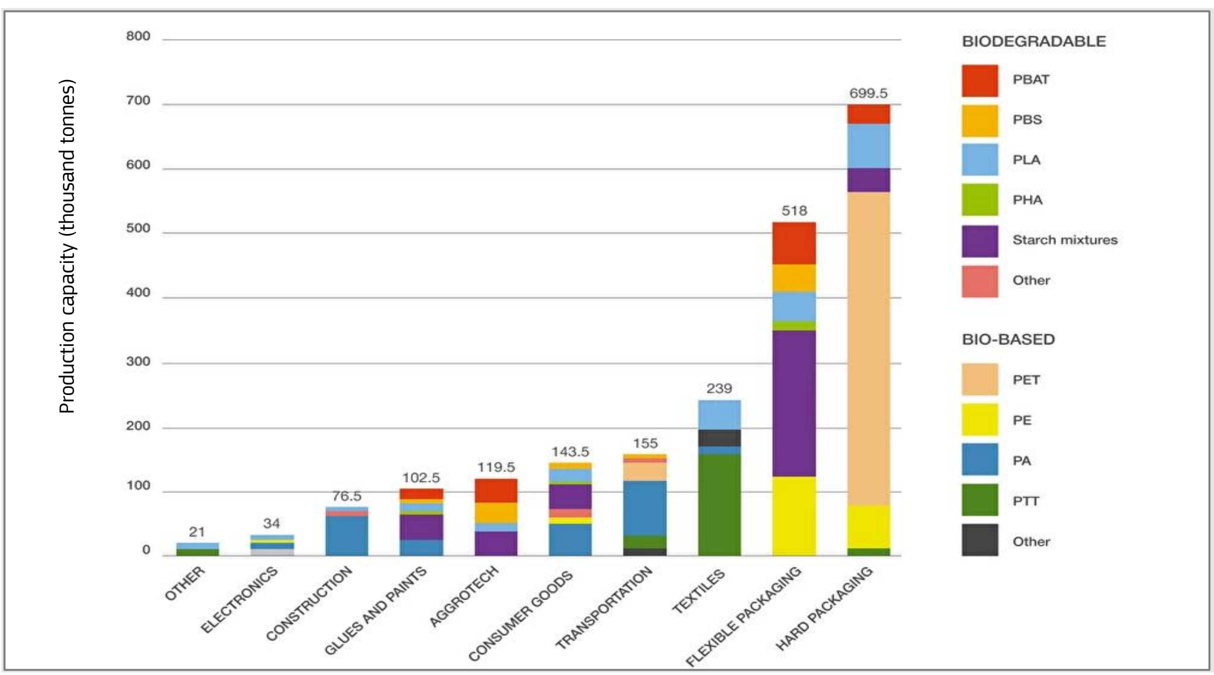
One of the advantages of using industrial side streams from the wood pulp industry (black liquor) as feedstock for bioplastics instead of agricultural crops is that woody biomass usually comes from non-arable lands. Thus, the GHG emissions related to land use change are lower (De Bruycker et al., 2014).

Black liquor is commonly used as a source of energy for the industry. However, value can be added when the black liquor is used to produce bioplastics (De Bruycker et al., 2014; Mäntyranta, 2020). The feedstock to produce bioplastics from tall oil could be undervalued forest-based industry by-products, such as small logs, residues, wood chips, sawdust and wood waste. Tall oil can be used to produce bio-based polyethylene, which is technically equivalent to polyethylene produced from fossil sources. The estimated production of crude tall oil in Europe is around 650 thousand tonnes (Fraunhofer Institute 2016), and is expected to increase to 2.3 million tonnes by 2030 (Aryan and Kraft, 2021)

Figure 117. Examples of bioplastics

Source: ©iStock

Figure 118. Global production capacity of bioplastics in 2017–2018, thousand tonnes by type of application



Source: European Bioplastics, 2021

11.4 Wood-based composites

Wood-based composites are made from various wood and non-wood materials that are bonded together using either natural or synthetic binders (Barbu et al., 2014). Wood-based composites can be made from wood flour, particles, chips, or solid wood mixed or coated with an adhesive, then recombined to create the desired product (Figure 119). The aim of this technology is to reduce synthetic content in products, while conferring a more natural appearance (Carus and Partanen, 2019). The wood-based composites combine the properties of wood and binders thus have improved weather resistance and lower maintenance needs compared to traditional wood-based products. These properties make them suitable for a wide variety of applications where a resistance to biodeterioration is welcome (e.g., packaging, decking, roofing, outdoor sidewalks, automotive industry, and furniture).

Traditionally when manufacturing wood-based composites, wood is mixed or coated with fossil-based plastics but some of the new wood-based composites are made with bio-based binders such as polypropylene or polylactide or with binders that are fully biodegradable (Mäntyranta, 2020). Some of these new wood-based composites can be mechanically recycled, compostable or biodegradable.However, it should be noted that there are technological and economic barriers to recycling and re-using composite materials. These barriers were studied and reported by Yang et al. (2012) and Najafi (2013). These studies identified various challenges, including difficulties in separating different components of the composite and the high cost of developing and implementing recycling technologies and processes. Currently, research and experimental studies are ongoing to overcome these barriers.

Various wood elements can be used to produce wood-based composites, such as solid wood, cork, wood chips, sawdust, and wood flours depending on the technical characteristics and end-use of the product (Carus and Partanen, 2019). Woody biomass used in composites can be obtained from side streams of the wood-based industry, making it a low-cost feedstock. Depending on the application of the composite product, the share of woody biomass can range from 50% to 75% (Chen et al., 2006).

In 2019, the global market size of wood-based composites was EUR 4.1 billion. It is expected to increase, with a mean annual growth rate of 12% (Zionmarket, 2021). North America, where most wood-based composites are used in decking, has the largest market share with EUR 1.8 billion (Fortune, 2021). In Europe there are roughly 30 major producers of wood-based composites in nine different countries. In 2018, the production was nearly 470 thousand tonnes of bio-based composites (Nova-Institute, 2019). The largest producer of these granulates in Europe is Portugal, where the production of cork-based composites in 2018 was over 50 thousand tonnes. Cork-based composites are mainly used for floor covering and thermal/acoustic/vibration insulation in construction and car industries (Gil, 2015). Other important producers of bio-based composites in Europe, in terms of volume, are Belgium, Germany, France, Finland, and Sweden (Carus and Partanen, 2019).

Figure 119. Examples of wood-based composites.

Source: ©iStock

11.5 Conclusions for Chapter 11

Innovative wood-based products can represent an improvement to older technologies. The products reviewed in this chapter are either produced at an industrial scale or entering mature markets. The scattered and limited statistical data on production quantities of innovative wood-based products in the EU do not allow for an in-depth study; however this chapter gives an overview of the four most relevant (market-wise) products, giving a hint to the future innovative uses of woody biomass.

Although there are little quantitative data available, an increase in use of woody biomass for innovative wood-based products can be expected. We looked closely at the feedstocks for the four innovative wood-based products: Cross-Laminated Timber, man-made cellulosic fibres (lyocell), bioplastics and wood-based composites.

The CLT is made from solid sawn wood. Its global production capacity in 2020 was estimated at 2.8 million cubic metres, of which 48% was produced in Europe. The global CLT production is expected to double by 2025.

Most man-made cellulosic fibres are based on dissolving wood pulp and are principally used in the textile industry. Among all man-made cellulosic fibres lyocell is considered the most innovative and environmentally friendly. However, the market share of this fibre is relatively small (only 0.3 percent of the total fibre production volume).

About a fifth of the global volume of bioplastics is produced in Europe and it is expected that, by 2023, the share of bioplastics manufactured in Europe will reach 27%. Bioplastics can be produced from various bio-based sources such as carbohydrate-rich agricultural crops (e.g., potato and sugar beet), woody biomass and even from algae.

Wood-based composites can be made from wood flour, particles, chips, or solid wood mixed or coated with an adhesive, then recombined. In Europe there are roughly 30 major producers wood-based composites in nine different countries. In 2018, the production was nearly 470 thousand tonnes.

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12 Environmental impacts of bioeconomy

Taija Sinkko, Esther Sanye Mengual, Jacopo Giuntoli, Serenella Sala

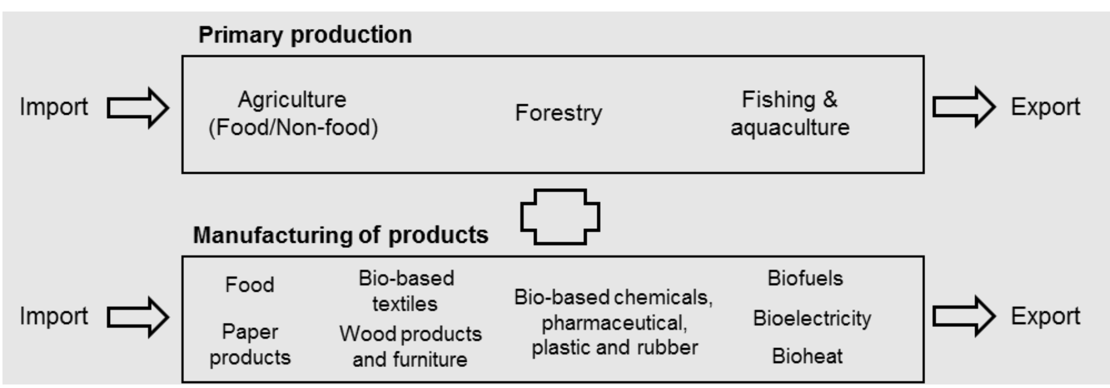
Key messages

- The environmental impacts of the EU bioeconomy are assessed based on 74 representative end-use products and 59 primary products.
- The total environmental impact of the EU bioeconomy has increased over time by +23% between 2010 and 2020 because of the increased consumption of bio-based products.
- The most contributing countries for the environmental impacts of bioeconomy are, in most cases, the countries with the highest population.
- In 2020, eleven countries had higher per capita impact compared to EU average. The environmental impacts of bioeconomy have increased in almost all EU-27 countries between 2010 and 2020.

The Bioeconomy Footprint approach is used to quantify the environmental impacts of the EU bioeconomy with the aim of contributing to the monitoring and assessment of the progress of the EU Bioeconomy Strategy (European Commission, 2018). The Bioeconomy Footprint will be used to develop one or more, meaningful and informative indicators to be included within the EU Bioeconomy Monitoring System (BMS) with the aim of providing useful information to decision-makers and other stakeholders on the evolution of the environmental impacts associated to the EU bioeconomy. This chapter is published in parallel to a peer-review paper: Sinkko et al, 2023.

The Bioeconomy Footprint is based on the consumption intensity and the environmental impact intensity of a set of representative products, following the rationale of the Consumption Footprint indicator (Sala & Castellani, 2019; Sala & Sanyé-Mengual, 2022). The products included account for processes from primary production (agriculture, forestry, fishing and aquaculture) and manufacturing of bio-based products, and take into account also the impacts of traded commodities, i.e. domestic production, import and export (Figure 120). The current version does not include services related to bioeconomy, and thus do not cover full bioeconomy, however the term “Bioeconomy Footprint” is used.

Figure 120. The Bioeconomy Footprint approach and included sectors.



Source: JRC 2022

12.1 Total environmental impact of the EU bioeconomy

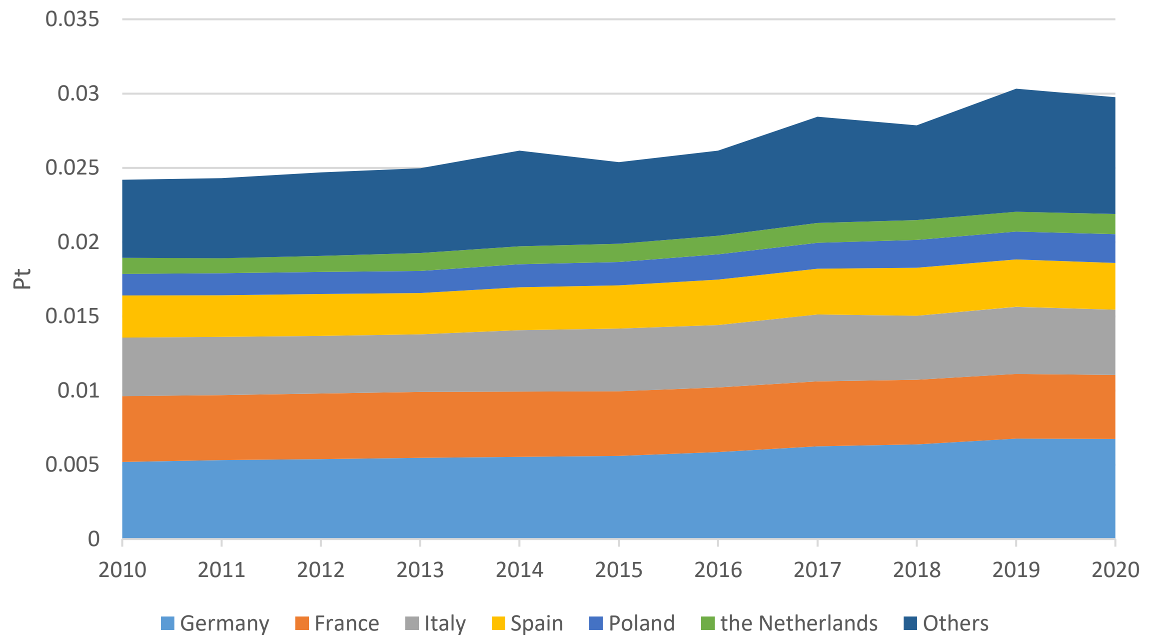
The total environmental impact of the EU bioeconomy has increased over time, with a total increase of +23% between 2010 and 2020 (Figure 121), which can only partly be explained by the increase of population (+1-2%).

The increase is mostly due to an increased consumption of bio-based products, rather than because of a change in product composition.

12.1.1 By country

The most contributing countries for the EU Bioeconomy Footprint are the countries with the highest population, i.e. Germany, France, Italy, Spain and Poland. However, the Netherlands is the sixth contributing country although its population is only the seventh highest after Romania. This can be explained with higher per capita impact in the Netherlands compared to Romania (Figure 121), mainly because of the higher impact from food consumption.

Figure 121. Single score impact (Pt) of the EU bioeconomy from 2010 to 2020 by highest contributing countries.

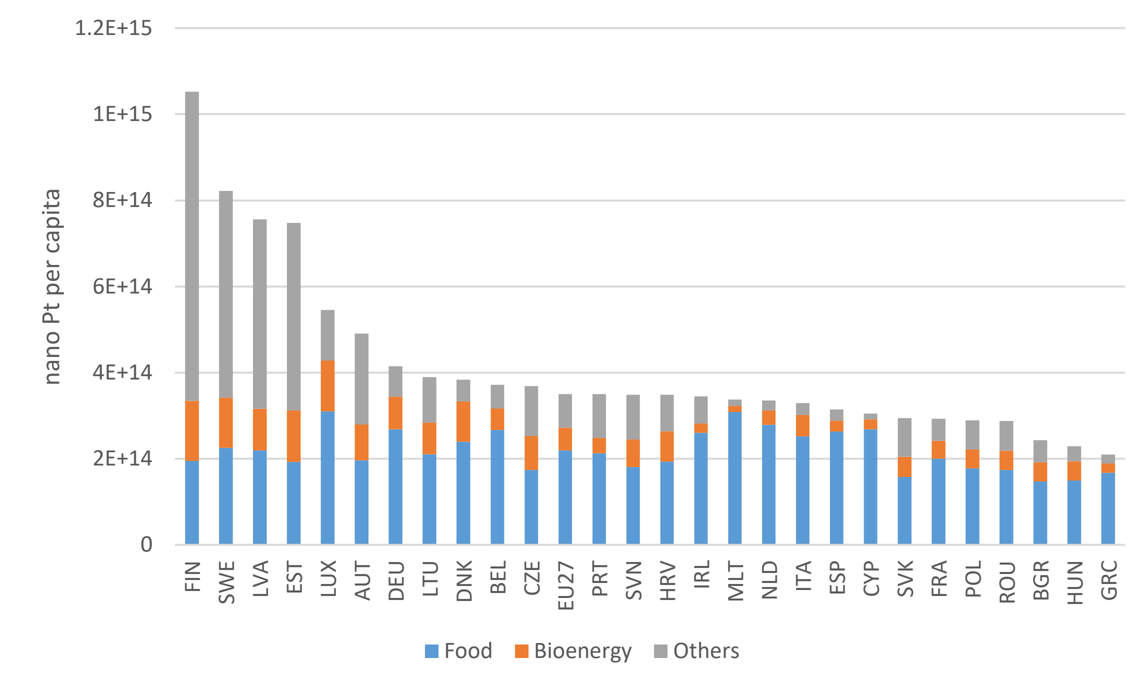


Source: JRC 2022

12.1.2 Per capita

Country contributions for the EU Bioeconomy Footprint shows different trends when results are compared per capita (Figure 122). In 2020, eleven countries had higher per capita impact compared to EU average. The per capita impact is the highest in northern countries (Finland, Sweden, Latvia, Estonia), because of the high amount of forestry and wood-based products, but also because of the high impacts from bioenergy, which is again linked with the forestry and forest-based energy. The lowest per capita impact of the bioeconomy is in Bulgaria, Hungary and Greece, of which Hungary and Bulgaria have the lowest per capita impact of food consumption, and Greece second lowest per capita impact of bioenergy, after Malta.

Figure 122. Single score impact (in nano Pt) per capita by different sectors in EU-27 countries in 2020.



Source: JRC 2022

The Bioeconomy Footprint per capita has increased in almost all EU-27 countries between 2010 and 2020 (Table 12) showing the increased consumption of bio-based products and bioenergy. The only exception is France, where the Bioeconomy Footprint has decreased -3% from 2010 to 2020, because of slight decrease in the impact of food consumption, and high decrease in other sectors (e.g. in forestry, and in some wooden furniture and paper products). At the same time, however, per capita bioenergy impact has increased in France from 2010 to 2020 (Figure 123). The highest increase in the Bioeconomy Footprint can be seen in Latvia (+60%), Estonia (51%) and Croatia (+36%), which all show the increase in all bioeconomy sectors, with the highest increase in other sectors than food and bioenergy. On the other hand, the Bioeconomy Footprint per capita has been very stable in Austria and Sweden (+1%) and in Hungary and Slovenia (+2%) between 2010 and 2020.

In 2010, the food consumption impact per capita was the highest in Luxembourg, Ireland and Malta, and the lowest in Romania, Slovakia and Bulgaria (Figure 123a). The impact of food consumption has increased in almost all EU-27 countries from 2010 to 2020, except in Ireland, France and Slovenia. On the contrary, the bioenergy impact per capita in 2010 was highest in Finland, Austria and Estonia, and lowest in Ireland, Slovakia and Malta (Figure 123b). Bioenergy impact has increased between 2010 and 2020 in almost all EU-27 countries, which may indicate that bioenergy use has increased in the different countries (it is confirmed to have increased in the EU-27 as a whole, see Chapter 7). The highest increases can be seen in Luxembourg, Bulgaria, Slovakia and Malta. However, some countries show decrease in bioenergy impacts, namely Austria, Slovenia, Portugal and Spain. Regarding to other sectors, many countries show the decreasing trend in impact per capita from 2010 to 2020, while at the same time Estonia and Latvia has almost doubled their impact (Figure 123c).

Table 12. Yearly change of the Bioeconomy Footprint in EU-27 countries per capita (2010 baseline), and change over the period from 2010 to 2020 (Total). Blue colour represents the increase in the impact, and red is a decrease. The darker shades represent higher increases or decreases.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
AUT	100%	100%	99%	99%	98%	103%	97%	101%	104%	100%	100%	**101%**
BEL	100%	103%	101%	101%	108%	97%	101%	106%	94%	109%	96%	**114%**
BGR	100%	100%	101%	105%	97%	115%	100%	101%	108%	104%	96%	**129%**
CYP	100%	102%	100%	104%	106%	100%	103%	108%	100%	106%	97%	**128%**
CZE	100%	98%	95%	103%	102%	103%	102%	103%	108%	101%	98%	**114%**
DEU	100%	104%	102%	102%	101%	101%	101%	107%	102%	105%	100%	**127%**
DNK	100%	103%	106%	100%	104%	104%	101%	102%	100%	102%	99%	**122%**
ESP	100%	100%	100%	96%	103%	102%	104%	103%	104%	97%	95%	**105%**
EST	100%	95%	102%	98%	106%	119%	107%	110%	104%	96%	107%	**151%**
EU-27	100%	101%	101%	101%	103%	99%	103%	106%	101%	105%	97%	**118%**
FIN	100%	99%	100%	107%	101%	101%	100%	102%	107%	95%	97%	**108%**
FRA	100%	99%	101%	100%	99%	99%	101%	100%	100%	100%	98%	**97%**
GRC	100%	101%	98%	102%	99%	99%	98%	105%	106%	101%	96%	**104%**
HRV	100%	103%	106%	99%	102%	103%	105%	108%	104%	101%	100%	**136%**
HUN	100%	103%	95%	101%	100%	102%	104%	102%	99%	95%	102%	**102%**
IRL	100%	103%	101%	101%	105%	98%	98%	106%	98%	95%	99%	**104%**
ITA	100%	96%	103%	99%	106%	104%	101%	106%	96%	105%	99%	**115%**
LTU	100%	100%	108%	98%	106%	96%	104%	100%	102%	100%	101%	**116%**
LUX	100%	106%	88%	110%	103%	101%	100%	105%	102%	101%	99%	**114%**
LVA	100%	106%	110%	102%	106%	102%	104%	103%	104%	104%	107%	**160%**
MLT	100%	106%	111%	96%	102%	100%	101%	107%	100%	104%	100%	**130%**
NLD	100%	101%	103%	110%	100%	101%	104%	112%	98%	98%	97%	**124%**
POL	100%	104%	99%	99%	105%	101%	105%	102%	109%	98%	102%	**126%**
PRT	100%	103%	96%	99%	105%	103%	103%	102%	103%	104%	98%	**118%**
ROU	100%	98%	101%	98%	110%	104%	102%	101%	103%	100%	109%	**128%**
SVK	100%	102%	92%	101%	120%	89%	109%	109%	102%	107%	94%	**124%**
SVN	100%	102%	97%	100%	105%	99%	100%	96%	105%	99%	97%	**102%**
SWE	100%	101%	99%	100%	103%	100%	101%	100%	100%	100%	97%	**101%**

Figure 123. Single score impact (in nano Pt) per capita in EU-27 countries in 2010 (blue bar) and 2020 (red bar) in: a) Food sector, b) Bioenergy sector, and c) other sectors.

Source: JRC 2022

12.2 Methods

The Bioeconomy Footprint results from the aggregated environmental impacts of the consumption of a set of representative products. For each representative product *'i'*, the consumption intensity and the environmental impact are quantified. The scope of the analysis included the timeframe 2010-2020 and targeted not only the whole EU-27 but also the individual EU-27 countries. The Bioeconomy Footprint is calculated using the following equation:

$$Bioeconomy\ Footprint\ = \sum_{i=0}^{n}(Consumption\ intensity_i\ \cdot Environmental\ impact_i)$$

Representative products: The Bioeconomy Footprint includes a total of 74 representative end-use products and 59 primary products (44 primary products used for food manufacturing, eight wood types used for manufacturing of paper and wood-based products, six crops used for biofuel production, and one crop used for manufacturing of textiles) (see Annex to chapter 12). The selection of these products was based on:

a) bio-based end-use products already included in the Consumption Footprint (i.e. 55 food, textiles, wood-based furniture and paper products), as a backbone of the analysis;
b) additional end-use products representing missing bio-based sectors (i.e. 19 bioenergy and bio-based plastic products);
c) intermediate products from primary production used in the manufacturing of final products already included in the Consumption Footprint (i.e. 44 food and aquaculture primary products); and
d) additional intermediate products from primary production used in the manufacturing of final products representing missing bio-based sectors (i.e. eight wood types to present whole forestry sector, six crops used as feedstock in biofuels production, one crop used for manufacturing of textiles).

Consumption intensity: The consumption intensity is based on apparent consumption (= production + imports – exports), which is retrieved from official statistics of consumption. Data sources employed depend on the bio-economy sector as detailed in Table 13. Data gap filling was employed in the case of missing data using linear regression (data was not reported for the most recent years) and interpolation (data was not reported in the middle of time series).

Environmental impacts: The environmental impact intensity of each representative product was calculated following a life cycle inventory (LCI) model and was maintained constant for all years. Modelling was done using SimaPro LCA software v.9.2 (Pré Sustainability, 2021). The LCI model of the products present in the Consumption Footprint were adapted from the same model (see the list of products in Annex to chapter 12). The environmental impacts of products not originally included in the Consumption Footprint (i.e. agriculture (non-food), forestry, bioenergy and bio-based plastics) were modelled using the most appropriate ecoinvent 3.6 processes (Wernet et al., 2016). Data sources, modelling assumptions and employed background datasets are detailed in Castellani et al. (2017), Sinkko et al. (2019), Castellani et al. (2019b), Sala & Sanyé-Mengual (2022), and Sinkko et al. (2023).

The Life Cycle Impact Assessment (LCIA) employs the EF 3.0 method (EC-JRC, 2018; Fazio et al., 2018), which includes 16 impact categories. Characterised impacts were then normalised and weighted into a single weighted score using EF 3.0 sets for normalisation and weighting to present results as a single weighted score (EC-JRC, 2018).

Table 13. Consumption intensity data sources.

Sector	Consumption intensity data source	Remark
Food (incl. agriculture, aquaculture and manufacturing)	Eurostat, 2021a, b; FAOSTAT, 2021; EFSA, 2021	-
Forestry	Eurostat, 2021c, d	Division between pulp wood and logs based on Cazzaniga et al. (2019)
Non-food agriculture	Eurostat, 2021a, b (textiles); Eurostat, 2021d (biofuels)	Cotton consumption for textiles based on Castellani et al. (2019); crop consumption for biofuels based on Wernet et al. (2016)

Textiles, furniture, paper products	Eurostat, 2021a, b	-
Bio-based chemicals, pharmaceuticals, plastic and rubber*	Eurostat, 2021a, b	Assumption that 1% of plastic bags are bio-based (EEA, 2021)
Biofuels	Eurostat, 2021d	Total amount allocated to different feedstocks based on USDA (2021)
Bio-based heat and electricity	Eurostat, 2021e, f	-

* This sector is represented only by bio-based plastic bags

Source: JRC, own elaboration

12.3 Conclusions for Chapter 12

The Bioeconomy Footprint is a process-based LCA approach to measure the environmental impacts of the EU bioeconomy and the individual countries with the aim of enabling the assessment and monitoring of the progress of the EU Bioeconomy Strategy. The Bioeconomy Footprint can support the goals of the EU Bioeconomy Monitoring System (BMS) to prioritise actions through its granularity and to inform stakeholders. Furthermore, this metric is based on the Consumption Footprint which is considered in the monitoring framework of other EU policies.

This assessment shows that the EU Bioeconomy Footprint has increased over the time period of 2010-2020, which means that bioeconomy is growing as promoted by the Bioeconomy Strategy. An increase is expected especially in the bioenergy sector and other sectors to replace fossil-based energy and products. However, current results show an increase also in the food sector. The highest contribution to the EU Bioeconomy Footprint comes from the countries with the highest population, while per capita impacts are the highest in those countries with a large tradition of bio-based products, e.g. forestry and wood-based products and energy in Finland, Sweden, Estonia and Latvia.

In the current analysis, the environmental impact of representative products is static over the time period. However, an increase in the consumption of bio-based products will be accompanied by more sustainable products lowering their individual impacts, which is an important aspect to take into account in the future assessments.

Future work includes the development of a specific indicator to provide a meaningful and informative use of the Bioeconomy Footprint within the EU BMS. Different options vary from basic indicators based on the assessment of trends to more elaborated metrics reflecting evaluations of resource decoupling and resource efficiency, to an assessment against the Planetary Boundaries framework to provide an absolute sustainability perspective.

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13 Trade volume, deforestation, and forest biomass embodied in traded bio-commodities and products

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Key Points:

- The European Union (EU-27) has been identified as an important contributor to tropical deforestation through the consumption and trade of products and commodities.
- The EU-27 plays a major role in the import of coffee and cocoa beans, palm oil, and cake of soybeans.
- On December 2022, the European Parliament, the Council, and the European Commission reached the provisional political agreement on the text of the EU Regulation on deforestation-free supply chains.
- According to our modelling based on land use change and trade flows, the imports of EU-27 between 2014 and 2019 contributed to 74.2% of the deforested area between 2010 and 2015 related to the production of cocoa, 23.7% for coffee, 15.9% for palm oil, 13.6% for soybeans, and less than 1% for cattle. For the deforestation embodied in the EU-27 consumption we also present relevant literature and the results of the impact assessments (SWD(2021) 326).
- The total forest biomass loss in 2010-2015 associated to products traded in 2014-2019 was 48.04 millions tonnes of dry matter

Deforestation and forest degradation, particularly in tropical areas, are recognised as important drivers of global warming, the global Carbon cycle, and biodiversity loss. For example, the recent publication "The state of world's forests" from the Food and Agriculture Organization of the United Nations (FAO) (FAO and UNEP, 2020) reported 420 million hectares (ha) of gross and 178 million ha of net forest loss between 1990 and 2020.

Recent estimates suggest that tropical forests store more than 200 petagrams of Carbon in the aboveground biomass (Li et al., 2022; Santoro et al., 2021; Saatchi et al., 2011). Therefore, deforestation and forest degradation strongly impact on the global Carbon cycle, forest biomass, greenhouse gas (GHG) emissions, and biophysical properties of the land. The 2021 report of the Intergovernmental Panel on Climate Change (IPCC) suggested that 23% of total anthropogenic GHG emissions (2007-2016) come from agriculture, forestry, and other land uses (AFOLU), while up to 11% of the overall emissions come from forestry and other land uses, mostly associated to deforestation. The remaining 12% are direct emissions from agricultural production, including livestock and fertilisers.

Different factors might drive forest losses: agriculture and pasture expansions to produce commodities, agroforestry expansion, wildfires and disturbances, and urbanisation. Using satellite imagery, Curtis et al. (2018) concluded that permanent land use change for commodity production was the cause of 27% of total losses of global forests between 2001 and 2015. Recently, Pendrill et al. (2022) ranked pasture expansion, which is related to cattle production, as the most important driver of tropical deforestation, accounting for about half of the total deforestation in the tropics. Together, soybeans, palm oil and fruit cultivation account for at least a fifth, while six other crops (rubber, cocoa, coffee, rice, maize, and cassava) likely account for most of the remainder, with significant regional variations and higher levels of uncertainty (Pendrill et al., 2022). Pendrill et al. (2019a, 2019b) showed that between 2010 and 2014, Europe was a major importer of CO_2 emissions embodied in the trade of commodities related to deforestation and that a sixth of the Carbon footprint of average European Union (EU) diets is due to emissions from deforestation.

In this context, in July 2019, the Commission adopted the Communication on 'Stepping up EU Action to Protect and Restore the world's Forests' (hereafter referred to as "Communication"), promoting a series of actions to fight deforestation. Later, on 17th November 2021, the European Commission proposed a regulation on deforestation free-products placed in the European Union (EU) market (COM(2021) 706). The main aim of the regulation proposal is to promote the consumption of ‘deforestation-free' products and reducing the EU's impact on global deforestation and forest degradation, with important potential co-benefits in terms of GHG emissions and biodiversity losses. On December 2022 the European Parliament, the Council, and the European Commission reached the provisional political agreement on the text of the EU Regulation on deforestation-free supply chains[79]. The European Parliament and the Council will now formally have to adopt the new Regulation before it can enter into force. Once the Regulation is in force, operators and traders will have 18 months to implement the new rules.

This chapter reports on the statistics and trends on the production of commodities potentially associated with deforestation and the bilateral trade flows of commodities and products between EU-27 and the producing countries. Finally, the share of deforestation attributed to the EU-27 is reported. To do so, satellite observation of tree cover loss and FAO statistics[1] on production, trade, and land use change are used. In this chapter, we focus on five commodities (soyabeans, palm oil fruit, coffee green, cocoa beans, and cattle) and associated products that were clearly identified in the regulation proposal in 2021. Other commodities such as rubber, and other wood related products have been included during the trialogue, and therefore wood and rubber are not included here, but further analysis will be conducted in the future years.

The chapter is divided into four sections: an introduction, a brief description of the methodology, the key results, and a section with an overview of the challenges and opportunities linked to new technologies and initiatives on the attribution of deforestation and forest biomass losses embodied in trade and consumption of commodities.

13.1 Key Results

13.1.1 Production of commodities potentially associated to deforestation

We report the key figures calculated from the FAOSTAT dataset regarding the production (‘quantity’, millions of tonnes - Mt) and land area needed for the production (‘area harvested’, Mha) of the agricultural commodities considered in the proposal of regulation for deforestation-free products. It should be noted that the area harvested does not refer to deforestation, but it is the total area of land required to produce the commodity, including the land area that did not experience recent land use change.

Figure 124 reports the tree map of the average area harvested by country to produce the main commodities in the period 2014-2020. Brazil and USA reported the highest area harvested to produce soybeans. For coffee, the three major producers are Brazil and Indonesia. Côte d’Ivoire is the country with the highest area harvested for cocoa production. Indonesia is the country with the highest area harvested associated with the production of palm oil fruit, followed by Malaysia and Nigeria. Figure 125 shows the production (Mt) of the crop commodities and cattle. The USA and Brazil are the most important producers of cattle, while USA, Brazil, and China are the most important producers of fresh cattle hides. Figure 126 shows the time series of the annual area harvested for the production of the four crop risk commodities (soybeans, coffee, cocoa, and palm oil fruit)[80] in the ten most important producing countries. Figure 126a shows a strong increasing trend of harvested area for the production of soybeans in Brazil, and USA. Figure 126b shows a relatively stable or slight increase in the harvested area for coffee production. Brazil is the largest producer of coffee but has shown a negative trend in the last 20 years. The harvested area for the production of cocoa beans is increasing in Côte d’Ivoire and Ghana (Figure 126c), while for palm oil, we observe an important positive trend in Indonesia, Malaysia, and Nigeria (Figure 126d).

The time series of production (Mt) of the crop risk commodities (Figure 127) resemble the time series of the area harvested (Figure 126). In Figure 127e and Figure 127f, the time series of meat of beef and fresh hides of cattle are also shown. USA is the most important cattle producer, but the production in Brazil and Argentina is increasing and showing the positive trend. The same is valid for fresh hides (Figure 127f), with China showing the most important positive trend, followed by Brazil. However, it should be verified if the high production of hides in China is generated by cattle actually grown up in China or imported (for instance, from South America).

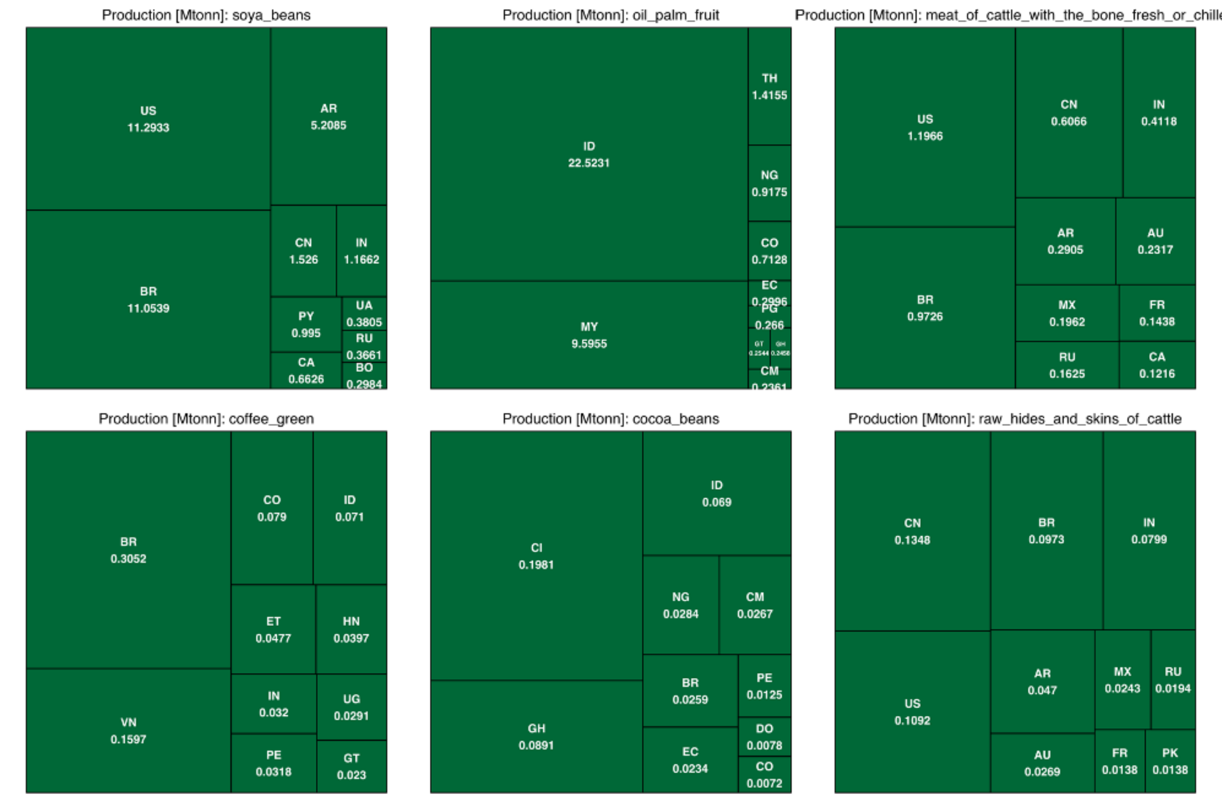
[79] Press release available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7444.

[80] The four crop risk commodities refer to the definition used in the COM(2021) 706, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the making available on the Union market as well as export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation, (EU) No 995/2010 Brussels, 17.11.2021 2021/0366 (COD).

Figure 124. Tree maps of country harvested area (millions of hectares, Mha) to produce the four risk crop commodities. Only the ten most important producers of each commodity are reported. The area of each box is proportional to the relative importance of each country. The numbers below the country name (reported as ISO alpha 2 code) represent the average harvested area of each country over the entire period of reporting.

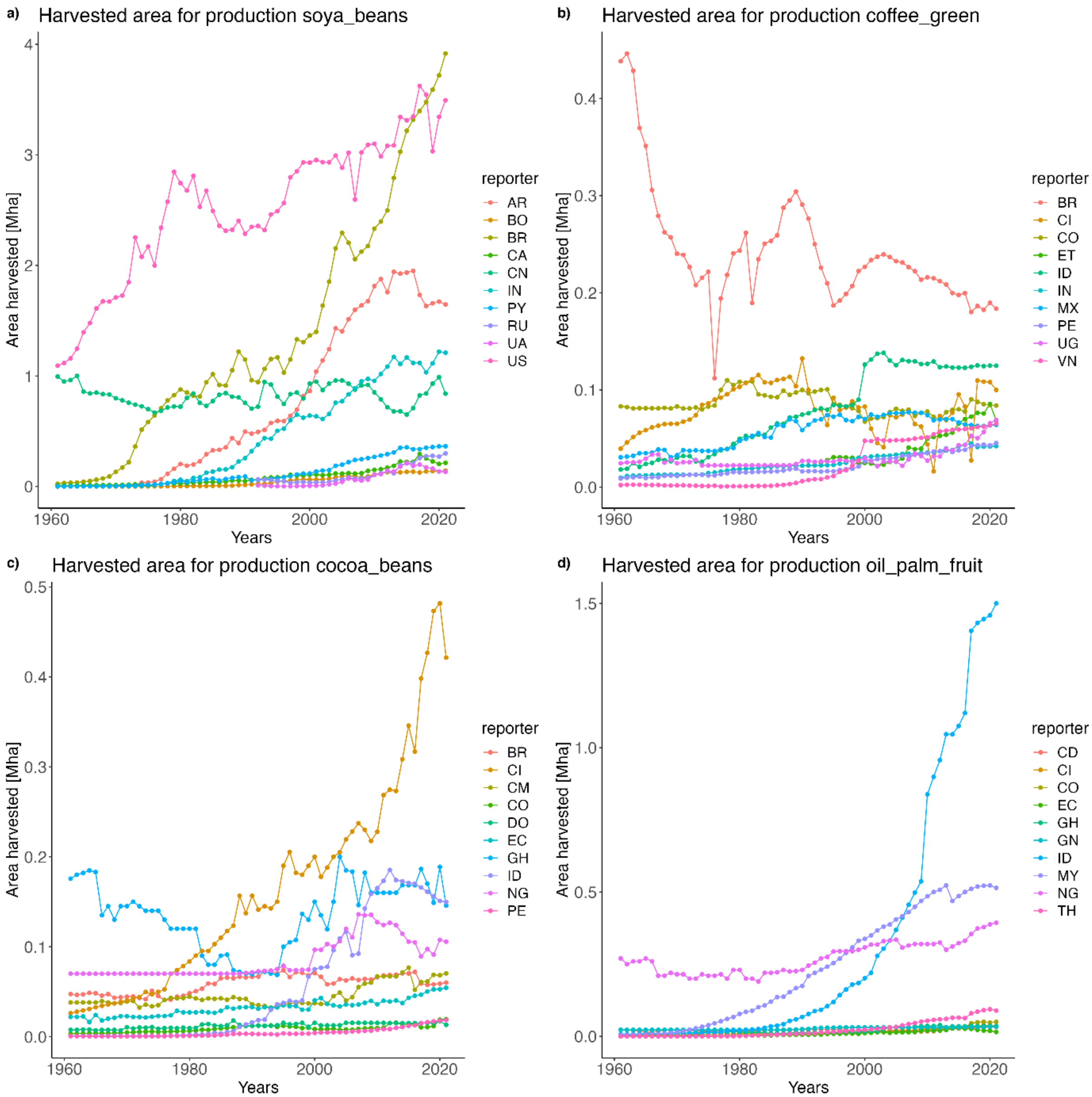
Source: JRC 2022 (own calculation).

Figure 125. Tree maps of country production (Mt) of four risk crop commodities and two of the most important meat products (meat and fresh hides of cattle). Only the ten most important producers of each commodity and product are reported. Each box is proportional to the relative importance of each country compared to the total of production of the ten most important producers. The numbers below the country name (reported as ISO alpha 2 code) represent the average quantity of commodity and products produced over the entire period of reporting.



Source: JRC 2022 (own calculation/visualization).

Figure 126. Time series of the area harvested for the production of the four crop risk commodities. Only the ten most important producers of each commodity are plotted. Country indicated using ISO alpha 2 code.



Source: JRC 2022 (own calculation/visualization).

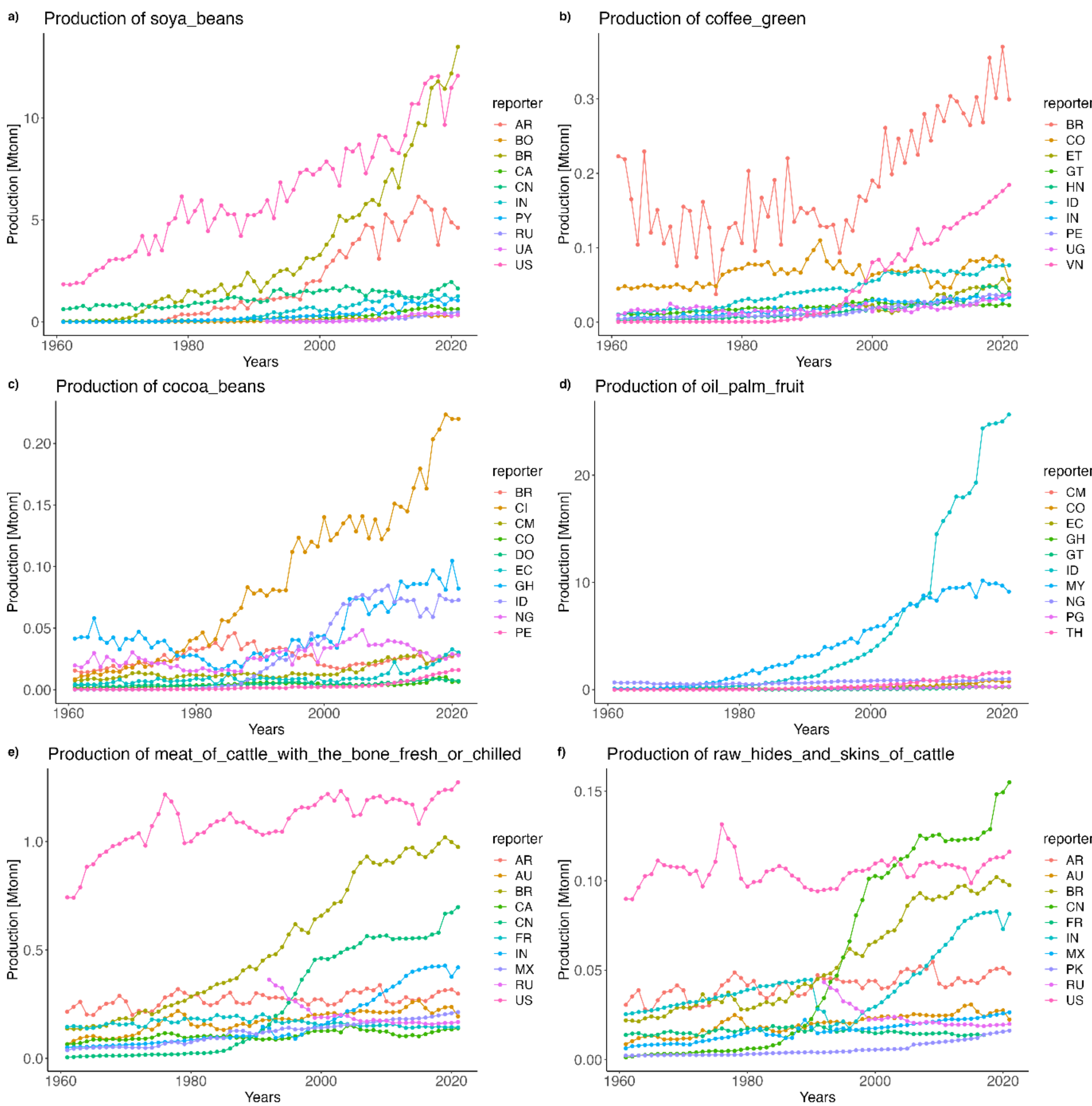
13.1.2 Trade of products and risk commodities

In Figure 128, we report as an example the quantity of products derived from cocoa (Figure 128a), soybeans (Figure 128b), palm oil (Figure 128c), and cattle (Figure 128d) imported by the EU-27. For each product, we show the five top exporters to the EU-27 in the period 2014-2019 (source: FAOSTAT). It is worth to note that for cake of soybeans Brazil and Argentina are the most important trade partners, while for soybeans, it is Brazil and USA (and interestingly not Argentina).

When focusing only on the import of soybeans products from Brazil as reported by the EU-27 and the rest of the world (ROW) (Figure 129), it can be noted that there is a steady increase in the export of soybeans products from

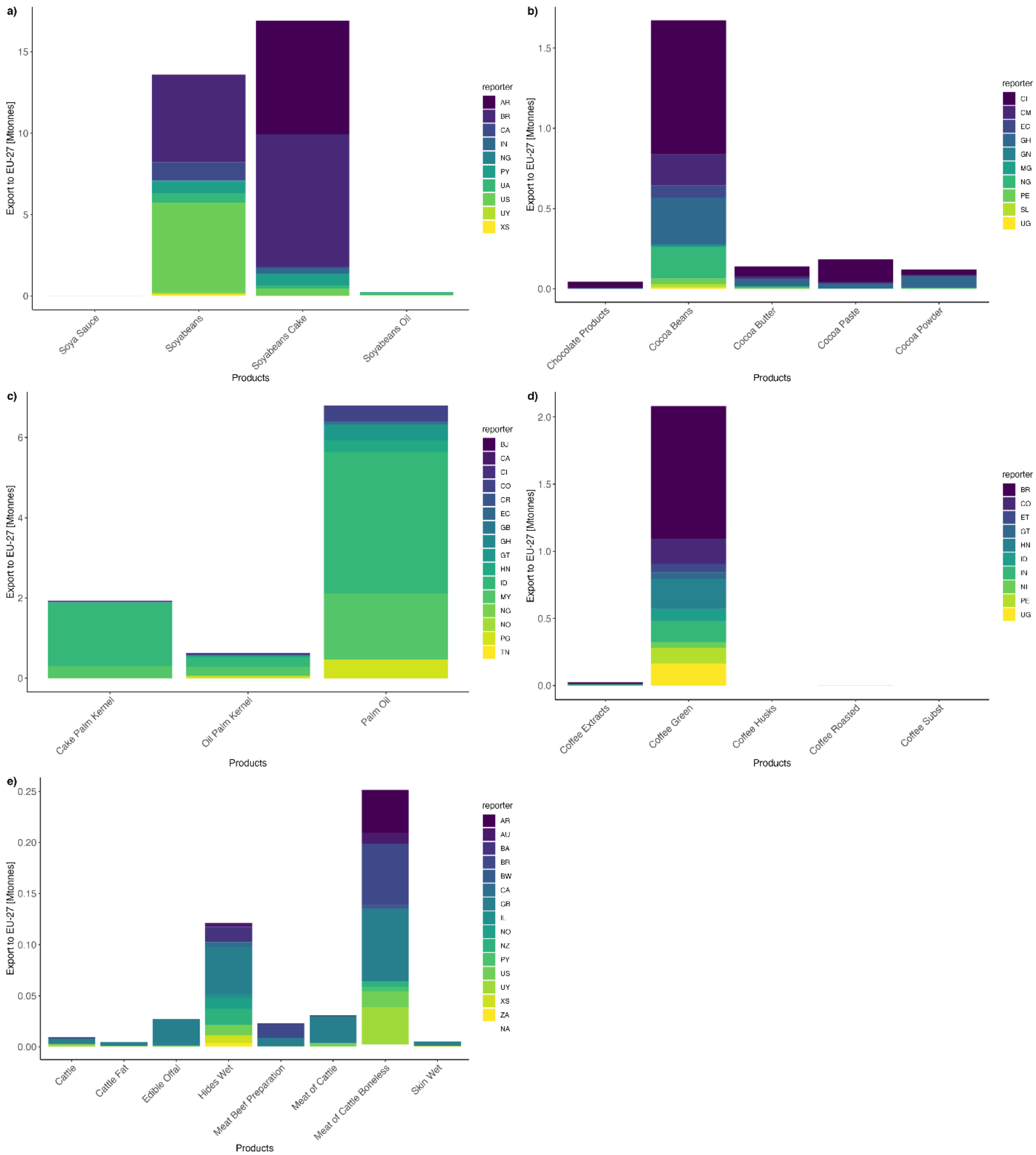
Brazil to the ROW. The export of Brazil to the EU-27 shows a decreasing trend. However, the EU-27 alone imports a quantity of cake of soybeans, typically used to feed animals and cattle, larger than the rest of the world.

Figure 127. Time series of the production for the production of the four crop risk commodities, meat and fresh cattle hides. Only the ten most important producers of each commodity and products are plotted. Country indicated using ISO alpha 2 code.



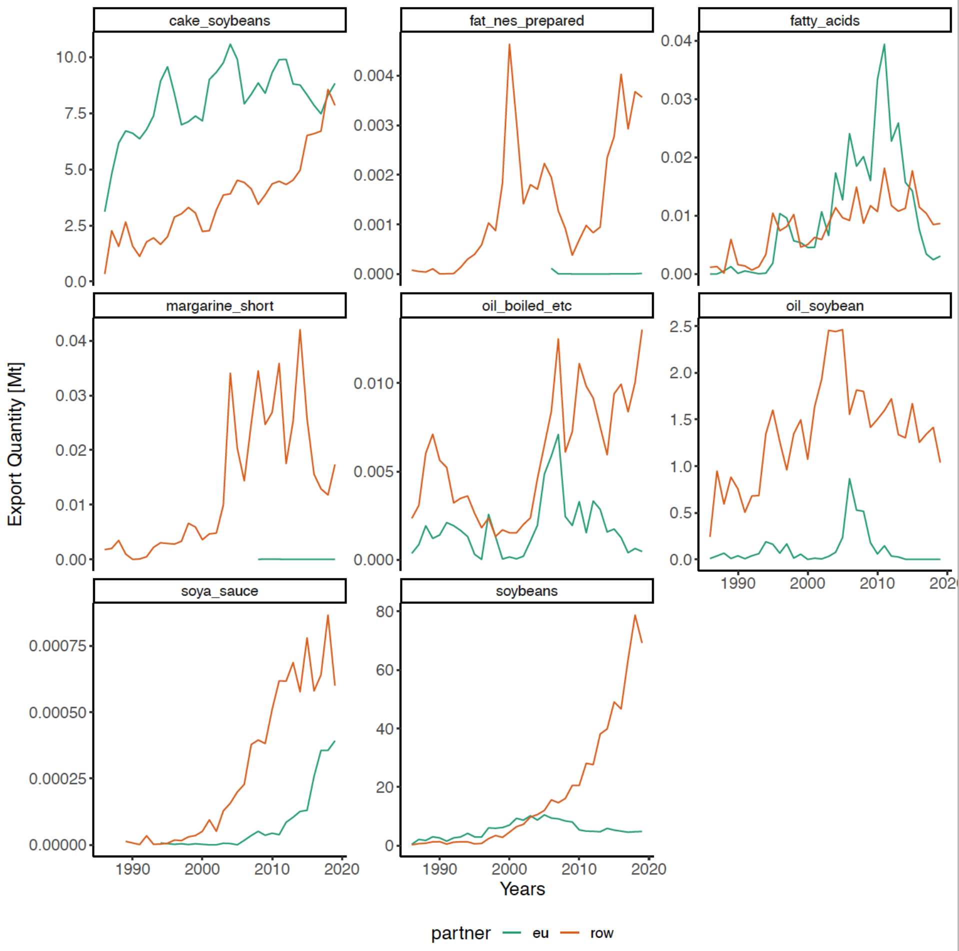
Source: JRC 2022 (own calculation/visualization).

Figure 128. Stack bar chart of the top 10 countries that export to the EU-27 for each product. Country indicated using ISO alpha 2 code.



Source: JRC 2022 (own calculation).

Figure 129. Time series of quantity (Mt, million of tonnes) of soybeans products exported from Brazil to the EU-27 and the rest of the world (ROW).



Source: JRC 2022 (own calculation).

13.1.3 Deforestation and biomass loss embodied in EU-27 import

In this section, we report on the calculation of the deforestation embodied in the EU-27 imports calculated using the land use balance approach described in section 13.2. The data refers to the deforestation that occurred in the period 2010-2015 and related to the trade between 2014 and 2019.

The results show that the EU-27 contribution to deforestation in the producing country compared to the rest of the world and internal consumption is very variable depending on the commodity (see Figure 130a). For commodities such as cocoa and coffee, the imports of EU-27 are a driver of deforestation, being the share of deforestation attributable to the EU-27 74.2% for cocoa and 23.7% for coffee (Figure 130b). For palm oil and soybeans, the share of deforestation due to EU-27 imports is 15.9% and 13.6%, respectively. Cattle is the commodity that shows the lowest share of deforestation, probably because the EU-27 is not a major partner of the producing countries for this commodity. However, the import of cattle product shows the highest impact in terms of deforested area (figure 130a), both for conversion to pasture and for the production of fodder.

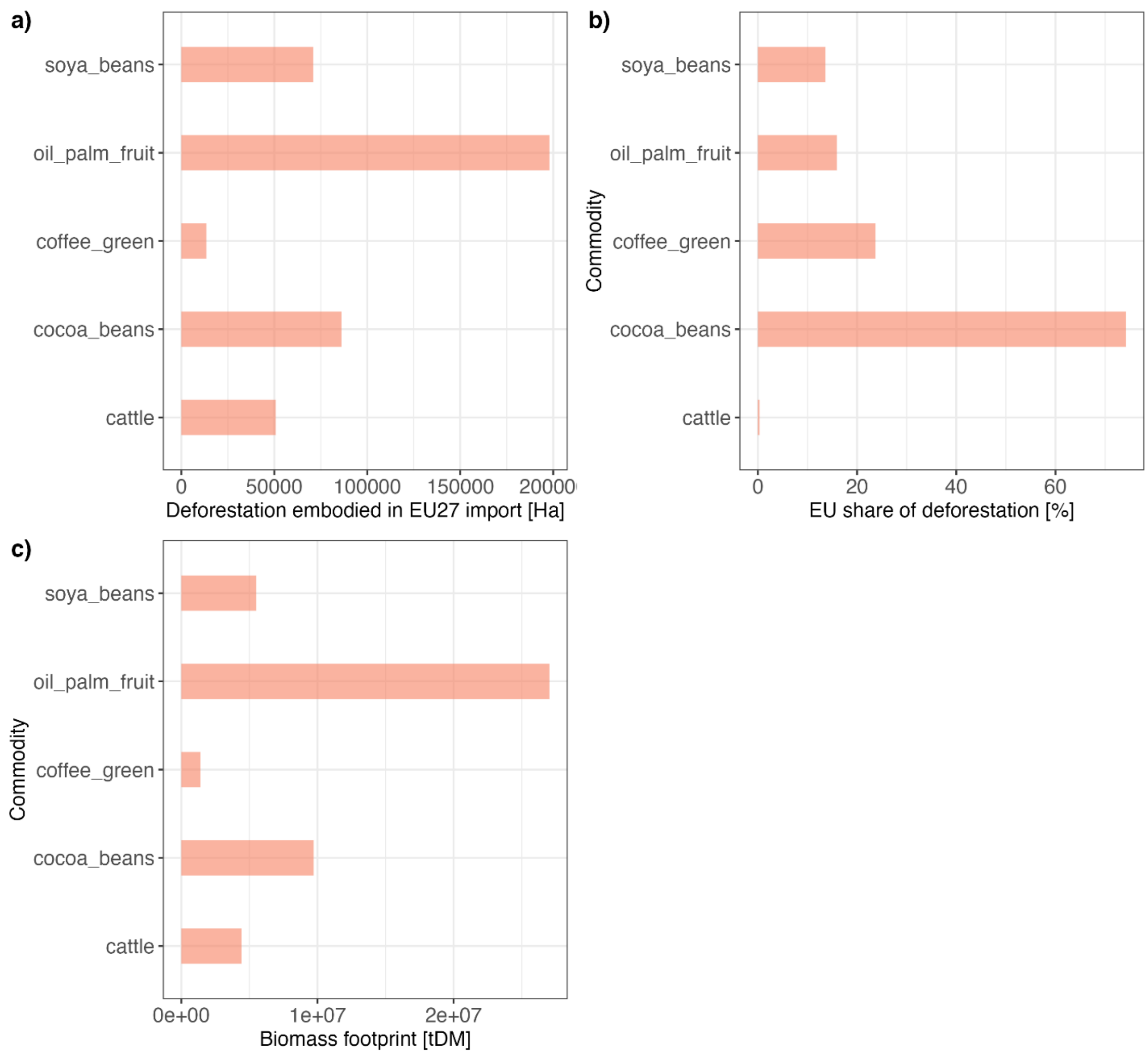
This study focuses on the deforestation embodied in the EU-27 import of risk commodities. Regarding the EU-27 consumption, the reader could refer to the Commission Staff Working document “Impact Assessment Minimizing the risk of deforestation and forest degradation associated with products placed on the EU Market” (SWD(2021) 326). The Impact Assessment reports that “EU consumption during the period 2008-2017 was responsible for 19%

of the tropical deforestation embedded in the international imports of six commodities" (cocoa, soy, wood, cattle, coffee, palm oil). The EU-27 contribution decreases to "6% if domestic consumption of producing countries is considered"(SWD(2021) 326). When looking at individual commodities, the EU-27 share of responsibility for deforestation linked to internationally-traded commodities (i.e., without accounting for domestic consumption of the producing countries) is 44% for coffee, 36% for cocoa, 25% for soybeans, 19% for palm oil, and 5% for cattle. These estimates are based on the re-elaboration of open data (Pendrill et al., 2020). It should be noted that the data reported in the Impact Assessment should not be directly compared with our study because, first, it reports EU-27 consumption (in this study, we report import); second, the underlying trade data and methods are slightly different; and finally, the reference periods considered are different, being this study focused to more recent trade (between 2014-2019).

The biomass losses per year are reported in Figure 130c, larger for the import of palm oil products (27.02 millions tonnes of dry matter, MtDM), followed by cocoa beans (9.72 MtDM), soybeans (5.50 MtDM), cattle (4.42 MtDM), and coffee (1.39 MtDM).

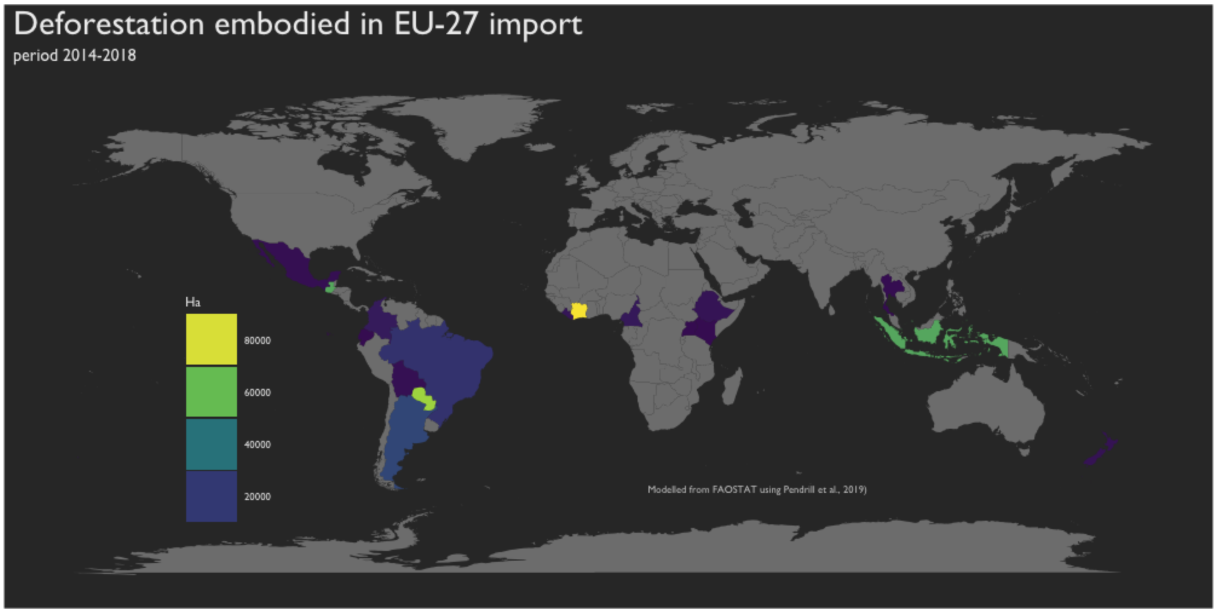
The geographical impact of the EU-27 imports is shown in the maps in Figure 131 where the deforested area per country due to the import of all the selected commodities is reported. The EU-27 imports of the selected commodities and products impact mostly in South America (mainly through the soybean and cattle supply chain), central western Africa (due to cocoa production), and South East Asia (where palm oil is produced). The relative impact of the EU-27 imports on deforestation is shown in Figure 132. The map shows that central American and central western Africa are the regions where the consumption of the EU-27 impacts the most in relative terms, and it is associated to the consumption of cocoa and coffee. The map of biomass loss per year (tDM) is reported in Figure 133 and broadly resembles the map of the deforestation embodied.

Figure 130. a) Total deforested area (2010-2015) embodied in mean annual trade volumes (2014-2019) of the selected commodities and related products; b) EU-27 share (in percentage) of deforestation per commodity; c) total biomass lost for the production of product imported by the EU-27 (tDM) of deforestation per commodity.



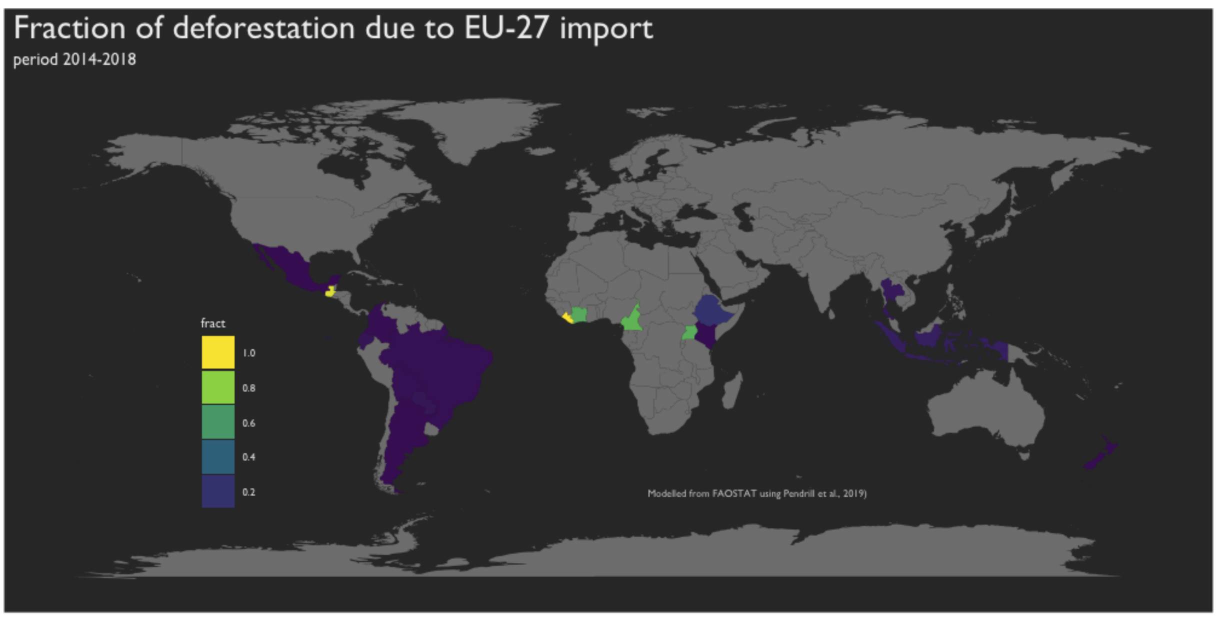
Source: JRC 2022 (own calculation).

Figure 131. Deforestation embodied (expressed in hectares per year) in the EU-27 imports of cocoa, coffee, cattle, palm oil and soybeans products.



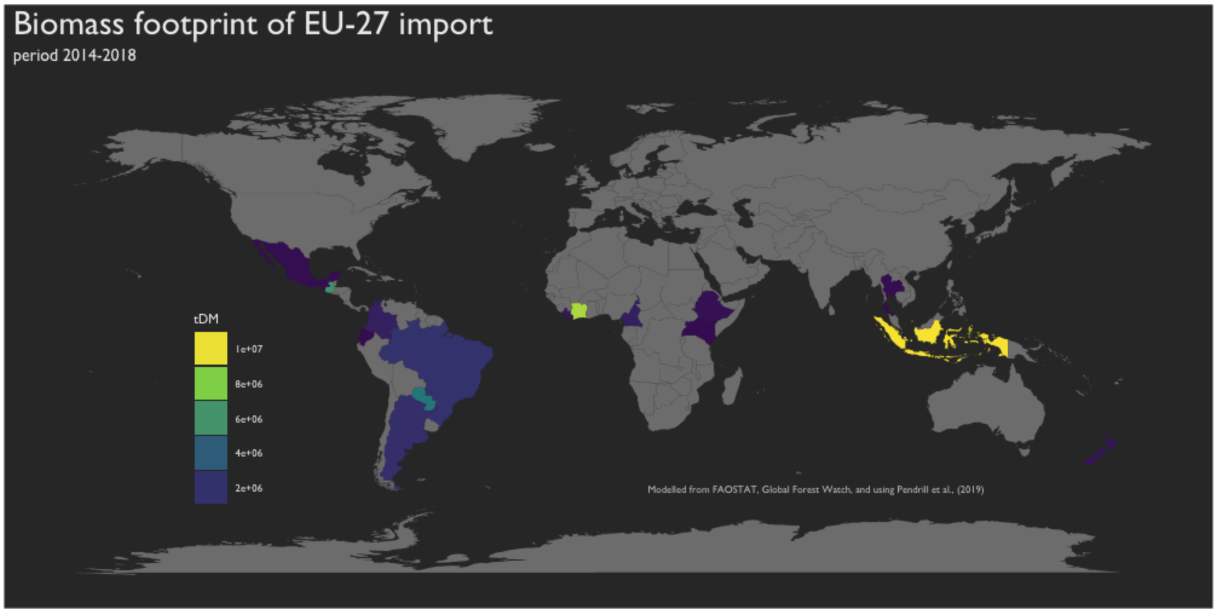
Source: JRC 2022 (own calculation).

Figure 132. Share of deforestation due to EU-27 imports of cocoa, coffee, cattle, palm oil and soybeans products.



Source: JRC 2022 (own calculation).

Figure 133. Biomass lost (tDM) related to the deforestation per year to produce cocoa, coffee, cattle, palm oil and soybeans products imported by EU-27.



Source: JRC 2022 (own calculation).

Box 1. Focus on bilateral trades of wood between EU, Ukraine, and Russia

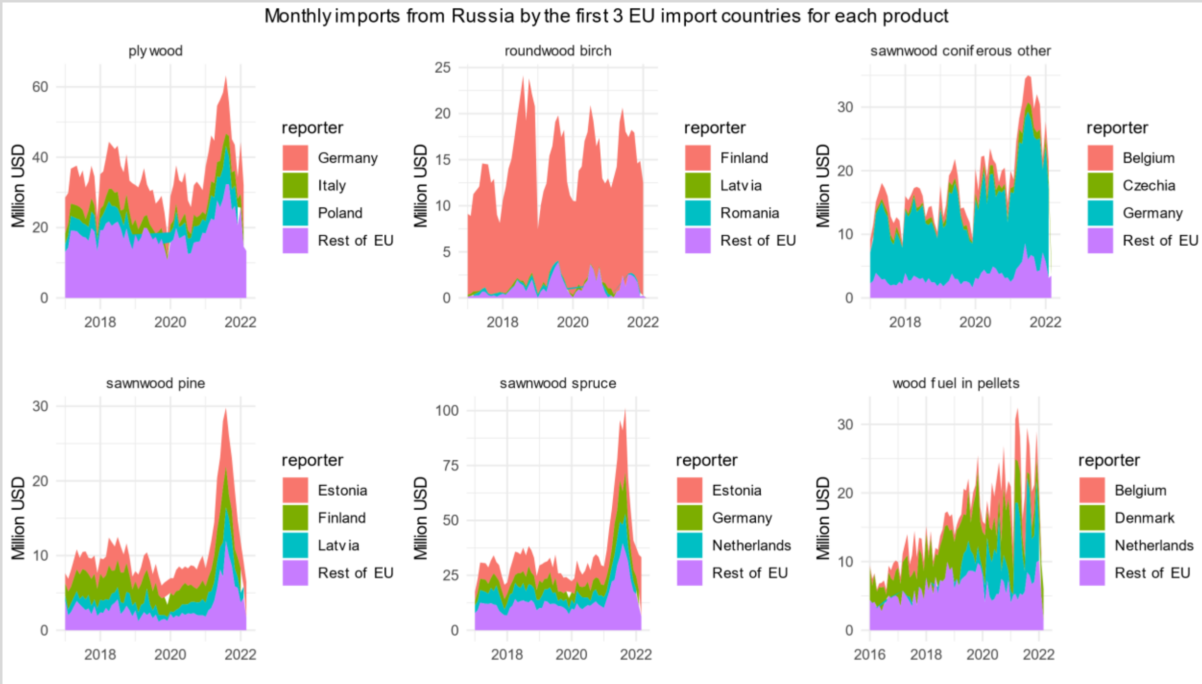
The tools developed in section 13.2 are used to monitor the bilateral trade flow between the EU-27, Ukraine and Russian Federation. We monitored the trade flow of wood products in the last six years using the United Nation Comtrade dataset to identify potential criticism in the supply of wood products in the EU-27 as consequence of the conflict.

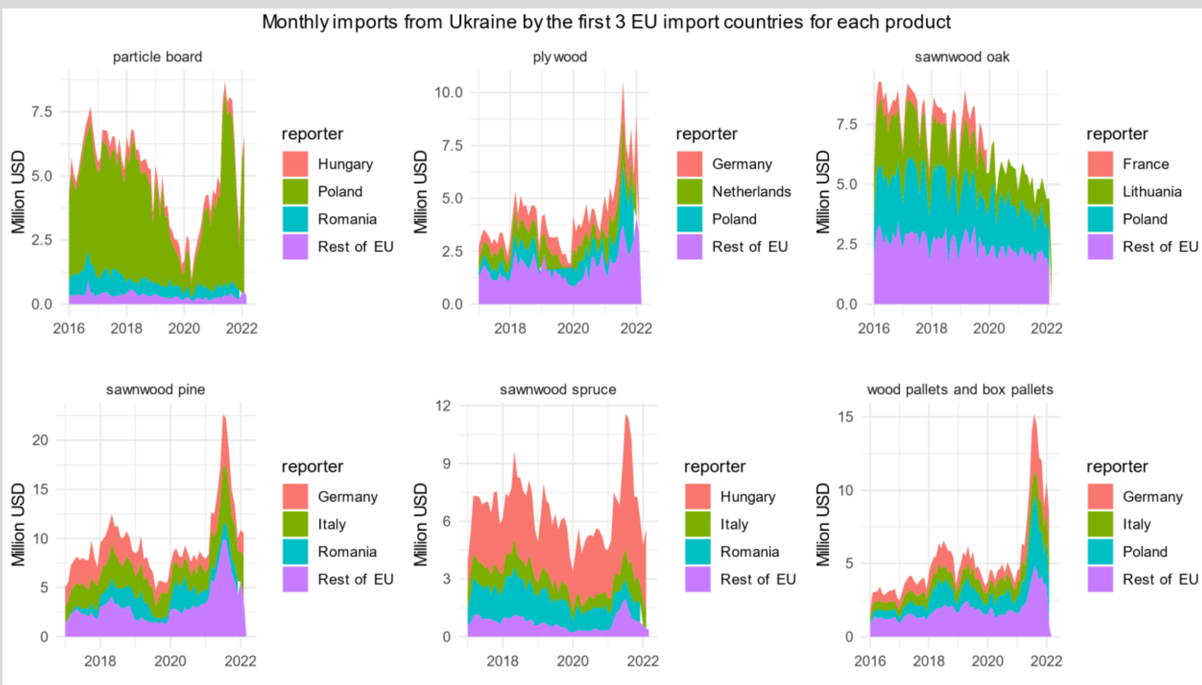
We analysed the monthly imports of EU-27 from Russian Federation (upper panel) and Ukraine (lower panel) for selected products. For each product we report the three main EU-27 importing countries.

The first key message is that before 2022 the monetary value of the import from Russian Federation is larger than the one from Ukraine. The import patterns are quite variable between countries.

Concerning the bilateral trade between Ukraine and EU-27 countries, we show that the profile of Ukraine's import partners changes depending on the product. Poland is the main importer of particle board and a large importer of sawnwood oak; Romania, Italy and Hungary are the main import partners of sawnwood coniferous.

Regarding the trade between Russian Federation and EU countries we show that Finland is the main imported of roundwood birch. Latvia (roundwood birch and sawnwood pine) and Estonia (sawnwood spruce and pine) are relevant importers of wood products. Germany is an important importer of sawnwood conifer, plywood, and sawnwood spruce.


Monthly imports from Russia by the first 3 EU import countries for each product
plywood
roundwood birch
sawnwood coniferous other
sawnwood pine
sawnwood spruce
wood fuel in pellets
Million USD
reporter
Germany
Italy
Poland
Rest of EU
Finland
Latvia
Romania
Belgium
Czechia
Estonia
Netherlands
Denmark
2016
2018
2020
2022


Monthly imports from Ukraine by the first 3 EU import countries for each product
particle board
plywood
sawnwood oak
sawnwood pine
sawnwood spruce
wood pallets and box pallets
Million USD
reporter
Hungary
Poland
Romania
Rest of EU
Germany
Netherlands
France
Lithuania
Italy
2016
2018
2020
2022

13.2 Data and Methodology

13.2.1 Data on deforestation, land use change, agriculture production, trade, and land footprint

FAOSTAT time series[81] contain annual data on the international trade of food and agricultural products for the period from 1961 to 2020 (latest data). Production, import and export quantities, livestock number, and monetary values for producers and bilateral flows of reporting countries are mainly obtained from the United Nations Statistics Division, excluding data associated with the EU, which are obtained from EUROSTAT and national authorities. Trade partner data are embedded for non-reporting countries.

FAOSTAT agricultural production data contain statistics on food and agriculture production for over 245 countries and territories and covers all FAO regional groupings from 1961. These data include quantities of commodities (tonnes), the area harvested for the production of commodities (ha), and the annual yield for the production of commodities.

The FAOSTAT Land use dataset contains country-based statistics on the socioeconomic use of land. The FAOSTAT Land Use domain includes categories of land primarily focusing on their use for agricultural and forestry activities[82]. The dataset was accessed through the self-developed 'biotrade' python package on August, 30, 2022. The data selected for this report are annual data on the country area (in ha) for the selected land uses: "Cropland", "Land under permanent meadows and pastures", "Planted Forest", and "Forest Land". We calculated the changes between 2015 and 2010 for each land use from this dataset. This data was used as input for the land use balance model implemented to calculate the deforestation embodied in trade.

In addition, to compute the environmental footprint of agriculture and forest products, we used the following coefficients and tables from De Laurentiis et al. (2022): grassland yields by country/region of origin (t/ha), feed conversion ratios for primary livestock product (input of dry mass feed per kg of live weight), the regional share of ruminant livestock biomass fed by grazing used to calculate the share of ruminant animals (and products) fed by grazing (beef, sheep, milk products). The diet composition (excluding grazing), and conversion coefficients to wet mass were also considered, as well as the coefficients gamma (diet share in wheat, pellets, molasses, oils) and beta (conversion fresh mass to dry mass). One of the critical steps to assess the deforestation embodied in trade and consumption is the calculation of the land embedded in commodities and goods imported or consumed in the EU-27, also known as land footprint modelling (e.g. De Laurentiis et al., 2022). There are three different methodologies for modelling the land footprint in the literature: 1) the physically-based approach; 2) the approach relying on multiregional input/output models; and 3) the so-called hybrid approach, which combines the strengths of 1 and 2. Despite the methods 2 and 3 being considered very promising because they allow for better monitoring of the supply chain, they rely on datasets that are not updated regularly. The physically-based approach instead can help to provide more timely results, still comparable with the state-of-the-art literature (De Laurentiis et al., 2022), and therefore it was selected for the present assessment. Therefore, we made use of the land footprint data developed within the JRC and recently published (De Laurentiis et al., 2022). The input data required for the methods are:

- import (export) quantities and monetary values of the bio-commodities and associated products from the origin country to the EU-27 (from EU-27 to rest of the world);
- commodity trees (i.e. tree-schemes of the relations between traded products for each commodity) used to calculate the primary commodity equivalent (i.e. the quantity of primary commodity needed to produce the traded products) from traded products;
- technical conversion coefficients to convert the quantity of a product ('child product') into equivalent quantity of the 'parent product' that is then used to produce the child product; and
- yield statistics to calculate the area of land required to produce the primary commodity equivalent.

[81] Available at: https://www.fao.org/faostat/en/#data/.

[82] Definitions of these items (land categories) are available online (https://www.fao.org/faostat/en/#data/RL). As reported by FAO, these definitions are compliant with those included in the SEEA AFF, the SEEA CF, and the Framework for the Development of Environmental Statistics (FDES 2013).

For the land footprint of cattle (beef) products, we used the data reported in De Laurentiis et al., (2022). The imported quantity of processed meat and livestock is converted into land footprint of cropland and grassland. The land footprint calculated refers to trade flows between 2014 and 2019.

13.2.2 Calculation of the deforestation embodied in EU-27 imports

Here we report on the method used to attribute deforestation to agricultural production and trade. The main steps of the analysis are reported in Section 13.2 and follow the methodology developed by Pendrill et al., (2019a) and Pendrill et al., (2019b). First, the land-balance model was used to attribute deforestation to major land-uses and commodities. Second, from the land footprint calculated from the bilateral trade, we calculated the portion of forest loss for the producing country due to crop and pasture expansion which is attributable to the EU-27 imports.

We first calculated the forest loss embodied in the selected commodities using a land-balance model encompassing cropland, pastures, and forest plantations. The model relies on FAOSTAT statistics on land use and land use change (latest access January 25th, 2023) and provides results at the national level. The model is based on two assumptions:

— if croplands expand, and there is a gross loss of pasture-land, we assume a first conversion into pastures and then into forests (if there is a net loss of forest land area);

— where pasture and forest plantation areas expand, they directly replace forest land.

These assumptions are drawn based on the land use patterns observed in the tropics: first, forests and other native vegetation as the main sources of new agricultural land; second, the expansion of forest plantations tend to come at the cost of natural forests; and finally, pastures are a significant source of new cropland, particularly in the tropical Americas (see Pendrill et al., 2019b for more details).

More specifically, the land-balance model attributes forest loss in a given country proportionally to the expansion of cropland, pasture, and forest plantations, capped at the total estimated forest loss in the region.

The forest loss attributed to cropland expansion is then further distributed to individual crops in relative proportion to their expansion in area. For example, if, for a given country, the expansion of cocoa growing areas accounts for half of the total cropland expansion, then half of the country's cropland deforestation will be attributed to the country's cocoa production.

There is a certain time lag between deforestation and the establishment of crop fields. Based on empirical evidence reported in the literature, we decided to average changes in the area of cropland, permanent pastures, and tree plantations over the five years following the forest loss. Moreover, to account for that, while deforestation is a one-time event, agricultural and forestry commodities will take a few years to grow and be traded. This is referred to as "amortisation time", and here we select 5 years. Therefore, the total amount of deforestation embodied in the production of a given commodity in a given year is calculated as the mean of the annual total deforestation attributed to the land use producing that commodity in the five previous years. The amortisation time is a critical parameter of the model. Pendrill et al. (2019b) showed that an amortisation period of five years yields similar results to one and ten years. As a result, in this chapter we calculated the deforestation embodied in the average trade flows between 2014 and 2019. This deforestation occurred in the time period 2010-2015.

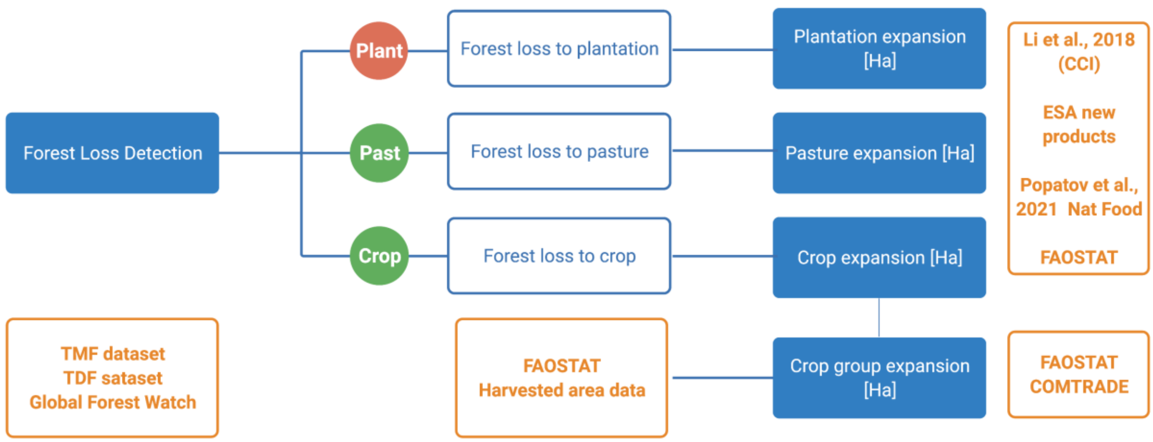
Eventually, we calculated the deforestation embodied in bilateral trade of risk commodities for the EU-27 and a given country that produces that commodity, as follows:

— we calculated the ratio between the land footprint for the import of the given commodity divided by the area harvested in the origin country to produce that commodity, hereafter called as 'percentage of imported harvested area';

— the 'percentage of imported harvested area' was then multiplied by the forest loss attributed to the expansion of the selected commodity in the producing country. In the case of cattle, the percentage of the imported harvested area was multiplied by the forest loss due to crop pasture expansion.

For this chapter we used FAOSTAT statistics only. However, an ensemble of statistics and satellite information (Orange boxes in Figure 134) such as the Global Forest Watch dataset, the Tropical Moist Forests products and recent crop expansion maps (e.g. Popatov et al., 2022) may be used in the future in the context of the EU Observatory of deforestation and forest degradation.

Figure 134. Flowchart of the methodology used for the calculation of deforestation embodied in the trade of risk commodities. Abbreviations list: Tropical Moist Forests (TMF) dataset; Tropical Dry Forests (TDF) dataset; Climate Change Initiative (CCI); European Space Agency (ESA); United Nations Comtrade database (COMTRADE); Plantations (Plant); Pasture (Past); Croplands (Crop); Hectares (Ha).



Source: JRC 2022 (own calculation/visualization). Created with BioRender.com.

The biomass loss as consequence of deforestation embodied in the import of the selected commodities in the EU-27 is calculated following these steps:

— for each country, we calculated the deforested area using the forest cover changes from the Global Forest Change (GFC) maps recorded at 30-m spatial resolution from Landsat imagery (REF). We used the "Forest Cover Loss" that is defined as the complete removal of tree-cover canopy at the Landsat pixel scale (natural or human-driven) and is reported annually;

— we aggregated the map of the deforestation area from the native resolution of 30 m at the resolution of the European Space Agency (ESA) Climate Change Initiative (CCI) Biomass product (Santoro et al., 2021) for the year 2010, which is 100 m;

— we then calculated the mean and the median biomass per area [tonns DM ha^{-1}] in the deforested areas using the ESA CCI Biomass map and the deforestation area embodied derived from the GFC map;

— we then calculated the biomass footprint of the EU-27 import of product derived from risk commodities by multiplying the deforestation are embodied in EU-27 import for the biomass per ha derived from ESA CCI Biomass map.

13.2.3 Limitations of the approach

The limitations embodied in the current approach as well as some potential solutions are described below:

— the approach assumes that forest loss attributed to cropland expansion is distributed to individual crops in relative proportion to their expansion in area. This is a questionable assumption because there might be a different contribution of the different crops. This issue can be solved using crop type maps that are not available globally but only for few specific countries. Future studies will quantify the uncertainty associated to this assumption;

— the amortisation time of five years set in the land balance model used is a critical parameter. Despite studies showing that the impact is small (e.g. Pendrill et al., 2019b), a better understanding of the optimal parameter and its variability between crops is needed;

— the bilateral trade used is reported at the country level. The availability of trade data at the subnational level might improve the attribution of deforestation to certain supply chains. The use of datasets such as the Trase initiative will help to quantify the uncertainty behind this limitation;

— the approach relies on a land footprint model that might not fully track the whole value chain. This can be improved by using Multi Regional Input-Output models.

13.3 Conclusions for Chapter 13

Deforestation and forest degradation are one of the major threats to global forest, with important consequences to the global Carbon cycle, forest biomass, and its biodiversity. Since 1990, global forest loss amounted to 420 million hectares through conversion to other land uses (FAO, 2020 state of forest). Deforestation in the tropics is mainly driven by the expansion of agriculture and the production of commodities (Curtis et al., 2019; Pendrill et al., 2019a; Pendrill et al., 2022). The European Union (EU-27) has been identified as an important contributor to tropical deforestation through the consumption and trade of products and commodities potentially associated to deforestation (Pendrill et al., 2019a). In this chapter we first summarised the existing literature linking EU-27 trade and consumption to deforestation; second, summarised the recent information on production and trade of commodities associated to deforestation, and, finally, we described the deforestation associated to the EU-27 import of products and commodities. We focused specifically on five commodities mentioned in the proposal for a regulation on deforestation-free products (COM(2021) 706): beef meat, cocoa, coffee, palm oil, and soybeans.

The EU-27 plays a major role in the import of the selected commodities (cocoa, coffee, soybeans, cattle, and palm oil). However, the share of EU-27 imports compared to the global trade volume is higher for coffee and cocoa beans, cake of soybeans, mostly used to feed animals, followed by palm oil, soybeans and cattle products. The import of palm oil is however showing a decreasing trend.

Palm oil, cattle, and soybean are the commodities with the highest deforestation embodied in EU-27 imports between 2014 and 2019, followed by cocoa and coffee. The share of deforestation embodied by EU-27 imports compared to the rest of the world is show a large variability between commodities (74.1% for cocoa, 23.7% for coffee, 15.9% for palm oil, 15.6% for soybeans, and <1 % for cattle. The total forest biomass loss in 2010-2015 of the products traded in 2014-2019 was 48.04 millions tonnes of dry matter (this study). Moreover, the Commission Staff Working document “Impact Assessment Minimising the risk of deforestation and forest degradation associated with products placed on the EU Market” (SWD(2021) 326) reports that “EU consumption during the period 2008-2017 was responsible for 19% of the tropical deforestation embedded in the international imports of six commodities” (cocoa, soy, wood, cattle, coffee, palm oil).

On 17th November 2021, the European Commission proposed a regulation aimed at curbing deforestation and forest degradation driven by the expansion of the land used for the production of six commodities: cattle, cocoa, coffee, palm oil, soya and wood. The regulation proposal envisions a due diligence mechanism and a benchmarking system that would identify countries presenting a low, standard or high risk of producing non-compliant commodities or products. In December 2022 the European Parliament, the Council, and the European Commission reached the provisional political agreement on the text of the EU Regulation on deforestation-free supply chains. The scope of the regulation was broadened in terms of commodities and products, particularly rubber and more products of wood are now included. The European Parliament and the Council will now formally have to adopt the new Regulation before it can enter into force.

In this chapter we report literature results and data from the European Commission’s Joint Research Centre that reinforce the need for such a regulation, and we discuss the limitations behind the state-of-the-art methods that can be used for the development of indicators for the benchmarking system.

13.4 References for Chapter 13

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https://environment.ec.europa.eu/system/files/2021-11/SWD_2021_326_1_EN_impact_assessment_part1_v4.pdf

14 Land use and land cover in the EU: considerations for biomass production

Sarah Mubareka, Javier Sánchez López, Grazia Zulian, Noemi E. Cazzaniga, Alessandra La Notte

Key messages

- Land is multi-functional and can offer many services including, but not only, the provision of biomass.
- Biomass is provided by different land systems: in 2017, 704.21 Mtdm were provided from agriculture and 248.06 Mtdm from forests as roundwood removals.
- Alterations to land should consider the pressures that will be put on the land systems, as well as the trade-offs in ecosystem services.
- The multi-functionality of land can be explored by overlaying different layers.
- Marginal lands are not a well-defined concept and should not necessarily be considered as available for production.

As reported in Chapter 1 of this report, land-based systems produce roughly 1 billion tonnes of dry matter (tdm) of biomass in the EU per year, of which 50% of this total amount in dry matter corresponds to crops, which are grown on 153 Mha (37% of the EU-27 territory, 2018 EEA extent accounts), while the woodlands and forests produce 27% of the total biomass in tonnes dry weight. The latter is grown on forest land and woodland, which covers about 38% of the EU-27 territory (2018 EEA extent accounts). In 2017, 704.21 Mtdm were provided from agriculture (of which 516 Mtdm were crops) and 248 Mtdm were from forests as roundwood removals.

Biomass is foreseen to become increasingly important as a resource in the EU (Muscat et al., 2021). The pressure on land to produce biomass is not limited to the biomass we take directly, but also what we take indirectly (i.e. water to produce biomass), as well as to what we put back into the land (i.e. fertiliser and pesticides) and these are pressures that lead to important impacts (Renner et al., 2020).

Land has multiple functions. Land is also an integral part of ecosystems and indispensable for biodiversity and ecosystem services. Ecosystem services range from the biomass provision (e.g. crop, timber and fisheries) to the filtration of pollutants (from air, water and soil) to the protection from natural hazards (e.g. flooding and landslides) and maintenance of habitats directly and indirectly used and valued by people (e.g. pollination, pest control and carbon sequestration) (Maes et al 2020).

As argued in Meyfroidt et al. (2021), land use change usually entails trade-offs between different benefits. This is where we begin the discussion about land systems. Land systems are defined as the result of human interactions with the natural environment (Verburg et al., 2015). They are complex and hard-to-predict systems (Meyfroidt et al., 2021). Thus, the study of land systems implies a study of the full socio-ecological system in which the impacts of society and climate on land are taken into consideration, and vice versa, where land system changes affect the functioning of the socio-ecological system (Verburg et al., 2015).

The purpose of studying land use, land cover and land systems change is to understand the pressures of our activities on this fundamental asset. Once a basic understanding is made at a system's level, thus of the combined set of pressures from all sectors, it is then possible to assess the environmental feasibility of policies (as was done in, for example, Renner et al., 2020). Land management has a huge potential to help the EU reach its EU Climate and Biodiversity goals, as recent modelling frameworks[83] and political agreements[84] show.

[83] COM(2021) 554 final.

[84] https://www.consilium.europa.eu/en/press/press-releases/2022/11/11/fit-for-55-provisional-agreement-sets-ambitious-carbon-removal-targets-in-the-land-use-land-use-change-and-forestry-sector/.

In this chapter, we aim to illustrate the multiple functionalities of unproductive lands through a simple example of marginal lands, to initiate a discussion on the possible consequences of land management choices including an assessment of trade-offs in the land systems domain.

14.1 EU land composition today

According to the 2018 Corine land cover map[85], the land breakdown in the EU-27 is as shown in Table 14. The land use categories follow the three-level hierarchy of the standard CLC nomenclature [86].

Table 14. Breakdown of main land use categories in the EU-27.

	Artifical surfaces	Agricultural land	Forest and semi-natural areas	Wetlands	Water bodies
EU-27	4.7%	44.6%	45.3%	1.90%	3.5%

Source: JRC (own calculation using the Corine Land Cover 2018 map)

While land may be attributed to the land use categories "agricultural land" and "forests and semi-natural areas", the land is not necessarily producing biomass for human consumption at all times and may be unmanaged for those purposes. Roughly 11% of the forests and woodland are not available for wood supply (see Chapter 6, *Forest biomass production*), while at any given time 0.5% of the total cropland is not under production[87]. It should be noted however that farming or 'agriculture' goes beyond the Corine Land Cover[88] classes or Utilised Agricultural Area (UAA) concepts with respect to how these statistics are compiled because land cover does not always coincide with land use. For example, grazing may occur in forest land, heathland and shrub ecosystems (Vallecillo et al., 2022), but the definition of UAA according to Eurostat is: '*The total area taken up by arable land, permanent grassland, permanent crops and kitchen gardens used by the holding, regardless of the type of tenure or of whether it is used as a part of common land'*[89].

[85] https://land.copernicus.eu/pan-european/corine-land-cover/clc2018.

[86] The standard CLC nomenclature includes 44 land cover classes. These are grouped in a three-level hierarchy. The five main (level-one) categories are: 1) artificial surfaces, 2) agricultural areas, 3) forests and semi-natural areas, 4) wetlands, 5) water bodies.

[87] https://ec.europa.eu/eurostat/databrowser/view/ef_m_farmleg/default/table?lang=en

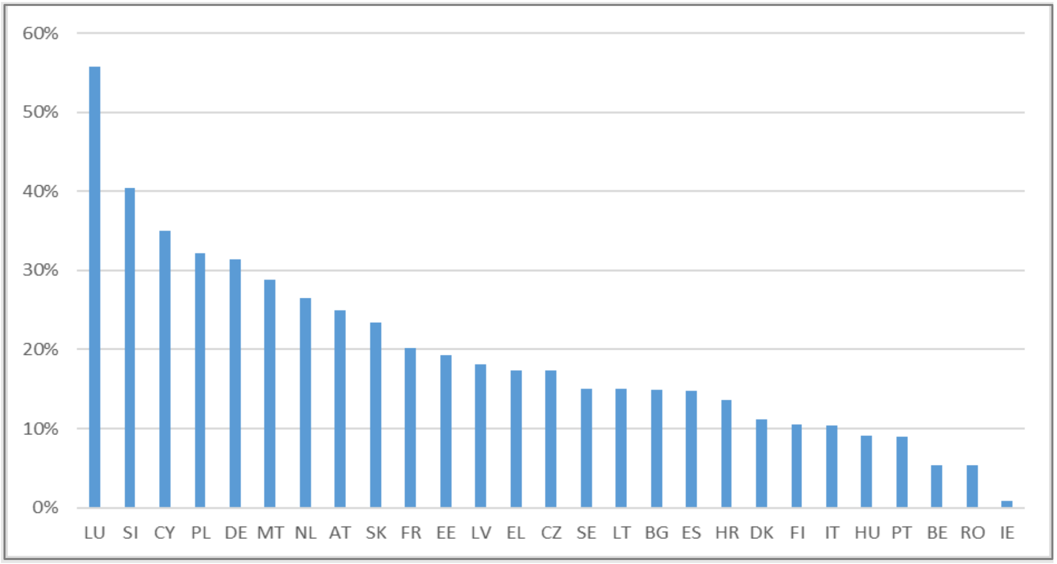
[88] https://land.copernicus.eu/pan-european/corine-land-cover.

[89] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Utilised_agricultural_area_(UAA).

14.1.1 Protected areas

The amount and spatial extent of protected areas is to be considered in the European context. In the EU-27, the protected areas cover a surface of 716.7 thousand km^2, amounting to 17.3% of its mainland[90]. The countries with a proportion of protected areas over 30% are Luxembourg, Slovenia, Cyprus, Poland and Germany (Figure 135).

Figure 135. Proportion (%) of land protected of the land surface of the land on continental European soil per EU-27 Member State.

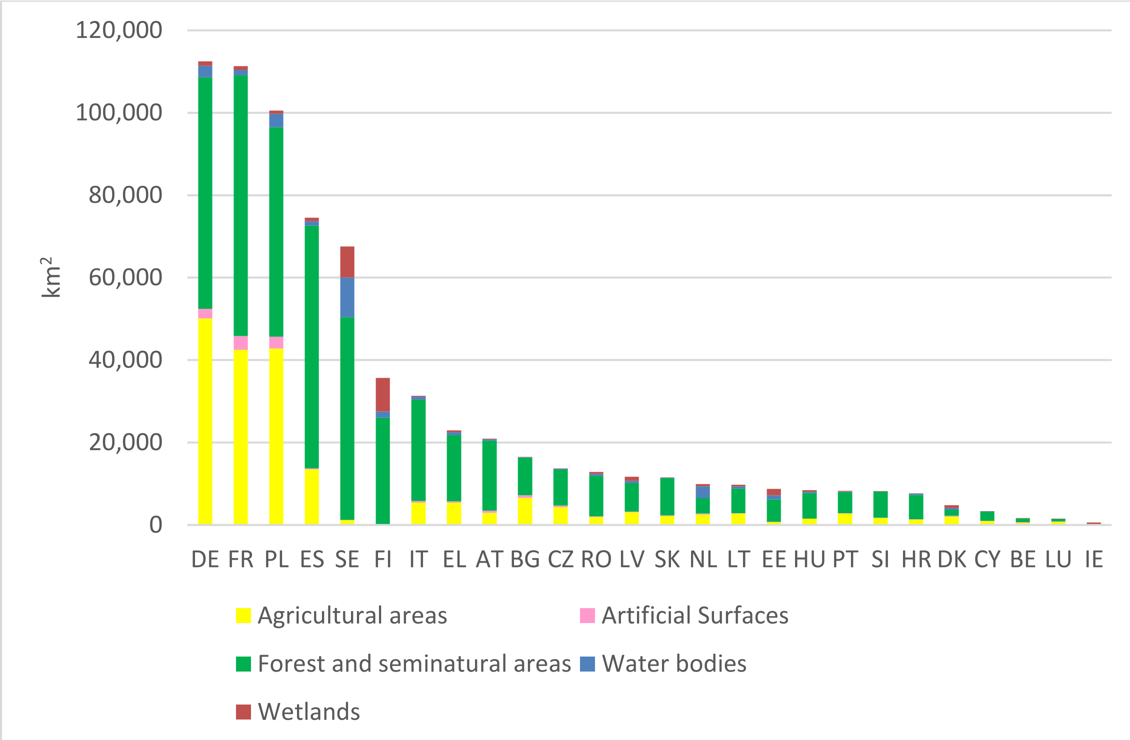


Source: JRC 2022 (own calculation).

Of the protected areas, 30% consists of agricultural land, 63% consists of forest and semi-natural land. The national level breakdowns of protected areas by land use are shown in Figure 136.

[90] Based on a raster calculation of size 100m x 100m. Protected areas covering land only (not the sea). Overseas territories excluded; the Canary Islands are included.

Figure 136. The breakdown of protected areas by land use per EU-27 Member State (km²).



Source: JRC 2022 (own calculation).

Within the category "protected areas", there are different levels of protection and relative management. IUCN[91] defines a protected area as '*A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*'. They then refine the protected areas according to a scale describing their level of protection based on six management categories (one with a sub-division), summarised below:

Ia: Strict nature reserve: strictly protected for biodiversity and also possibly geological / geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.

Ib: Wilderness area: usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.

II: National park: large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.

III: Natural monument or feature: areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.

[91] Dudley, N. (Editor) (2008). Guidelines for Applying Protected Area Management Categories. Gland, Switzerland: IUCN.

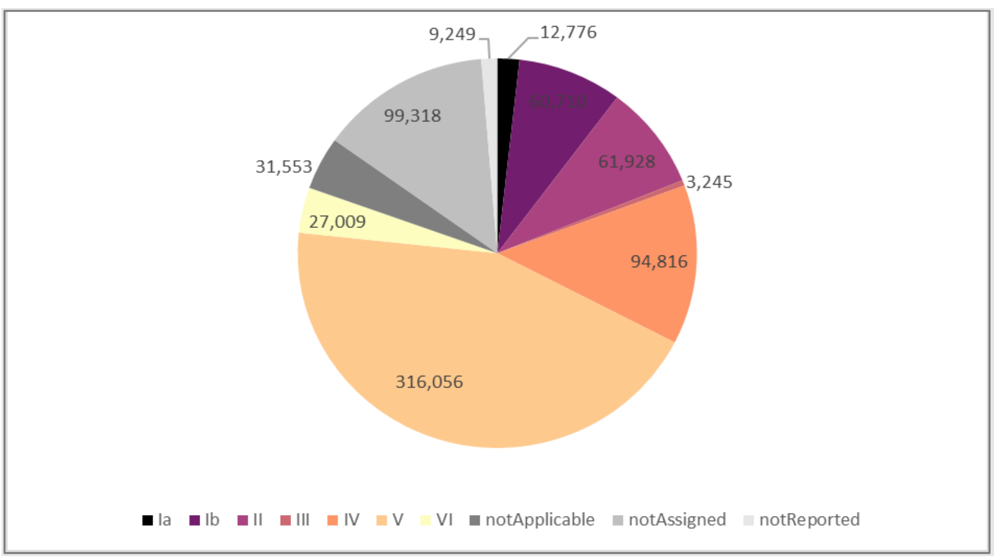
IV: Habitat/species management area: areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.

V: Protected landscape or seascape: where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.

VI: Protected areas with sustainable use of natural resources: areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The classification is based on the primary management objective(s), which should apply to at least three-quarters of the protected area. Some geographical areas belong to more than one category, so to avoid multiple accounting in the presentation of this data, we assigned the strictest category to the land in case of overlapping polygons and when overlaps occur, the strictest category is retained[92]. Figure 137 shows that the majority of the land-based protected areas according to IUCN[93] fall into the category V, where the concept of land systems is exemplified: the characteristic of this class is the long-term interaction between humans and nature that has produced the resulting characteristics of the land.

Figure 137. The breakdown of all land-based protected areas in the EU-27 by categorisation. Note: when areas overlap in the original dataset, the higher level of protection prevails (km^2).



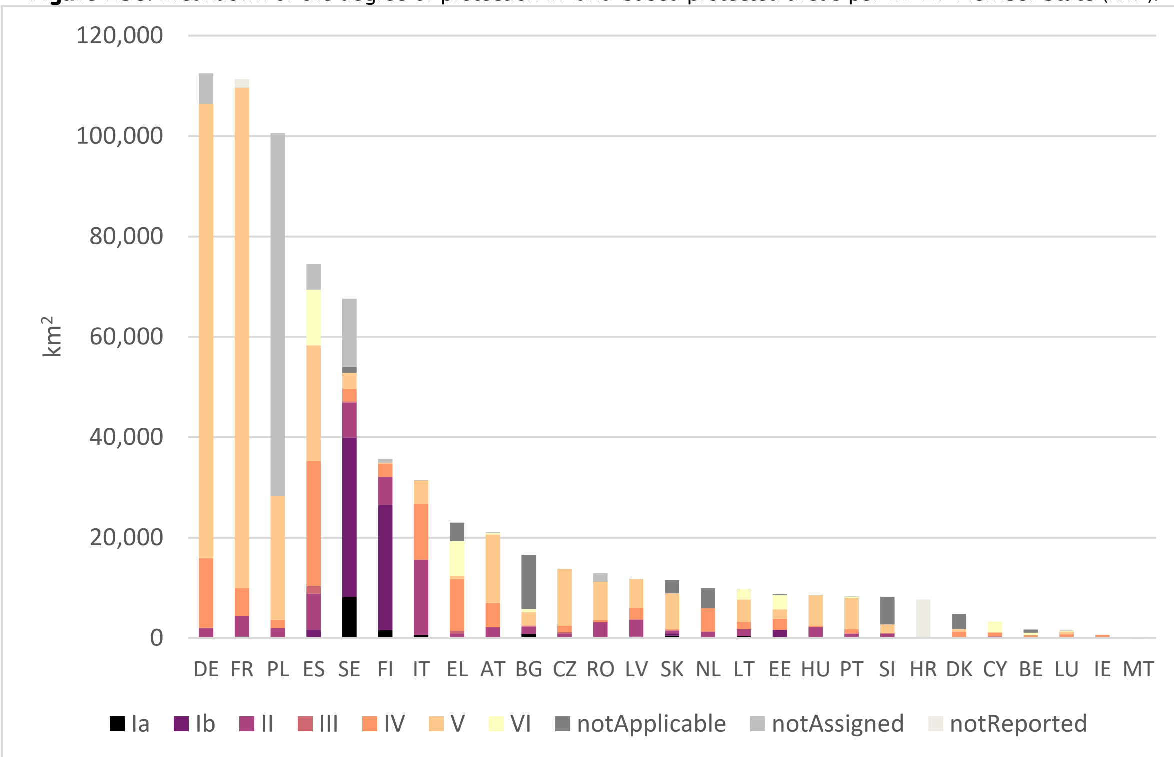
Source: JRC 2022 (own calculation).

As shown in Figure 138, this is most prevalent in two large countries, Germany and France. Stricter protection is prevalent in Sweden and Finland. Poland has a large amount of unassigned protected areas.

[92] First a geometrical correction to ensure that geometry was topologically correct was performed using the ESRI validation method. Then, the vector map was redrawn starting from the polygons of the original dataset, by overlaying, comparing and clipping or deleting the different geometries according to our "relevance criterion".

[93] Downloaded from https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-17 in September 2022.

Figure 138. Breakdown of the degree of protection in land-based protected areas per EU-27 Member State (km²).



Source: JRC 2022 (own calculation).

Although there is an increased number of land and marine areas designated as "Natura 2000 sites" (European Commission, 2022), habitat fragmentation does have important impacts (Kuipers, May & Verones, 2021). According to the EEA[94], large parts of Europe have become fragmented because of the expansion of urban areas and transport infrastructures.

14.2 Ecosystem services and land use / land cover

Land use and land cover provide the basis to measure ecosystem properties and conditions that together determine the ability to generate services (i.e. potentials). Ecosystem properties and condition reflect the type of ecosystem as the result of a specific land use. Ecosystem services are in turn generated by ecological processes within their area of influence such as catchments, habitats, natural regions and land use units.

According to CICES[95], one of the most popular classification system currently used, ecosystem services are generally divided into three broad categories: Provisioning, Regulating and Maintenance, and Cultural services.

Ecosystem services correspond to the contributions of ecosystems to the benefits that economic sectors and societies demand and use (United Nations et al., 2021). These services are divided into three broad categories (ref: CICES, Ecosystem Accounting - SEEA):

— provisioning: are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems;

[94] https://www.eea.europa.eu/ims/landscape-fragmentation-pressure-in-europe.
[95] European Environment Agency. Towards a common classification of ecosystem services. https://cices.eu/

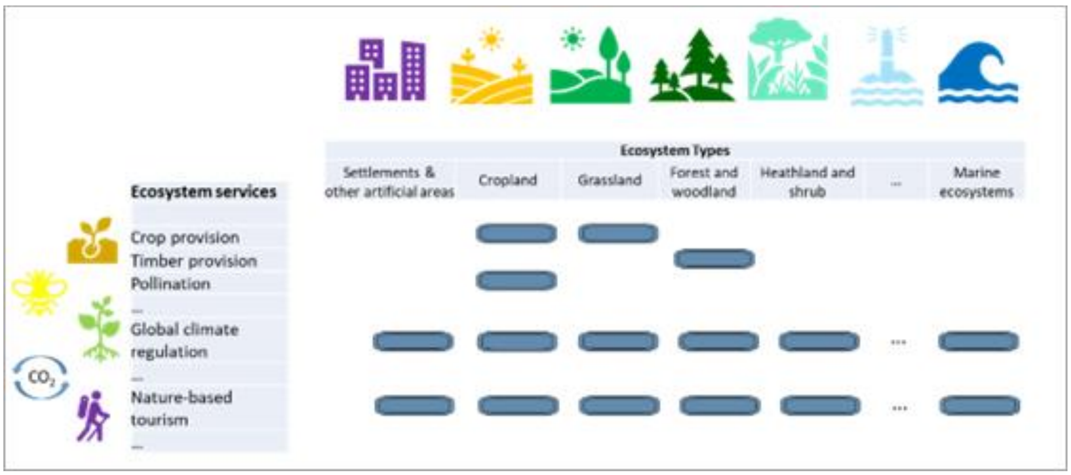
— regulating: are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society;

— cultural: are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.

In land use modelling terms, these services correspond to the potential and the demand: the potential is the ability of the ecosystem to provide a service while the demand is the expected requirement from society.

Each ecosystem type can provide one or many ecosystem services, as shown in Figure 139, and fully described and reported by La Notte (2019b, 2020, 2021) and Vallecillo (2018, 2019). Ecosystem services are related to land cover and land use since these describe the ecosystem types. As the land is converted, the services it provides change.

Figure 139. Relationship between ecosystem types and ecosystem services.



Source: INCA platform Welcome to INCA | INCA Platform (europa.eu).

Trade-offs may arise between the different ecosystem services. Climate change mitigation is one ecosystem service, but it should not necessarily be prioritised at the expense of the rest. To take this to an extreme example, Erb et al. (2018) estimate that land use halves the amount of carbon that is potentially stored in terrestrial biomass. Thus, a straightforward solution to increasing carbon stored in vegetation would be to completely rewild the land. The issues this approach would bring are obvious when taking into account the food systems, settlements, and other anthropogenic uses of land. Erb et al. point out that some land cover types have more potential than others to stock carbon, e.g. tropical forests vs. temperate and boreal forests. From a strict climate mitigation point of view, the former should rather be prioritised (i.e. left intact) at the expense of the latter. This seems unreasonable as other factors come into play: namely society's relationship with land, including the most land-use intensive sectors: forestry, food, beverages, mining and energy (D'Amato, Korhonen and Toppinen, 2019).

According to Vallecillo et al. (2022) when describing the EU-wide methodology to map and assess ecosystem condition, and achieve based on System of Environmental Economic Accounting a '*good ecosystem condition will be considered when it presents good physical, chemical, and biological condition, or good physical, chemical and biological quality with self-reproduction or self-restoration capability, in which species composition, ecosystem structure and ecological functions are not impaired*'.

The EU Ecosystem Assessment (Maes et al., 2020) reports on trends in pressures and ecosystem condition in the EU and its marine regions using the year 2010 as a policy baseline. The analysis of trends in pressures on ecosystems presented in the report shows a mixed picture. While there is a decline in overall land take, pressures remain high for air pollutants and critical loads of nitrogen. Further to the direct anthropogenic pressures are the indirect ones: Impacts from climate change on ecosystems are increasing, causing concern for rising land and sea surface temperatures and a reduction in rainfall. Drought events are increasing relative to the 2010 baseline values as well.

14.3 Environmental pressures on land and drivers of change

In this section we focus on the concepts of drivers of land use change, pressures on land, and land use intensity. There are several important drivers for land-use change in Europe. Climate, societal, economic and policy-driven land use change can result in land use transformations and competition for land for different uses. Constraints in land availability within the EU could lead to an expansion of the EU access to third country markets as a means to complement domestic supply, raising additional concerns about potential spillovers of EU trade deals, i.e. the export of environmental impacts (see Chapter 13). For example, Foong et al., (2022) discuss the need to consider emissions embodied in trade.

The EEA cites the following drivers for land-use change in Europe[96]:

- Production of food and fibre;
- Production of biomass for bioenergy;
- Carbon storage in land and soil;
- The increasing demand for housing and living space per person;
- Increased mobility and growth of transport infrastructure.

Pressure on land from human activities can come in many shapes and forms. For example, pesticide residues, fertiliser leakage, or overdraft of water (one third of water abstraction is for agricultural land), are all considered pressures (Renner et al., 2020). Environmental pressures may manifest as land use change, but the land use intensity is an important concept to consider and is the result of land management practices (Levers et al., 2015) thus they may not be dissociated. For example, in Spain, land-use intensification for food production is recognised as one of the main drivers for land use change because of its indirect effect: the agricultural lands are producing higher yields in very fertile areas, and the less fertile areas are then abandoned (Santos-Martin et al., 2019).

According to the EU Bioeconomy monitoring system, the level of intensity type of farming in the EU-27 is shared almost equally between the three broad classes, high, medium and low intensity farming. High and medium intensity farming occupy a share of 36% each, while low intensity farming occupies the remaining >30%[97].

The concept of land use intensity is relevant to the quality of ecosystem services provided. Intact and continuous ecosystems that are in good condition are able to provide higher flows and more services than fragmented and degraded ecosystems. The management of land, which includes the concept of intensity, will impact not only on the principal ecosystem service in biomass-producing areas, such as food production, but on a wider range of ecosystem services.

The most land-use intensive sectors are forestry, food, beverages, mining and energy (D'Amato, Korhonen and Toppinen, 2019) and, as argued in Meyfroidt et al. (2021), land use change usually entails trade-offs between different benefits.

14.4 Marginal land

Marginal lands are in part the result of land abandonment. Land abandonment is a term used to refer to former agricultural land that is no longer in production for any number of reasons, normally economic (Muscat et al. 2022). Perpiña Castillo et al. (2018) estimate that about 11% of the agricultural land in the EU (≈ 20.86 Mha) are under high potential risk of abandonment between 2015 and 2030. The authors identified the main underlying reasons for this as the deterioration of biophysical land suitability, farm structure and agricultural viability, as well as urbanisation. To these drivers of land abandonment, Dolton-Thorton (2021) also adds technology and market globalisation. They estimated that the five main EU-27 countries where abandonment will take place are, in order of magnitude of absolute values, Spain, Poland, France, Germany and Italy, comprising a sum of circa 70% of the

[96] https://land.copernicus.eu/user-corner/land-use-cases
[97] Intensification of farming indicator, EU Bioeconomy Monitoring System, https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=2.2.d.5

total land potentially abandoned. In terms of share per UAA within the country itself, the five main EU-27 countries where agricultural land abandonment represents the highest values are Spain (5%), Poland (4.8%), Slovakia (4.6%), Greece (3.7%) and Finland (3.5%).

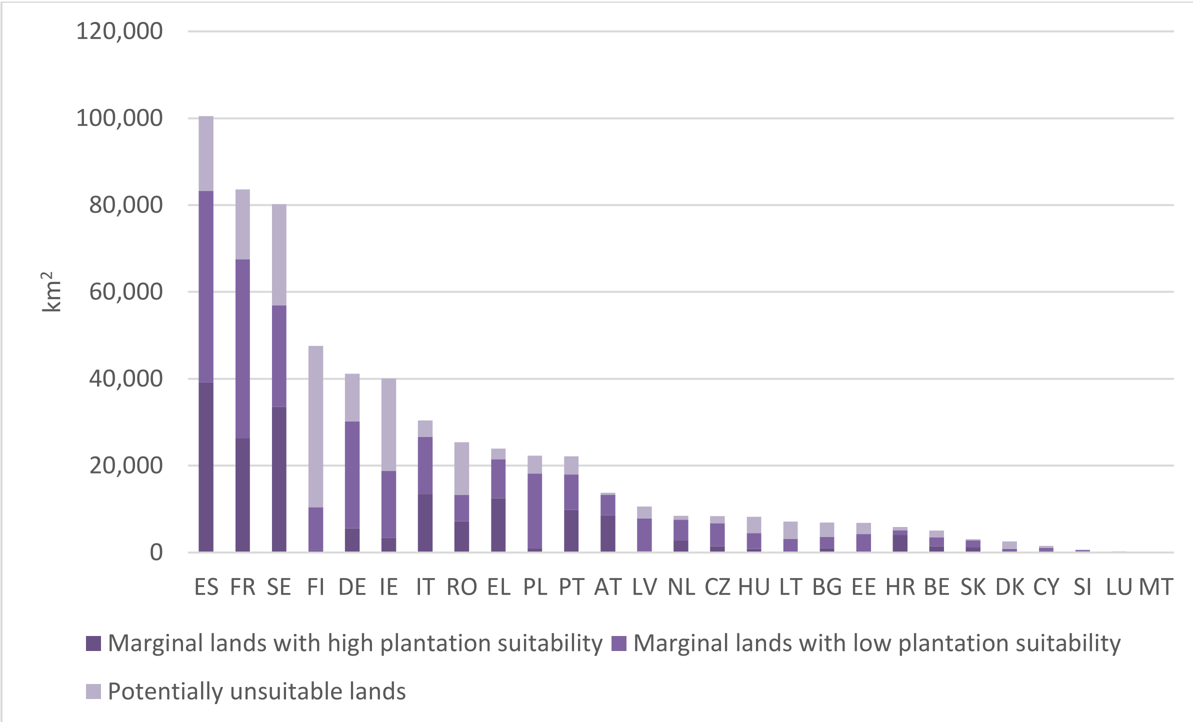
The current energy crisis, are refocussing our attention to the so-called “Marginal lands”. Marginal lands have been defined in many ways (Shortall, 2013), some argue that this ambiguity allows for different stakeholders to turn to marginal lands for solutions (Muscat et al 2022), mainly to produce biomass for industrial purposes with low input systems (e.g. Scordia et al., 2022) while enhancing soil carbon sequestration (e.g. Xu et al., 2022), restoring saline lands (e.g. Sánchez et al., 2017) or remediating heavy metal-contaminated soils (e.g. Barbosa et al., 2015). Additional synergies with other ecosystem services further than the provision of biomass are sought, like improving soil properties and reducing soil erosion, but other trade-offs such as the depletion of water resources may occur (Fernando et al., 2018). Moreover, marginal lands are also considered a potential mitigation strategy as potential carbon sinks regardless of the biomass produced (https://marginallands.eu/).

The idea of a productive use of marginal land is appealing because it implies that biomass could be locally grown, produced with few inputs, not compete with food production, contribute to self-sufficiency of e.g. renewable energy and give farmers an additional income (Shortall, 2013). In this section we explore the land that has been defined and mapped as marginal land in the H2020 project “Magic” (grant agreement No 727698)[98]. This project takes a biophysical and practical perspective, aiming to help primary producers identify the industrial crops and farming methods that could be suitable for their land. During the project six main clusters of factors that define land as being “marginal” were identified: adverse climate, excessive wetness, low soil fertility, adverse chemical conditions, poor rooting conditions and adverse terrain conditions and found that 29% of the agricultural area for EU-27+UK can be defined as marginal, with the three most common reasons for this classification being poor rooting conditions (e.g. low rootable soil volume or unfavourable soil texture), adverse climate (i.e. low temperature or dryness), and excessive moisture.

Although other projects focus on marginal lands (e.g. BIOPLAT-EU), this one produced 1km-resolution maps of marginal lands for the EU, divided into three categories: 1) marginal lands with high plantation suitability; 2) marginal lands with low plantation suitability; 3) Potentially unsuitable lands. Figure 140 and Table 15 show the number of hectares of marginal land identified per country per category.

[98] Other EU-funded research projects with similar objectives and outputs exist, e.g. https://bioplat.eu/. Nevertheless, the Magic project (https://magic-h2020.eu/) was considered for the present study since the geo-referenced information was publicly available.

Figure 140. Categorical breakdown of marginal lands per EU-27 Member State, as defined in the H2020 project MAGIC (km²).



Source: H2020 Magic project (https://magic-h2020.eu/).

Table 15. Land considered "marginal" per category and EU-27 Member State, as described in the MAGIC H2020 project.

MS	Marginal lands with high plantation suitability (km²)	Marginal lands with low plantation suitability (km²)	Potentially unsuitable lands (km²)	Total (km²)
ES	39,181	44,054	17,258	100,493
FR	26,355	41,210	16,067	83,631
SE	33,559	23,401	23,272	80,232
FI	472	9,977	37,126	47,575
DE	5,576	24,605	10,967	41,149
IE	3,337	15,419	21,336	40,092
IT	13,483	13,209	3,743	30,434
RO	7,170	6,074	12,195	25,439
EL	12,506	8,980	2,477	23,964
PL	923	17,251	4,131	22,306
PT	9,825	8,120	4,218	22,162
AT	8,568	4,776	384	13,728
LV	240	7,648	2,670	10,559
NL	2,777	4,801	906	8,485
CZ	1,439	5,307	1,614	8,360
HU	888	3,567	3,811	8,266
LT	79	3,055	3,982	7,116
BG	1,032	2,576	3,323	6,931
EE	89	4,182	2,578	6,848
HR	4,045	1,061	789	5,895
BE	1,436	2,047	1,551	5,035
SK	1,186	1,591	314	3,091
DK	24	843	1,661	2,528
CY	419	683	425	1,527
SI	269	276	75	619
LU	59	166	22	247
MT	35	0	1	36
EU	174,973	254,879	176,896	606,747

Source: MAGIC H2020 map

14.4.1 What else is marginal land for?

The consensus that marginal land must be defined to identify areas that are not suitable for food production because of biophysical or economic restrictions but could be put into production for certain industrial use of biomass already implies that this land should be somehow used at all (Shortall, 2013). As stated above, this is an appealing concept, not least because it is seen as an opportunity to increase the biomass production in unproductive areas but also as a way to enhance other ecosystem services such as climate regulation through carbon sequestration, or for other reasons such as soil remediation, soil protection, etc. However, we ask ourselves whether the land is truly unproductive, and whether or not the transformation of those lands would have an overall positive impact.

We explore what is underlying the mapped polygons of marginal land. We do this by overlaying this map with other products that describe the underlying land, beginning with high nature value farmlands, moving to ecosystem services.

14.4.2 High Nature Value Farmland

High Nature Value Farmland is a concept that describes the farmland with an inherent biodiversity value (Parrachini et al., 2008). Parrachini et al. (2008) describe typical high nature value farmland areas as, for example, alpine meadows and pasture, steppic areas in eastern and southern Europe and dehesas and montados in Spain and Portugal, respectively.

If we overlay the marginal lands layer with the 2018 HNV layer (M.L. Paracchini, pers. comm), we find that while most HNV farmland is not considered also marginal land, some 171,463 km^2 (17.1 Mha) of the HNV in the EU-27 is also considered as marginal land, 66,130 km^2 (6.6 Mha) of which is considered with high plantation suitability (Figure 141). An example of an area that is both considered as marginal and of high nature value is shown in Figure 142.

Figure 141. Marginal land inside and outside of High Nature Value Land (km^2).

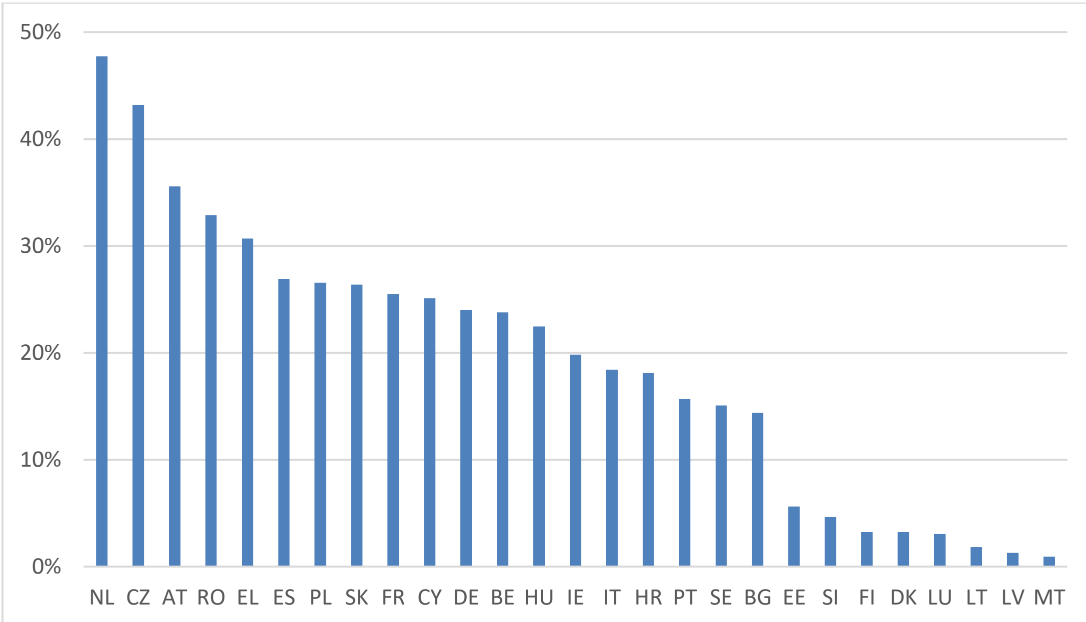
Source: JRC 2022 (own calculation).

Figure 142. An example of land both labelled as marginal land, but also as High Nature Farmland in Sardegna, Italy.

Source: Google Maps 2022.

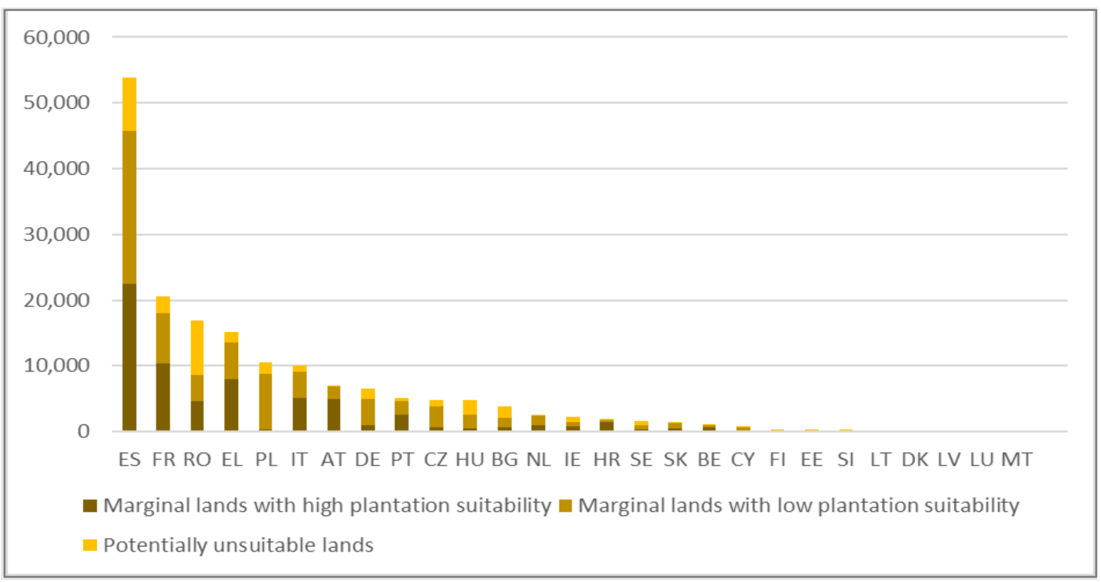
The Member State breakdown identifies four countries with at least 30% of the marginal land also classified as HNV land: the Netherlands, Czechia, Austria, and Romania (Figure 143), although it is Spain the MS that has the highest proportion of marginal land considered to be of high plantation suitability (Figure 144).

Figure 143. Proportion (%) of High Nature Value Land in marginal lands per country.



Source: JRC 2022 (own calculation).

Figure 144. Breakdown of marginal lands per category of potential plantations per country (km²).



Source: JRC 2022 (own calculation).

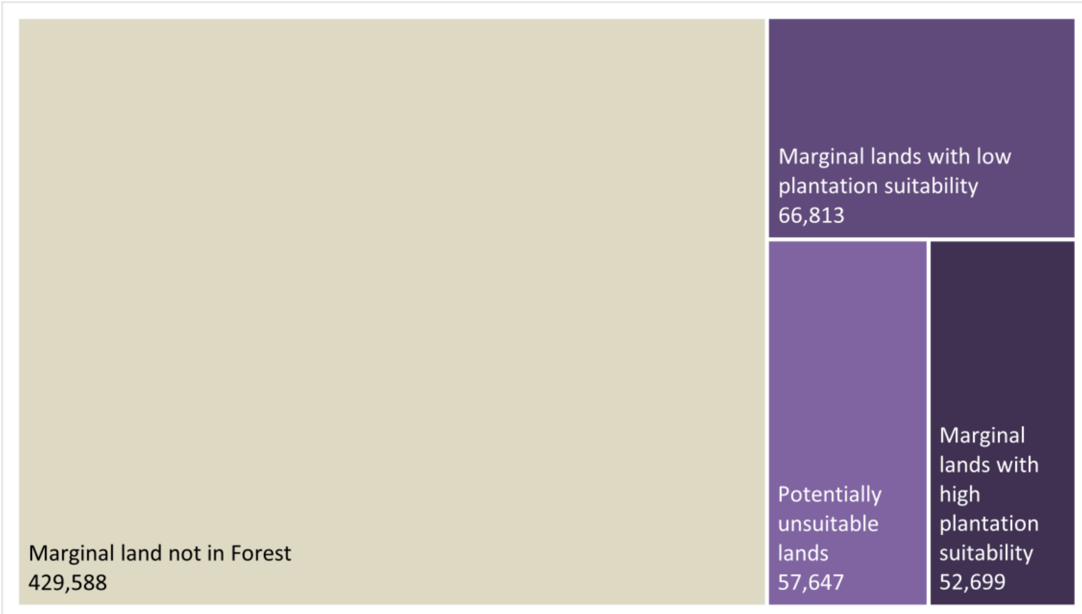
14.4.3 Forest land

Although marginal land is expected to be in agricultural land, it does overlap with forest land with 177,159 km² (17.7 Mha), according to the JRC Forest Map (see Chapter 7)[99]. Figure 145 shows the amount of marginal land in

[99] In the Magic project, marginal lands are mapped using a spatial agricultural area mask to include all land that was classified in an agricultural land cover class in at least one of the four Corine Land Cover versions (1990. 2000, 2006, 2012). This may be one of the reasons why there is an overlap with the forest land identified in the JRC Forest Map.

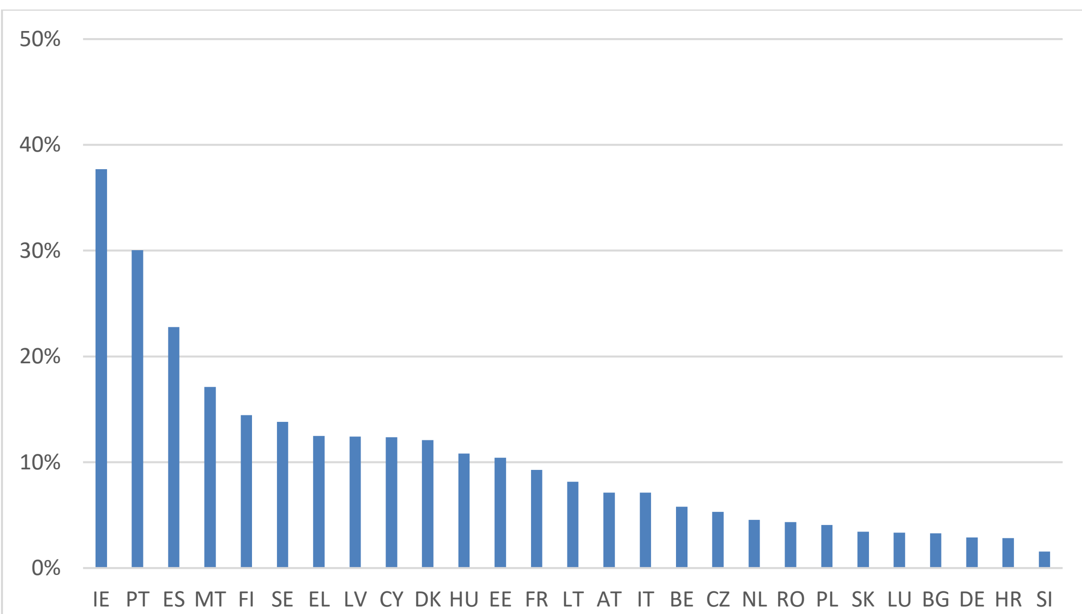
forests -both in forests available for wood supply and not available for wood supply (see Chapter 7 for a closer look at these categories of forests and what defines them as such). The breakdown by country is shown in Figure 146, where we see that, e.g. more than 30% of Ireland's marginal lands are composed of forests.

Figure 145. Marginal land inside and outside of Forest Land (km^2).



Source: JRC 2022 (own calculation).

Figure 146. Proportion (%) of Forest Land in marginal lands per country.



Source: JRC 2022 (own calculation).

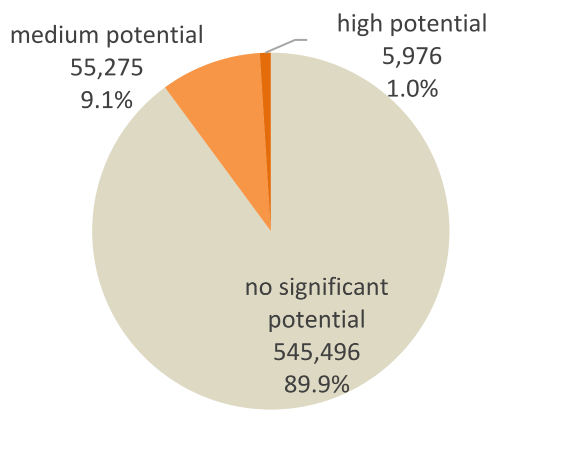
14.4.4 Ecosystem Services in marginal land

Marginal lands vary across Europe, and as such so do their capacity to provide ecosystem services. We assessed the non-provisional ecosystem services in marginal lands as defined in the MAGIC project. The services we looked at were crop pollination, global climate mitigation, water purification, flood control, soil erosion control and daily outdoor recreation services (Vallecillo et al., 2018; Vallecillo et al., 2019; La Notte et al., 2021).

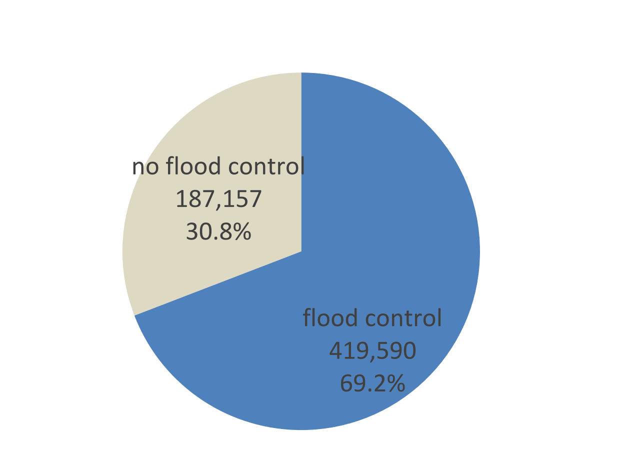
We found that the total carbon sequestration in marginal land is 27,567,758 tC, which is 11% of the total in EU-27, according to the INCA data source used; that marginal lands purify a total of 2,283,632 tonnes of water, which is 12% of the total in the EU-27, according to the INCA data source used; and that the total soil retention in marginal land amounts to 1,253,944,192 tonnes, which is about 14% of the total soil retention services in the EU-27, according to the INCA data source used. In Figure 147 we show the ecosystem services potentials in marginal lands (for pollination, flood control and daily outdoor recreation). The pollination potential includes roughly 61,250 km^2 of the total 606,747 km^2 marginal lands.

Marginal lands contribute to control flooding events, they offer opportunities for daily outdoor recreation activities and are suitable to support pollinator insects.

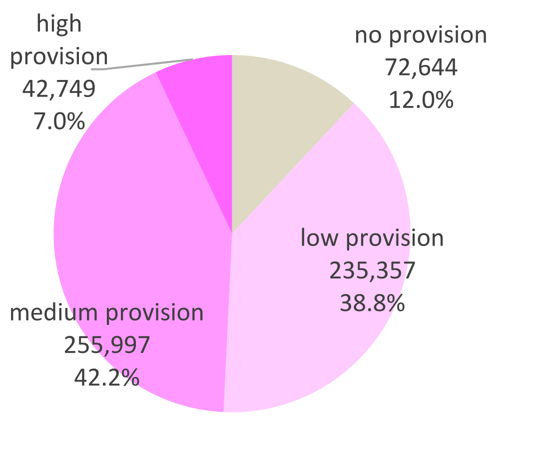
Figure 147. Ecosystem services potential in marginal lands: pollination potential, flood control and recreational opportunities.



Total Marginal Land by pollination potential (km^2 and %)



Marginal Land providing flood control services (km^2 and %)



Total Marginal Land by recreation opportunity spectrum (km^2 and %)

Source: JRC 2022 (own calculation).

On the other hand, the ecosystem services provided by the marginal lands that are turned into production also depend on the approach followed to produce such biomass and the socioeconomic or biophysical limitation that causes the marginality. For example, a marginal bare land that is used to produce perennial grasses or Short Rotation Coppice (SRC), which provide a permanent vegetation canopy –except at harvest- and an input of organic matter (by e.g. decomposition of leaves), may reduce water and wind erosion, sequester soil carbon and provide shelter to biodiversity (Fernando et al., 2018; Blanco-Canqui, 2016). According to the meta analysis conducted by Immerzeel et al. (2014), biodiversity benefits are found in both tropical and temperate regions, when abandoned cropland, degraded or marginal lands are converted, especially to second generation crops, but the authors call for caution when making general assumptions about the (potential) biodiversity benefits of using these broadly defined land uses.

The point is, without a counterfactual, we are unable to assess whether or not conversion of marginal land is effectively positive or negative. This depends entirely on the state of the marginal land in the first place, as well as the proposed interventions. Our purpose here was to bring forward the possible externalities and impacts as well as the potential benefits of conversions.

14.5 Conclusions for Chapter 14

Land has multiple functions, and trade-offs between different benefits will inevitably occur when land use is altered. It is only by studying land through a land systems perspective and seeking to understand the pressures of human activities that we may govern land knowledgeably.

Different policy domains in the EU affect land. In this chapter we bring forward the interacting concepts within the land systems domain of ecosystems, ecosystem services, drivers of land use change, pressures on land, and land use intensity. The purpose of this chapter was twofold. First, to emphasise the importance of considering land in policy impact assessments, because the concept of land impacts is often not embedded in policy assessments (Fidelis et al. 2021), yet land management has a huge potential to help the EU reach its EU Green Deal Goals (see for example, Searchinger et al, 2022). Second, this chapter aimed to emphasise the importance of assessing trade-offs in the land systems domain when designing and implementing policies that impact land through the example of ecosystem services and marginal lands, but much more can be done.

As argued in Muscat et al (2021), the scientific literature often offers partial views on biomass availability because it focusses on one or two uses for biomass (e.g. energy and materials is a common pair). However, the whole systems and their connections are not considered. It was not the aim of this chapter to assess the policy drivers and their implicit pressures on land systems, but rather to open the discussion on the importance of the whole system's view when addressing biomass production and uses.

The conversion of marginal land to cultivated land will have implications on biodiversity and emissions as the result of land use change. They may be positive (see for e.g. Jager et al., 2022; Blanco-Canqui, 2016; Haughton et al., 2015), or they may be negative (see for e.g. Hof et al., 2018) for EU land, but again, the land management choices made for the EU will have impacts on the land outside of the EU unless we do curb our consumption (see for e.g. O'Brien, Shutz & Bringezu, 2015). Putting land into production that has been stabilised in its current status requires a full impact assessment to assess the consequences (and real benefits) of such transitions.

14.6 References for Chapter 14

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15 Biomass for selected bio-based industrial value chains in a dynamic global economy

Myrna van Leeuwen, Robert M'barek, Kirsten Boysen-Urban, Patricia Gurría, Tevecia Ronzon, Viktoriya Sturm

Key messages

- Europe, Asia and North America have very similar shares in the global bio-based chemical markets of around 30%.
- It is estimated that 13.2% of corn, 7.4% of wheat, and 8.2% of sugar beets in the EU is used for material purposes.
- The main (processed) feedstocks (incl. imports) used for bio-based products are plant oil (30%) and starch (25%).
- In terms of volume, biofuels (42%) is the most important application category within bio-based chemicals, followed by bio-based agrochemicals (21%) and bio-based surfactants (12%).
- Under unchanged policies, the share of arable crops for material use is projected to rise slightly from 8.2% in 2020 to 9.7% in 2050, so the intended growth of bio-based materials may be met with a stronger increase of imported feedstock unless targeted policies and technologies (e.g. upscaling valorisation of unused biomass from waste streams and residues) to increase domestic production are deployed.

The European Commission defines bio-based products as products that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised[100]. As a central element of EU's Bioeconomy Strategy, bio-based products and its related processing plants, the biorefineries at scale, could play an important role in transforming industrial facilities towards the environmental ambitions of the EU, while creating jobs and growth in rural areas (European Commission, 2022). Bio-based products can also contribute to a sustainable economy by reducing dependency on fossil resources, and bring new functionalities (Spekreijse et al., 2019). Bio-based products comprise established products that have been in the market for long time, and some novel ones that are not fully commercialised yet.

While bio-based production is still small in scale, (bio-based) plastics is a good example to show the potential and challenges of the bio-based economy. Fossil-based plastic production in 2018 reached 62 million tonnes in Europe (EU-28 + Norway and Switzerland) while worldwide the production amounted to 359 million tonnes. In the meanwhile, the bio-based production worldwide reached only 7.4 million tonnes[101]. The demand of plastics is expected to increase to 1,200 million tonnes by 2050, where 135 million tonnes will be met with bio-based plastics and the biggest amount by plastics recycling[102].

While the additional economic value of an increased use for bio-based products for rural areas is undisputed, the question of competition for feedstock for food and non-food purposes remains a central question, also raised in the latest Bioeconomy Progress report (European Commission, 2022). In this chapter, we support this debate with the latest research on feedstock use of the main arable crops in bio-based chemical value chains.

Before turning to the feedstock use, we provide insights into the global bio-based chemical market, including comparisons of bio-based and fossil-based value chains. While the numbers provided are only a snapshot of a particular market situation and cannot be compared to the exceptionally high energy prices in the year 2022, they nonetheless point to the main factors determining the competitiveness of EU bio-based products – in the domestic and global market.

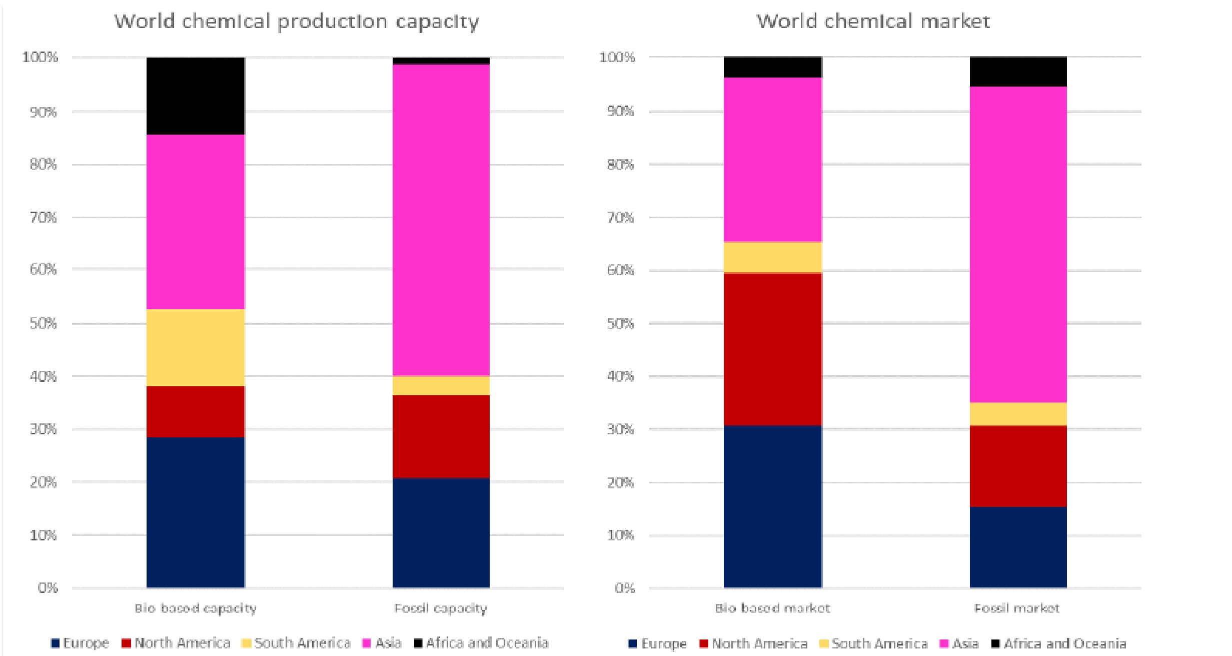
[100] https://single-market-economy.ec.europa.eu/sectors/biotechnology/bio-based-products_en.
[101] https://nova-institute.eu/press/?id=164.
[102] http://bio-based.eu/downloads/world-plastic-production-and-carbon-feedstock-in-2018-and-scenario-for-2050/.

The reader should note that due to the different sources of information and the limited data availability, the definitions applied for bio-based chemical products are variable in this chapter, for instance excluding or including biofuels.

15.1 EU bio-based chemicals production in the global market

Asia is the global leader in fossil-based chemical production (comprising of chemicals, plastic and pharmaceuticals) by a share of 58%. Europe follows with a 21% share as presented in Figure 148. In terms of bio-based chemical markets (economic values), Europe, Asia and North America have very similar shares of around 30% each (Spekreijse et al., 2021).

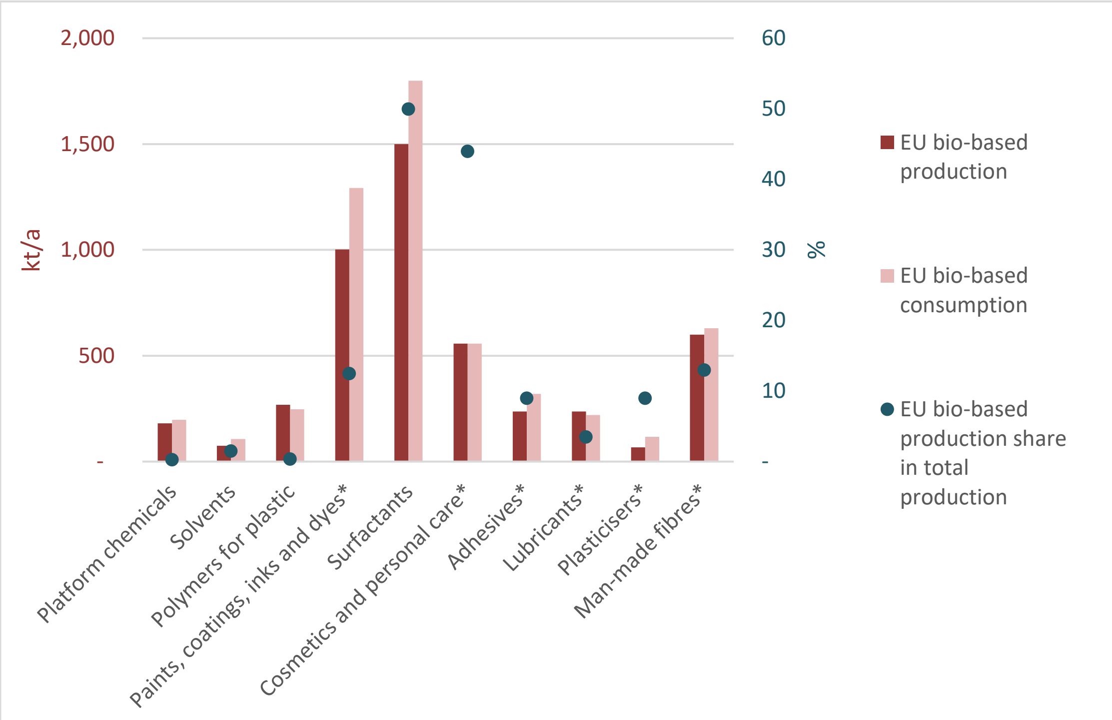
Figure 148. Share of fossil and bio-based chemicals (including chemicals, plastic and pharmaceuticals) for the global production capacities (based on ktonnes/years) and market (based on EUR millions/year).



Source: Spekreijse et al., 2021.

Spekreijse et al. (2019) estimate the size of total bio-based production for 10 selected chemical product categories. Taking the period 2000-2016 as reference, surfactants and paints, coatings, inks and dyes had the highest share of bio-based production, remaining below or around 10% for the majority of the products. For most of the products, EU's bio-based consumption was higher than the domestic production, indicating a net import position.

Figure 149. Size of total bio-based production for 10 selected chemical product categories.



Note: No total EU production data were found; it has been assumed that total EU production (fossil- and bio-based) equals the total EU market (fossil- and bio-based consumption).

Source: Adapted from Spekreijse et al., 2019.

15.2 Exploring bio-based and fossil cost shares at industry level

The competitiveness of bio-based industrial products is often seen in the context of its fossil-based counterparts. Indeed, the importance of the costs for either fossil or bio-based feedstocks has been demonstrated for example in Philippidis et al. (2019), where higher oil prices trigger a certain growth of bio-based alternatives.[103]

In Spekreijse et al. (2021), cost-share data has been compared with fossil industries, focussing on sectors, processes, feedstocks, and regions, grouped at industry level (i.e. chemicals, plastics, and pharmaceuticals). The key difference between the fossil and bio-based industries is the higher cost shares in feedstock for bio-based industries, particularly in the plastics sector and for those value chains that use vegetable oil as feedstock.

As a limitation of the quantitative analysis, it should be noted that bio-based cost shares are based on the bio-based products that have successfully reached large-scale production. These results are therefore biased towards bio-based products that can compete with their fossil-based counterparts. The cost shares of all bio-based products, regardless of their success in large-scale production, would better reveal where the hurdles are for the large-scale production of innovative bio-based products. Table 16 provides a summary of the information available on production and costs for seven selected value chains.

[103] The reader should however bear in mind that high oil prices also dampen the overall economic activity and therefore, depending on the price shock, reduce ceteris paribus the overall size of the market due to reduced consumption, limiting also the perspectives of the bio-based alternatives.

Table 16. Summary of production and cost data collected per value chain (ktonnes/year).

Industrial sector	Chemicals			Plastics		Pharmaceuticals	
Intermediary chemical	**Acetic acid**	**Propylene glycol**	**Succinic acid**	**PET**	**PUR**	**Lactic acid**	**Levulinic acid**
Drop in or dedicated	drop-in	drop-in	drop-in	drop-in	drop-in	dedicated	dedicated
Total (fossil & bio-based) production	16546	2520	50	24059	22334	769	6
Bio-based production ktonnes/year	346	424	10	559	7.5	769	6
- Europe	72	28	10	0	0	149	3
- North America	34	196	0	0	7.5	245	0
- Asia	240	200	0	161	0	375	3
- Rest of the world	0	0	0	0	0	0	0
Bio-based share in total production	2.1%	17%	20%	2.3%	0.03%	100%	100%
- Europe	0.4%	1%	20%	0	0	19%	50%
- North America	0.2%	8%	0	0	100%	32%	0%
- Asia	1.5%	8%	0	100%	0	49%	50%
- Rest of the world	0	0	0	0	0	0%	0%
Price bio-based €/kg	0.94	1.34	2.61	1.13	2.04	1.17	4.50
Price fossil-based €/kg	0.56	1.34	2.25	1.05	1.76	1.75	N/A
Cost disadvantage (-) /advantage (+) ratio	-66.70%	0%	- 16%	-7%	-16%	+ 33%	N/A

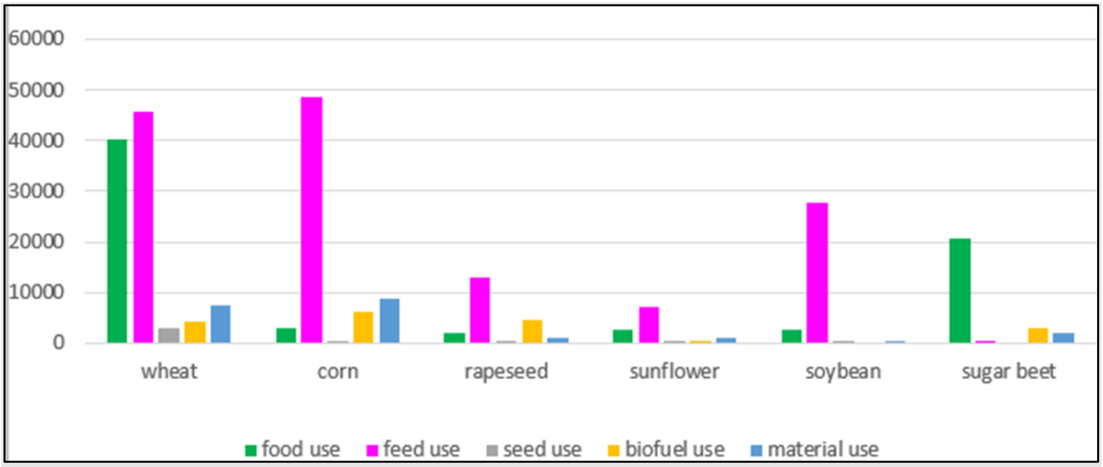
Source: Spekreijse et al., 2021.

15.3 EU feedstock use for selected bio-based industrial products

With regard to the use of marketable agricultural products, i.e. without grazing, the H2020 project BioMonitor provides insights into the EU (and Member State) allocation of arable biomass over uses. The results depicted are based on the combined use of the AGMEMOD (AGriculture MEmber State MODelling) and the newly developed BioMAT (Bio-based MATerials) models. The BioMAT model is a multi-regional partial equilibrium model of innovative bio-based products markets. It applies the same framework as AGMEMOD, accounting for the supply, import, export, use, and price of innovative bio-based materials in EU Member States (Van Leeuwen et al., 2022).

Looking at the overall use of arable biomass from agricultural production for the year 2020 (see Figure 150), corn and soybean are mainly used as feed. Common wheat is used mainly for food and feed, whereas sugar beet is used in particular for food. Regarding the material use (i.e. excluding biofuels) of agricultural products, we observe that a share of 13.2% of corn, 7.4% of wheat, 8.2% of sugar beets and 4.1% of seeds is allocated to material purposes. The values in kton of dry matter are reported in Figure 150.

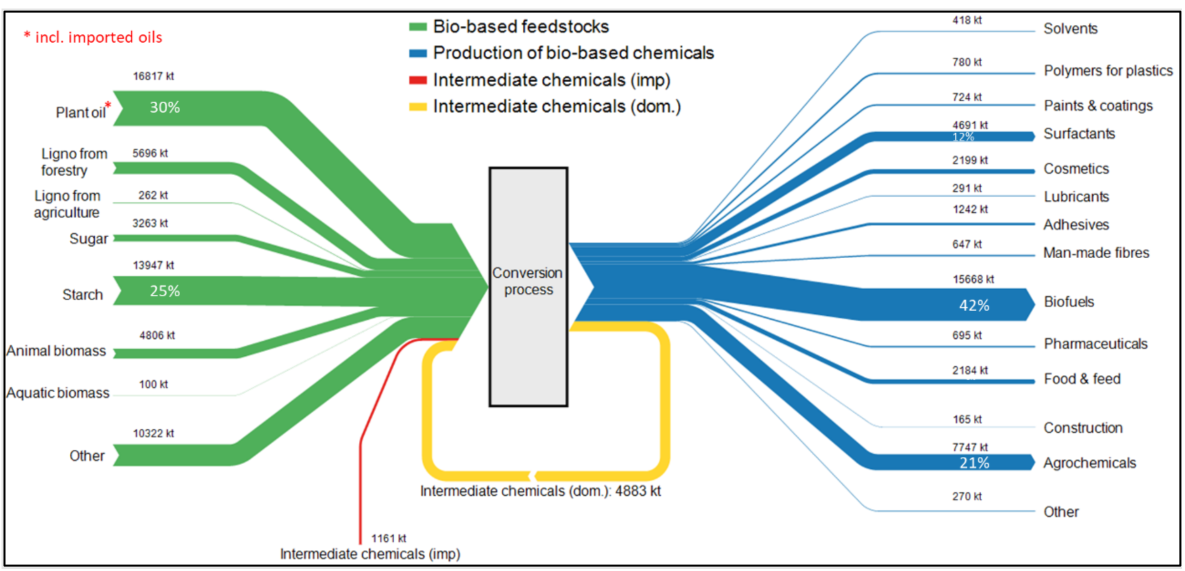
Figure 150. Uses per crop in the EU-27, 2020 in kton dry matter.



Source: AGMEMOD baseline results.

The combination of the agrifood modelling with the detailed depiction of the feedstock used for the production of bio-based industrial products allows to create a detailed flow chart for the first time. Figure 151 shows the different feedstocks used, summing up to around 55 million tonnes, including imports. This feedstock, mainly in the form of plant oil (30%) and starch (20%), enters the conversion process. As shown in Figure 151, the total physical quantity of bio-based chemicals (incl. biofuels) is estimated, according to the C20 NACE classification[104] "Manufacture of chemicals and chemical products", with biofuels accounting for approximately 42% of the total output, followed by agrochemicals (21%) and bio-based surfactants (12%). The developed approach enables also the creation of more detailed flow charts that show, for example, the use of different feedstocks for only one specific application category or the distribution of use of one specific feedstock over different application categories (Sturm et al, 2023).

Figure 151. Flow chart of the feedstocks for the selected bio-based industrial products (C20), EU-27+UK, 2018

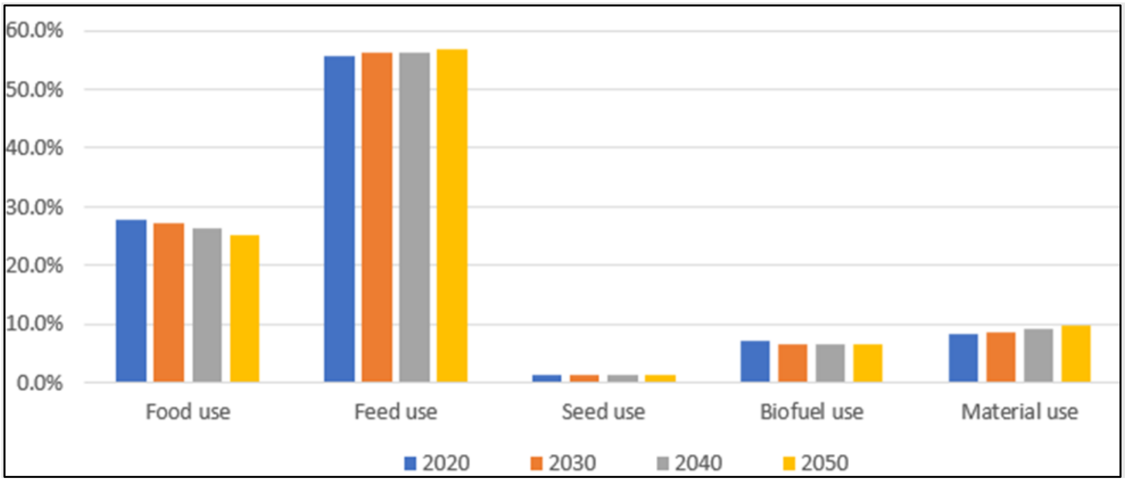


Source: Sturm et a.l, 2023.

[104] NACE is the statistical classification of economic activities NACE Rev. 2 .

In addition, the BioMonitor forward-looking modelling exercise provides projections until 2050 by applying different assumptions, including the scenarios from the Global Energy and Climate Outlook (GECO) published by the EC's Joint Research Centre.[105] With a shrinking population, the share of food use would be slightly reduced (towards one quarter), while still more than half of the arable crops go into animal feed. The share of arable crops for material use is projected to slightly rise from 8.2% in 2020 to 9.7% in 2050 (see Figure 152), that is, under the assumed status quo of policies, not adding pressure on markets and ecosystems.

Figure 152. Uses of arable crop in EU, 2020-2050, % share.



Source: *AGMEMOD baseline projection results.*

The modelling exercise calculates, for the current situation, a net import position for bio-based chemicals of about 8 million tonnes, which could more than double towards the end of the projection period, because of the increased domestic use.

15.4 Conclusions for Chapter 15

The EU is well-positioned in the world market for bio-based chemical products. Since higher cost shares in (bio—based) feedstock have been identified as the main difference between fossil and bio-based chemical products, (particularly in the plastics sector and for the use of vegetable oil), the EU's competitiveness is very much linked to the costs for feedstock.

Further insights into the value chains of EU bio-based products are provided through an analysis of the different feedstock used, namely the arable crops maize, wheat, and sugar beet, if looking at domestic production. When including biofuels in the definition of bio-based chemical products, the analysis shows that biofuels account for about 42% of the total output, followed by agrochemicals (21%) and surfactants (12%). A detailed flow from feedstock to the products is not yet available. Latest research shows that the main (processed) feedstocks (incl. imports) are plant oil (30%) and starch (25%).

Focusing on primary agriculture (arable crops), the share of material use of agricultural products in total use, i.e. mainly non-food/non-biofuels, is estimated to 8.2% in the EU-27, which is much smaller compared to the use for food (27%) and animal feed (56%). While under unchanged policies the share of arable crops for material use in the EU is projected to rise only slightly from 8.2% in 2020 to 9.7% in 2050, it can be expected that the import of feedstock for material use could rise further to allow for the intended growth of the bio-based industry, especially those not produced in the EU, e.g. palm oil. To this end, targeted policies and the deployment of technologies to valorise unused biomass from waste streams, residues and other sustainable sources, would be needed to increase domestic production.

[105] More information available in the BioMonitor Policy Brief [2021-03-11_BIO_PolicyBrief-3_digital.pdf (biomonitor.eu)]

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Annexes to the Chapters

Annex to Chapter 4

Table A4.1. Quantity harvested of wild seaweed in tonnes wet weight worldwide per country. EU-27 countries highlighted in bold.

Country	2020	2021
Chile	409,258	394,860
China	217,390	202,850
Norway	152,810	159,803
Indonesia	64,030	56,357
Japan	63,392	61,900
Peru	50,424	49,491
France	**47,435**	**57,037**
Ireland	**29,500**	**28,000**
India	28,545	33,345
Morocco	22,219	20,426
Iceland	15,725	16,407
Mexico	10,203	7,250
Canada	9,886	12,542
Russian Federation	8,923	7,464
Republic of Korea	7,580	7,435
United States of America	7,059	6,864
South Africa	6,848	6,327
Spain	**2,402**	**2,603**
Australia	1,923	1,923
Italy	**1,200**	**1,200**
Portugal	**1,175**	**1,766**
Madagascar	800	800
United Rep. of Tanzania	600	600
New Zealand	579	666
Philippines	385	377
Taiwan, Province of China	317	323
Estonia	**200**	**181**
Samoa	10	8

Table A4.2. Quantity (tonnes wet weight) and value (thousands EUR) of global seaweed produced by aquaculture in each country. EU-27 countries highlighted in bold. Portugal did not report production nor value in 2020.

Country/Year	2020			2021		
	Production (t.w.w)	Value (*000 EUR)	Price (EUR/ t.w.w)	Production (t.w.w)	Value (*000 EUR)	Price (EUR/ t.w.w)
China	20,800,263	9,915,456	477	21,500,705	10,159,747	473
Indonesia	9,618,420	1,642,287	171	9,091,307	1,834,251	202
Republic of Korea	1,761,635	590,399	335	1,845,682	611,557	331
Philippines	1,468,653	196,779	134	1,343,707	189,413	141
Dem. People's Rep Korea	603,000	83,352	138	603,000	83,352	138
Japan	398,315	1,174,892	2,950	342,100	979,116	2,862
Malaysia	182,061	12,871	71	178,897	12,856	72
U.R. Tanzania	89,671	2,496	28	77,150	1,867	24
Russian Federation	20,832	24,838	1,192	23,863	28,452	1,192
Chile	18,269	199,162	10,902	15,571	181,872	11,680
Viet Nam	13,883	3,577	258	13,154	3,442	262
Madagascar	8,085	1,375	170	11,658	1,960	168
Solomon Islands	5,500	189	34	12,456	584	47
India	5,300	359	68	5,300	360	68
Venezuela (Boliv Rep of)	4,501	1,656	368	4,501	1,656	368
Papua New Guinea	4,300	172	40	4,300	169	39
South Africa	3,715	1,038	279	2,883	897	311
Taiwan Province of China	1,690	246	146	290	39	135
Tanzania, United Rep. of	1,410	34	24	3,954	1,662	420
Brazil	1,050	375	357	1,130	385	341
Cambodia	1,000	184	184	1,000	184	184
Kenya	850	18	22	850	18	21
Timor-Leste	700	64	92	700	64	92
Sri Lanka	422	125	297	218	61	278
Norway	336	841	2,503	246	667	2,704
United States of America	300	201	672	380	253	666

Morocco	190	18	97	84	9	102
Fiji	159	35	221	73	17	230
France	121	962	7,969	130	2,487	19,128
Tonga	105	21	200	100	20	203
Faroe Islands	105	401	3,824	110	438	3,977
Saint Lucia	82	1,681	20,376	204	3,346	16,386
Ireland	42	44	1,051	214	815	3,808
Denmark	22	57	2,602	9	25	2,707
Grenada	22	51	2,300	22	51	2,300
Tunisia	20	2	98	30	2	66
Portugal	17	32	1,910	17	34	1,978
Saint Vincent/Grenadines	13	33	2,556	13	33	2,555
Antigua and Barbuda	10	44	4,430	10	44	4,430
Spain	6	1,890	336,322	5	1,741	348,198
Belize	5	9	1,840	5	9	1,840
Saint Kitts and Nevis	1	1	1,003	1	1	1,003
Ecuador	0	0	368	100	37	368
TOTAL	35,015,081	13,858,272		35,086,128	14,103,993	

Table A4.3. Quantity of seaweed commodities (t w.w.) imported, exported and re-exported worldwide in 2019 and 2020. EU-27 countries highlighted in bold. Source: FAO 2020.

Reporting country (Name)	Export		Import		Re-export	
	2019	2020	2019	2020	2019	2020
Afghanistan	0.88	0.00	0	0		
Albania	10.72	0.33	1.09	1.67		
Algeria			28.31	3.22		
Angola			29.44	0.78		
Antigua and Barbuda	0.11	0.01	4.84	0		
Argentina			827.51	774.19		
Armenia			17.66	9.73		
Aruba	0.11	0.00	20.37	16.81		
Australia	1,058.73	625.55	17,577.91	16,889.13		
Austria	111.06	100.36	1,321.47	1,161.93		
Azerbaijan			22.99	26.85		
Bahamas	0.00	1.47	1	1.55		
Bahrain	7.07	5.15	26.78	15.14		
Bangladesh	3.54	4.96	56.7	45.78		
Barbados	0.36	0.00	5.6	7.05		
Belarus	43.44	111.01	1,183.03	1,585.64		
Belgium	577.50	775.59	1,040.41	1,372.74		
Belize	0.15	0.14	6.02	2		
Benin			1.05	0.66		
Bermuda			14.33	14.5		
Bhutan			0.12	0.02		
Bolivia (Plurinat.State)			6.08	4.5		
Bosnia and Herzegovina			11.43	8.71		
Botswana			0.19	0.13		
Brazil	617.15	8,011.65	2,008.61	1,607.44		
Brunei Darussalam	3.65	19.84	191.65	182.74		
Bulgaria	33.75	52.88	32.15	76.56		
Burkina Faso	0.85	0.78	0.56	0		
Burundi			0	0.12		
Cabo Verde			2.37	1.48		
Cambodia			42.43	29.07		
Cameroon			4.08	3.88		
Canada	6,130.81	7,404.04	2,162.84	2,129.21	21.93	142.84
Cayman Islands	0.00	0.82	0.54	0.02		
Central African Republic			0.03	0		
Chad	0.00	0.00	0.07	0		
Chile	60,951.49	69,814.99	5,684.49	4,278.08		

China	24,111.01	20,263.04	262,594.9	260,933.9		
China, Hong Kong SAR	89.91	58.53	1,089.96	1,064.76		
China, Macao SAR			43.66	46.03		
Colombia			145.1	229.23		
Congo			0.48	0.84		
Congo, Dem. Rep. of the			19.51	9.97		
Cook Islands			0.16	0.51		
Costa Rica	0.25	0.00	91.68	80.72		
Côte d'Ivoire	0.04	0.00				
Croatia	0.53	0.36	125.73	99.27		
Cuba	0.00	0.00	2.96	5.69		
Curaçao			3.21	3.75		
Cyprus	0.01	0.03	281.18	342.61		
Czechia	34.22	28.78	398.27	423.05		
Côte d'Ivoire			0.95	7.38		
Denmark	1,042.10	1,151.32	8,435.46	7,880.2		
Djibouti			0.04	0		
Dominica	2.73	0.00	0.45	0.36		
Dominican Republic	0.00	0.98	15	11.82		
Ecuador	36.69	40.00	62.99	47.6		
Egypt	110.79	0.00	119.43	108.49		
El Salvador			7.36	2.88		
Equatorial Guinea			0.00	0.00		
Eritrea			0.00	0.00		
Estonia	0.39	1.11	52.07	50.81		
Eswatini			0.29	0.3		
Ethiopia	1.00	0.03	1.43	4		
Faroe Islands			0.13	0.09		
Fiji	0.01	0.00	18.46	8.28		
Finland	5.24	6.08	155.63	145.16		
France	8,776.45	9,537.31	50,024.52	71,879.81		
French Polynesia	0.00	0.00	10.7	10.58		
Gabon	0.08	0.00	11.03	1.51		
Gambia			0	0.85		
Georgia	0.50	0.00	8.34	7.25		
Germany	1,665.88	1,389.84	2,922.99	2,973.46		
Ghana	0.03	0.46	2.91	2.67		
Greece	9.92	10.74	208.03	170.94		
Greenland	0.05	0.75	2.58	2.07		
Grenada	0.00	0.14	1.21	1.28	0.07	0
Guatemala	0.14	0.09	5.02	1.47		

Guinea			0.03	40.5		
Guinea-Bissau			0.01	0		
Guyana			0.95	3.79		
Haiti			0.01	0.83		
Honduras	0.81	0.50	11.29	14.32		
Hungary	4.45	2.20	268.04	223.94		
Iceland	3,773.10	4,048.66	28.64	32.54		
India	271.83	176.23	548.19	765.45		
Indonesia	196,315	182,339	482.09	420.05		
Iran (Islamic Rep. of)	3.38	61.67	247.26	148.11		
Iraq			13.17	11.87		
Ireland	69,758.21	77,942.28	6,9467.41	64,793.01		
Israel	3321.00	2200.87	63	93.43		
Italy	1,272.80	1,632.06	2,566.66	3,568.62		
Jamaica	0.04	9.38	48.81	31.31	0.11	0.34
Japan	1,434.89	1,303.87	49,913.21	46,409.57		
Jordan			8.05	14.15		
Kazakhstan	39.97	14.53	282.32	393.69		
Kenya	100.04	19.70	13.54	8.67		
Kiribati			0	0.02		
Korea, Dem. People's Rep	0.08	0.00	10.21	0.01		
Korea, Republic of	31,567.46	29,540.17	17,543.37	18,497.13		
Kuwait			30.17	48.14	0.12	0.01
Kyrgyzstan			28.34	2.3		
Lao People's Dem. Rep.	0.36	0.01	2.45	23.91		
Latvia	102.86	84.90	122.62	124.59		
Lebanon	0.50	0.03	21.45	1.96		
Lesotho			1.45	1.27		
Liberia	0.20	0.00	0.03	0.02		
Libya	0.02	0.00	1.02	1.2		
Lithuania	85.26	224.31	112.64	683.21		
Luxembourg	5.47	17.92	34.67	36.08		
Madagascar	2,122.84	2,257.29	3.51	2.21		
Malawi			1.72	1.39		
Malaysia	1,524.90	1,602.72	1,374.89	1,374.27		
Maldives			132.71	105.66		
Mali			2.8	1.3		
Malta	31.41	0.00	39.47	5.48		
Marshall Islands			0.33	0.42		
Mauritius	9.50	0.62	45.02	39.65		
Mexico	809.97	694.49	983.79	822.45		

Micronesia (Fed. States)			0.03	0		
Moldova, Republic of			9.91	36.21	2.51	2.1
Mongolia			152.79	172.85		
Montenegro			4.19	0.61		
Montserrat			0.00	0.04		
Morocco	3,399.50	2,528.05	90.26	84.13		
Mozambique			1.61	6.26		
Myanmar			873.95	2,414.41		
Namibia	0.84	0.00	0.32	0.18		
Nepal			1.55	1.77		
Netherlands	686.08	566.26	1,876.92	2,414.84		
New Caledonia	0.00	0.00	0.44	0.56		
New Zealand	20.17	13.23	560.97	535.81	0.77	18.37
Nicaragua	0.01	0.00	7.33	7.18		
Niger	0.00	12.50	0.01	1.35		
Nigeria	0.00	101.30	137.21	22.39		
North Macedonia	0.27	0.01	16.31	17.93		
Norway	3,759.20	3,549.52	4,774.91	4,649.76		
Oman	0.00	2.76	29.83	51.91	0.02	0.01
Pakistan	7.43	0.00	81.21	76.86		
Palau			10.07	1.44		
Palestine			1	1.5		
Panama	0.00	12.50	110.78	123.19		
Papua New Guinea			0	1.09		
Paraguay			45.75	35.38		
Peru	35,284.86	29,641.57	11.87	31.55		
Philippines	19,730.71	16,209.23	2,553.79	3,065.81		
Poland	186.01	150.71	1,881.49	1,806.16		
Portugal	1,146.80	655.34	725.5	814.36		
Romania	0.34	0.21	144.88	138.05		
Russian Federation	468.00	560.00	188.23	97.53		
Rwanda			0.51	0.23		
Saint Kitts and Nevis			0.11	0		
Saint Lucia	7.85	43.32	5.58	0.42		
Saint Vincent/Grenadines	2.86	9.23	0.26	0.01		
Samoa			2.34	0.14		
Sao Tome and Principe			0.01	0.12		
Saudi Arabia			10,026.51	11,135.6	0	16.61
Senegal	17.30	0.00	1.69	0.61		
Serbia	18.04	4.60	183.11	170.51		
Seychelles			12.32	7.33		

Sierra Leone			0	0.01		
Singapore	162.59	198.54	1,168.53	1,046.64		
Slovakia	43.68	139.20	128.3	146.09		
Slovenia	10.60	3.40	24.26	29.35		
Solomon Islands	187.00	130.86	0.19	0.01		
South Africa	1,059.13	2,365.25	3,815.19	4,228.06		
Spain	3,753.23	3,818.34	14,490.37	11,695.42		
Sri Lanka	57.83	124.24	73.71	36.14		
Sudan			0.06	0.08		
Sweden	146.32	36.80	413.8	425.88		
Switzerland	13.73	18.96	98.36	124.76		
Syrian Arab Republic	0.00	0.42	2	1		
Taiwan Province of China	942.59	544.68	16,514.29	15,588.76		
Tajikistan			2.1	0.73		
Tanzania United Rep. Of	10,848.00	11,503.15	0.75	0.23		
Thailand	351.95	345.79	5,003.38	5,088.96		
Timor-Leste	95.10	56.60	15.96	3.88		
Togo			0.51	0		
Tonga	88.17	107.09	0	0.18		
Trinidad and Tobago	47.97	63.34	82.38	105.59	3.96	10.87
Tunisia	70.38	18.28	329.34	171.16		
Turkmenistan			4.3	3.52		
Turks and Caicos Is.			0	0.16		
Tuvalu			0	0		
Türkiye	2.33	4.21	1,790.68	1,603.43		
Uganda	0.00	0.40	6.4	12.79		
Ukraine	39.91	42.82	744.5	920.63		
United Arab Emirates	46.19	36.33	327.59	248.69	2.76	26.82
United Kingdom	3,321.58	3,235.21	8,168.52	3,156.48		
United States of America	1,628.75	1,818.66	29,051.01	26,338.28	279.82	217.43
Uruguay	10.01	5.05	154.04	119.79		
Uzbekistan			52.68	54.28		
Vanuatu			0.22	0.2		
Venezuela (Boliv Rep of)	262.75	375.28	20.19	7.55		
Viet Nam	3,307.58	3,595.27	1,094.52	1,264.39		
Yemen			1.87	0.3		
Zambia			2.86	0.78		
Zimbabwe			0.02	0.36		
Zanzibar						

Table A4.4. Quantity of seaweed commodities (t w.w.) in China. Source: Shaojun Pang pers. Comm

	Province	2015					2016					2017				
		Kombu kelp (*S. japonica*)	Wakame (*U. pinnatifida*)	Nori *(Porphyra* spp)	*Gracilari a* spp.	TOTAL	Kombu kelp (*S. japonica*)	Wakame (*U. pinnatifida*)	Nori *(Porphyra* spp)	*Gracilaria* spp.	TOTAL	Kombu kelp (*S. japonica*)	Wakame (*U. pinnatifida*)	Nori *(Porphyra* spp)	*Gracilari a* spp.	TOTAL
Production (tonnes)	Lianoning	196,094	152,171			348,265	218,704	106,855			325,559	213,959	116,277			330,236
	Jiangsu	330	6	27,575		27,911	300	4	28,405		28,709	300	4	41,860		42,164
	Zhejiang	11,587		26,373	700	38,660	10,363		32,178	635	43,176	16,964		42,632	40	59,636
	Fujian	642,494	658	52,908	154,737	850,797	693,533	723	66,440	173,233	933,929	720,017		63,509	195,626	979,152
	Shandong	556,264	38,940	690	48,940	644,834	533,439	43,961	972	51,996	630,368	531,330	49,514	14,931	48,394	644,169
	Guangdong	4,520	727	8,329	54,904	68,480	4,719	1,029	7,257	55,501	68,506	4,075	1,000	10,373	53,257	68,705
	Hainan				10,868	10,868				11,814	11,814				11,357	11,357
	Total National	1,411,289	192,502	115,875	270,149	1,989,81	1,461,058	152,572	135,252	293,179	2,042,061	1,486,645	166,795	173,305	308,674	2,135,419
Area (ha)	Lianoning	6,571	5,653			12,224	6,634	5,889			12,523	5,814	5,102			10,916
	Jiangsu	600	3	39,618		40,221	550		41,066		41,616	520		47,255		47,775
	Zhejiang	910		9,966		10,876	836		13,694	40	14,570	865		13,709	4	14,578
	Fujian	18,429	12	15,216	6,543	40,200	19,789	12	17,008	6,675	43,484	18,529		15,178	5,765	39,472
	Shandong	17,014	1,230	170	1,116	19,530	16,494	1,363	460	1,117	19,434	18,397	1,313	2,978	1,299	23,987
	Guangdong	95	10	796	1,792	2,693	95	10	749	1,675	2,529	111	16	487	1,334	1,948
	Hainan				439	439				411	411				408	408
	Total National	43,619	6,908	65,766	9,890	126,183	44,398	7,274	72,977	9,918	134,567	44,236	6,431	79,607	8,810	139,084

Table A4. 5. Quantity of seaweed aquaculture production (t w.w.) in China. Source: FAO, 2023

Year	Kombu kelp (*Saccharina japonica*)	Wakame (*Undaria pinnatifida*)	Nori *(Porphyra* spp)	*Gracilaria* spp.	Other seaweed	TOTAL
2015	9,332,389	1,843,870	1,109,903	2,587,608	664,151	15,537,921
2016	9,687,668	1,519,530	1,312,850	2,865,830	1,041,520	16,427,398
2017	10,049,720	1,667,950	1,733,050	3,086,740	924,190	17,461,650

Annex to Chapter 6

Table A6.1: Harmonised reference statistics at national scale in the year 2020 for EU countries on forest area, Forest Available for Wood Supply (FAWS), Forest Not Available for wood supply (FNAWS), Biomass stock, Biomass Available for Wood Supply (BAWS), Biomass Not Available for Wood Supply (BNAWS) and biomass density (tonnes/ha). The harmonised statistics refer to the forest area reported by the NFIs in their reporting year (updated to 2020 by the JRC) using the most appropriate forest definition for these variables. Because, in some cases, this definition does not match the forest definition used in the SoEF, the forest area reported here does not always correspond to the forest area time series reported in the SoEF and used in the Table A7.2 to report the forest increment. See section 7.5.1.4 for further details.

Country	Forest area (ha)	FAWS (ha)	FNAWS (ha)	Biomass stock (tonnes)	BAWS (tonnes)	BNAWS (tonnes)	Biomass density (t/ha)
AT	3,899,000	3,483,834	415,166	803,146,364	750,911,640	52,234,724	206.0
BE	688,810	664,350	24,460	111,833,488	103,902,914	7,930,574	162.4
BG	3,893,000	3,190,814	702,186	426,841,586	324,977,405	101,864,180	109.6
CY	172,700	41,120	131,580	6,170,213	1,975,356	4,194,857	35.7
CZ	2,785,430	2,620,011	165,419	666,717,960	632,570,831	34,147,130	239.4
DE	10,563,496	9,908,373	655,124	1,958,959,764	1,844,244,278	114,715,486	185.4
DK	628,440	613,880	14,560	71,404,506	69,456,475	1,948,032	113.6
EE	2,438,400	2,106,040	332,360	282,531,915	241,565,788	40,966,127	115.9
ES	18,572,170	17,698,001	874,169	1,119,428,668	1,062,428,185	57,000,483	60.3
FI	22,409,000	19,719,020	2,689,980	1,585,981,279	1,553,542,355	32,438,923	70.8
FR	17,253,000	16,493,000	760,000	2,629,993,611	2,514,141,360	115,852,251	152.4
GR	3,903,000	3,594,660	308,340	211,527,038	194,376,197	17,150,841	54.2
HR	1,939,110	1,742,500	196,610	330,511,111	311,301,826	19,209,285	170.4
HU	2,147,296	1,972,064	175,232	330,966,336	318,480,839	12,485,497	154.1
IE	653,825	539,475	114,350	87,764,656	73,226,348	14,538,308	134.2
IT	9,566,130	8,454,330	1,111,800	1,093,861,357	1,023,281,956	70,579,401	114.3

LT	2,201,000	1,800,380	400,620	298,571,011	233,996,992	64,574,019	135.7
LU	88,700	86,100	2,600	16,021,277			180.6
LV	3,410,790	3,011,042	399,748	442,157,687	368,202,202	73,955,486	129.6
MT	350	350	-	-	-	-	0.0
NL	369,500	309,986	59,514	78,821,198	61,097,825	17,723,373	213.3
PL	9,300,393	8,803,804	496,589	1,661,221,193	1,558,259,986	102,961,207	178.6
PT	2,711,815	1,375,395	1,336,419	138,899,421	61,578,417	77,321,004	51.2
RO	6,929,050	6,009,193	919,857	1,222,796,287	1,057,886,203	164,910,084	176.5
SE	27,213,654	22,336,151	4,877,503	2,059,843,036	1,825,692,916	234,150,120	75.7
SI	1,207,646	1,090,059	117,586	286,735,844	265,368,717	21,367,127	237.4
SK	2,187,362	1,989,695	197,668	475,643,218	442,145,722	33,497,496	217.5
EU 27	157,133,067	139,653,628	17,479,439	18,398,350,025	16,894,612,733	1,487,716,016	117.1

The difference between the NFI and SoEF forest area were assessed for each country by a detailed analysis of the NFI and SoEF Country reports, and are described below. Here, the "NFI data" refer to the harmonised data at sub-national scale produced by the NFI for the JRC using a common biomass and FAWS definition, and may differ from the NFI data based on national definition (also regarding forest definition, see below). Also, the comparison between the SoEF and the NFI area is performed for the forest area reported in the NFI year, and not for the SoEF and NFI forest area updated to 2020.

Czech Republic: the NFI data refer to the year 2003 and report a forest area of 2.752 Mha while the forest area in SoEF in 2005 is 4% lower (2.647 Mha). This difference is due to the use of a different forest definition, because the NFI forest area includes the areas classified as Other Wooded Land (*Pinus mugo* stands) and Other Land with Tree Cover, which were excluded in the SoEF Report.

Germany: the NFI data refer to the second NFI (2002) for biomass stock and the third NFI (2012) for FAWS. The NFI forest area is 10.887 Mha in 2012, 4.6% lower than the SoEF value in 2010 (11.409 Mha). The difference is due to the use of a different forest definition: the NFI excludes unstocked forest areas (2.87%) and inaccessible areas (1.78%), while these areas are included in the SoEF report.

Hungary: the NFI data refer to the period 2010 – 2014 and report a forest area of 2.142 Mha, 4.7% higher than the forest area reported in SoEF for 2010 (2.046 Mha). Both the NFI and the SoEF data refer to the FAO forest definition, but the comparison of the definitions showed that the NFI uses as minimum tree cover 10% while the SoEF uses 30%, thus excluding the NFI forest areas with a tree cover in the range 10 – 30%.

Ireland: the NFI data refer to the year 2006 and report a forest area of 567,763 ha, 18% lower than the forest area reported in SoEF for 2005 (689,810 ha). The difference is due to the fact that the NFI data were estimated only for the stocked forest areas and excluded the unstocked forest areas, while the SoEF forest area includes the unstocked forests.

Poland: the NFI data refer to the period 2010 – 2014 and report a forest area of 9.177 Mha, 2.6% lower than the forest area reported in SoEF for 2015 (9.420 Mha). The NFI report indicates that the forest definition used in SoEF is different than the national Polish definition, and such difference is responsible for the area difference between the two data sources. However, there is no further explanation about the difference between the two forest definitions.

Portugal: the NFI data refer to the year 2005 and report a forest area of 2.703 Mha, 18% lower than the forest area reported in SoEF for 2005 (3.303 Mha). The NFI area refer to the FAO forest definition, and it specifies that, due to the difficulty to assess trees able to reach 5m high in situ, a list of species considered "trees" was established to assess if a vegetated area was considered forest or not. The SoEF country report does not provide a description of the forest definition but the information provided by the NFI suggests that the SoEF forest area also includes areas with tree cover between 5% and 10%, trees in agro-silvo pastoral areas, and burned areas.

Sweden: the NFI data refer to the period 2009 – 2013 and report a forest area of 27.297 Mha, 3% lower than the forest area reported in SoEF for 2010 (28.073 Mha). The difference is due to the fact that, while both the NFI and SoEF use the FAO forest definition, the NFI data excludes the forest areas in the alpine zone, which covers an area of approx. 0.7 Mha.

Slovenia: the NFI data refer to the year 2012 and report a forest area of 1.215 Mha, 2.8% lower than the forest area reported in SoEF for 2010 (1.247 Mha). The difference is likely due to the fact that SoEF and the NFI use a different forest definition and estimation method. The SoEF forest area is based on data from Forest stand map (Slovenia Forest service) and Land use map (Ministry of Agriculture, Forestry and Food). The NFI instead estimates the forest area by classifying the NFI plots according to the national forest definition that, differently from the FAO definition, also includes land covered with forest trees spanning at least 0.25 hectares (instead of 0.5 ha, in the FAO definition).

Slovakia: the NFI data refer to the year 2006 and report a forest area of 2.174 Mha, 14% higher than the forest area reported in SoEF for 2005 (1.912 Mha). The difference is due to the fact that the SoEF forest area is based on Forest Management Plans that includes only the forest area recorded in cadastre as forest land. The NFI, instead, includes all forests in Slovakia, both recorded and not recorded in cadastre, that meet the criteria for forest definition (minimum area of 0.5 ha, minimum width of 20 m, and minimum canopy cover of 20%).

Table A6.2: Impact of the temporal harmonisation of the biomass statistics. The biomass stock provided by the NFI (Biomass NFI) is attributed to the NFI Reference year (usually, the average year of the NFI duration) and is updated to the year 2020 (Biomass 2020) using the Carbon Budget Model. The Biomass change per year (in %) is computed as the difference between the Biomass NFI and the Biomass 2020, divided the Biomass NFI.

Country	NFI Reference year	NFI duration	Biomass NFI (tonnes)	Biomass 2020 (tonnes)	Biomass change/year
AT	2008	2007-2009	730,656,226	803,146,364	0.8%
BE	2010	2008-2015	111,175,429	111,833,488	0.1%
BG	2007	2001-2014	402,097,123	426,841,586	0.5%
CZ	2003	2001-2004	581,621,450	666,717,960	0.9%
DE	2002	2001-2003	1,854,966,885	1,958,959,764	0.3%
ES	2002	1997-2007	936,268,803	1,119,428,668	1.1%
FI	2006	2004-2008	1,309,007,910	1,585,981,279	2.1%
FR	2010	2008-2012	2,290,179,522	2,629,993,611	1.5%
HU	2012	2010-2014	314,376,439	330,966,336	0.7%
IE	2006	2006	63,638,738	87,764,656	2.7%
IT	2005	2003-2006	898,586,382	1,093,861,357	1.4%
LT	2010	2008-2012	279,697,680	298,571,011	0.7%
LV	2011	2009-2013	415,625,952	442,157,687	0.7%
NL	2013	2012-2013	74,219,701	78,821,198	0.9%
PL	2012	2010-2014	1,589,527,991	1,661,221,193	0.6%
PT	2005	2005-2006	113,905,203	138,899,421	1.5%
RO	2011	2008-2013	1,168,208,524	1,222,796,287	0.5%
SE	2011	2009-2013	1,990,138,619	2,059,843,036	0.4%
SI	2012	n.a.	275,760,000	286,735,844	0.5%
SK	2006	2005-2006	437,313,636	475,643,218	0.6%
Total			15,836,972,213	17,480,183,965	

Table A6.3: Harmonised reference statistic at national scale for EU countries on forest area, Gross Annual Increment (GAI), Annual Natural Losses (ANL) and Net Annual Increment (NAI) for total forest area and for Forest Available for Wood Supply (FAWS) area in 2015. The forest area and the FAWS area match the values reported in the SoEF for the year 2015.

Country	**FOREST**							**FAWS**						
	Area	GAI	ANL	NAI	GAI	ANL	NAI	Area	GAI	ANL	NAI	GAI	ANL	NAI
	(1000 ha)	(1000 m³/yr over bark)			(1000 m³/ha/yr o. b.)			(1000 ha)	(1000 m³/yr over bark)			(1000 m³/ha/yr o. b.)		
AT	3,881	36,175	4,046	32,130	9.32	1.04	8.28	3,319	30,937	3,460	27,477	9.32	1.04	8.28
BE	689	5,823	312	5,510	8.45	0.45	7.99	666	5,592	302	5,291	8.40	0.45	7.94
BG	3,833	17,677	3,703	13,974	4.61	0.97	3.65	2,514	11,594	2,429	9,165	4.61	0.97	3.65
CY	173	217	20	197	1.25	0.11	1.14	41	52	5	47	1.25	0.11	1.14
CZ	2,668	25,427	4,317	21,110	9.53	1.62	7.91	2,298	22,738	3,860	18,878	9.89	1.68	8.21
DE	11,419	130,360	11,196	119,164	11.42	0.98	10.44	10,124	113,498	9,748	103,750	11.21	0.96	10.25
DK	625	7,267	597	6,670	11.63	0.96	10.68	617	7,196	589	6,608	11.66	0.95	10.71
EE	2,421	15,818	2,200	13,618	6.53	0.91	5.62	2,110	14,126	1,800	12,326	6.69	0.85	5.84
ES	18,551	46,031	19,596	26,435	2.48	1.06	1.42	17,082	42,385	18,044	24,341	2.48	1.06	1.42
FI	22,409	97,320	5,765	91,556	4.34	0.26	4.09	19,719	92,435	5,475	86,959	4.69	0.28	4.41
FR	16,836	102,325	12,577	89,747	6.08	0.75	5.33	16,015	97,335	11,964	85,371	6.08	0.75	5.33
GR	3,903	18,468	7,025	11,442	4.73	1.80	2.93	3,595	17,009	6,470	10,538	4.73	1.80	2.93
HR	1,922	10,210	1,292	8,918	5.31	0.67	4.64	1,740	9,651	788	8,863	5.55	0.45	5.09
HU	2,061	13,029	1,551	11,478	6.32	0.75	5.57	1,910	12,338	1,469	10,869	6.46	0.77	5.69
IE	755	8,140	446	7,694	10.79	0.59	10.20	586	7,627	335	7,291	13.01	0.57	12.44
IT	9,297	34,918	5,018	29,900	3.76	0.54	3.22	8,216	30,860	4,435	26,425	3.76	0.54	3.22
LT	2,187	19,330	3,740	15,590	8.84	1.71	7.13	1,924	16,800	3,220	13,580	8.73	1.67	7.06

LU	89	827	44	783	9.33	0.50	8.83	86	803	43	760	9.33	0.50	8.83
LV	3,391	25,750	6,070	19,680	7.59	1.79	5.80	3,177	24,125	5,687	18,438	7.59	1.79	5.80
MT	0	0	0	0	0.00	0.00	0.00	0	0	0	0	0.00	0.00	0.00
NL	365	2,820	157	2,663	7.73	0.43	7.30	295	2,283	127	2,156	7.73	0.43	7.30
PL	9,420	86,801	8,993	77,808	9.21	0.95	8.26	8,268	76,186	7,893	68,293	9.21	0.95	8.26
PT	3,312	22,553	4,968	17,585	6.81	1.50	5.31	2,199	14,977	3,299	11,678	6.81	1.50	5.31
RO	6,901	36,317	7,608	28,709	5.26	1.10	4.16	4,627	28,762	6,026	22,737	6.22	1.30	4.91
SE	27,980	111,460	16,744	94,716	3.98	0.60	3.39	19,664	91,919	13,809	78,110	4.67	0.70	3.97
SI	1,248	11,182	1,797	9,385	8.96	1.44	7.52	1,139	10,205	1,640	8,565	8.96	1.44	7.52
SK	1,922	16,058	2,696	13,362	8.36	1.40	6.95	1,795	14,967	2,286	12,681	8.34	1.27	7.07
EU-27	158,258	902,324	131,021	770,081	5.70	0.83	4.87	133,728	796,418	113,386	682,609	5.96	0.85	5.10

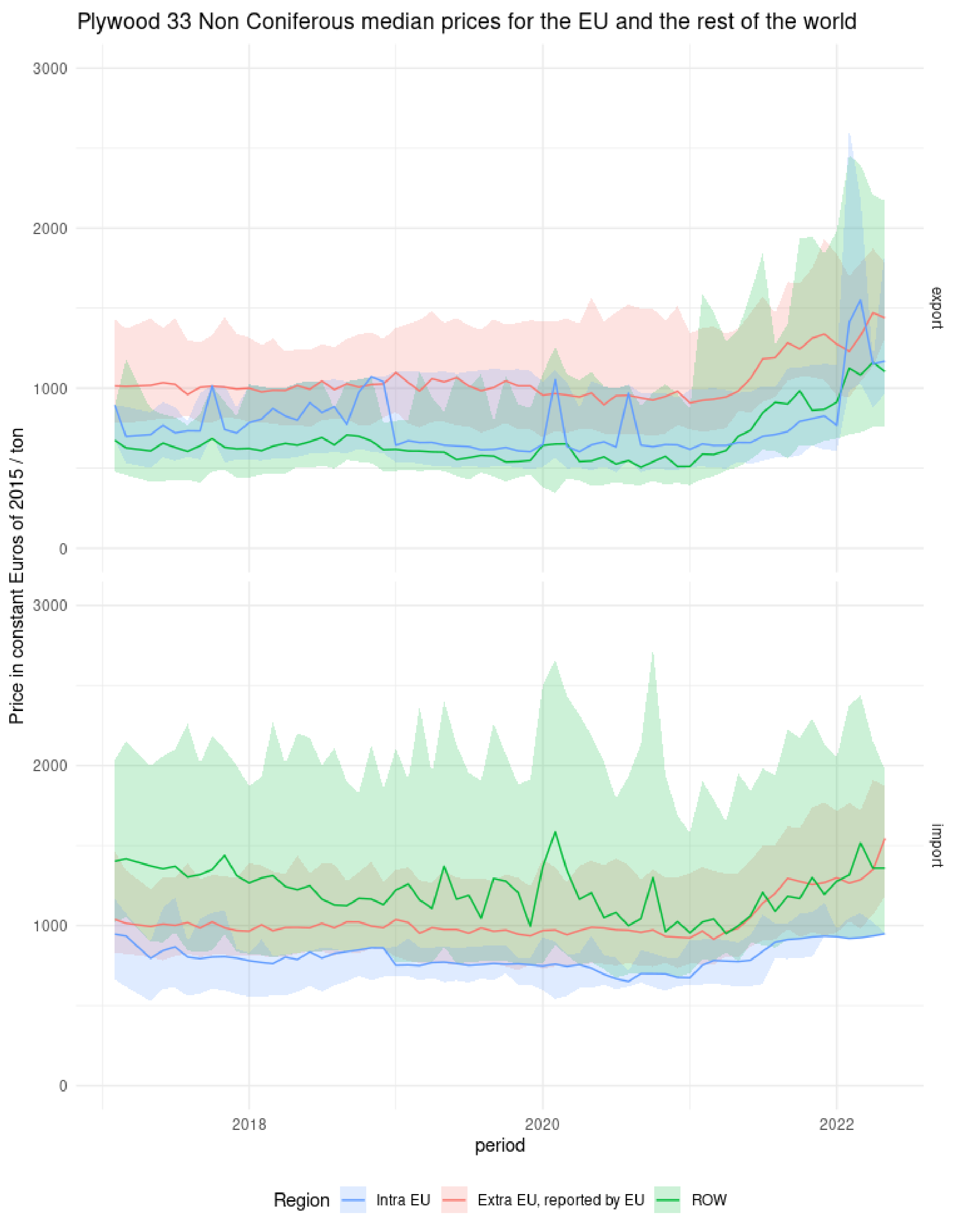
Annexes to Chapter 8

Annex 8.1 Methods

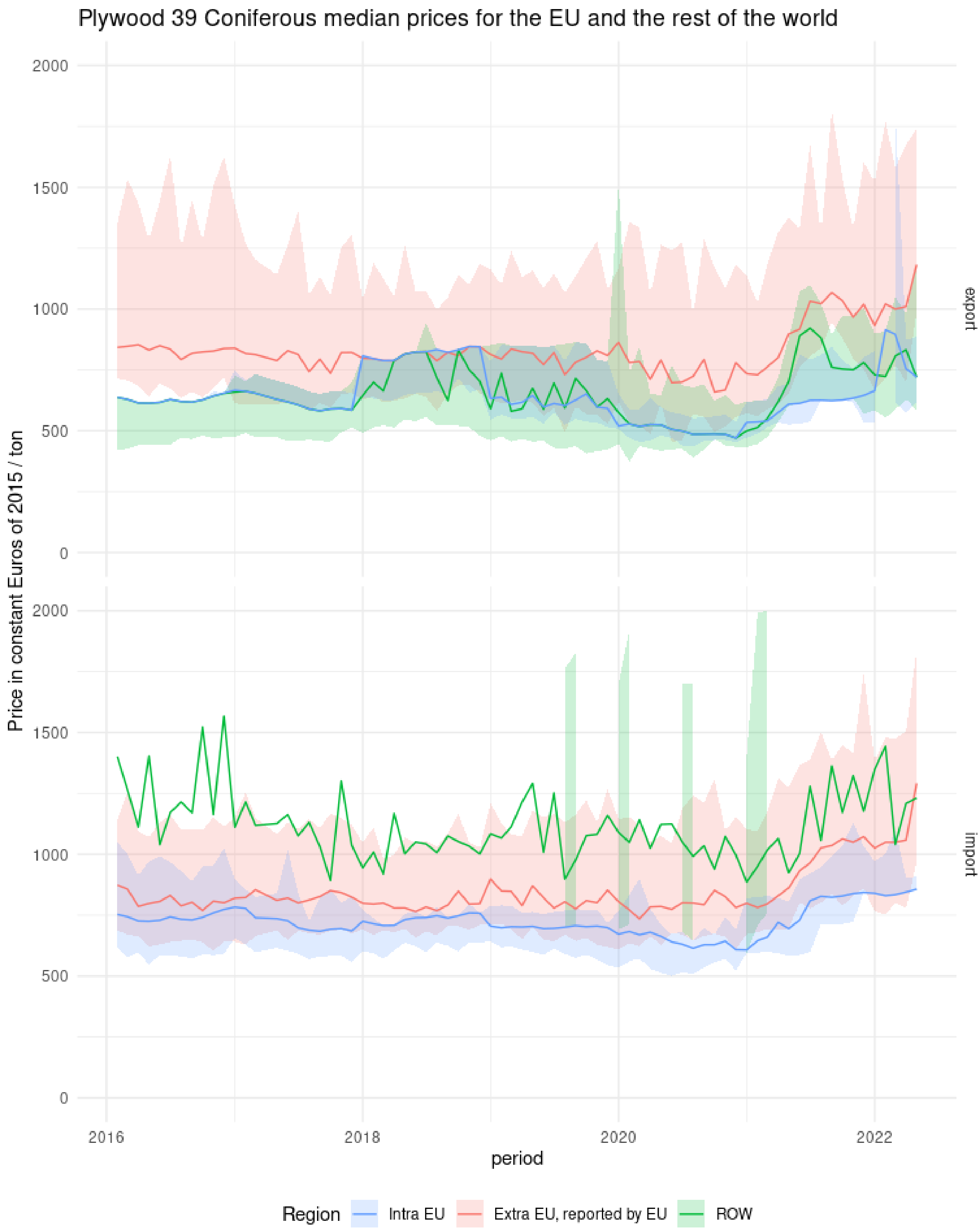
Trade unit values are based on Comtrade monthly data from 2016 to today. Country report trade data every month, with at least a three-month delay. The delay varies greatly among reporting countries. In general data availability increases with time. A comparison of the year of reference and the year of upload time on the UN Comtrade data availability dashboard (Comtrade 2022) illustrates how country update data retroactively up to several years after the physical trade flows have taken place. Data tend to stabilise after a couple of years. For this reason, it is difficult to interpret a recent decrease in trade: is it a real change in the physical trade flows, or a lack of reported data? In the absence of recent trade data, external market experts can provide insights or estimate of trade flows, based on observation of shipping boats for example, or on industry knowledge.

We converted trade unit values from US dollars to euros using a monthly exchange rate (Eurostat 2022a). To compensate for inflation, we converted to real constant prices using a monthly harmonised index of consumer prices (Eurostat 2022b).

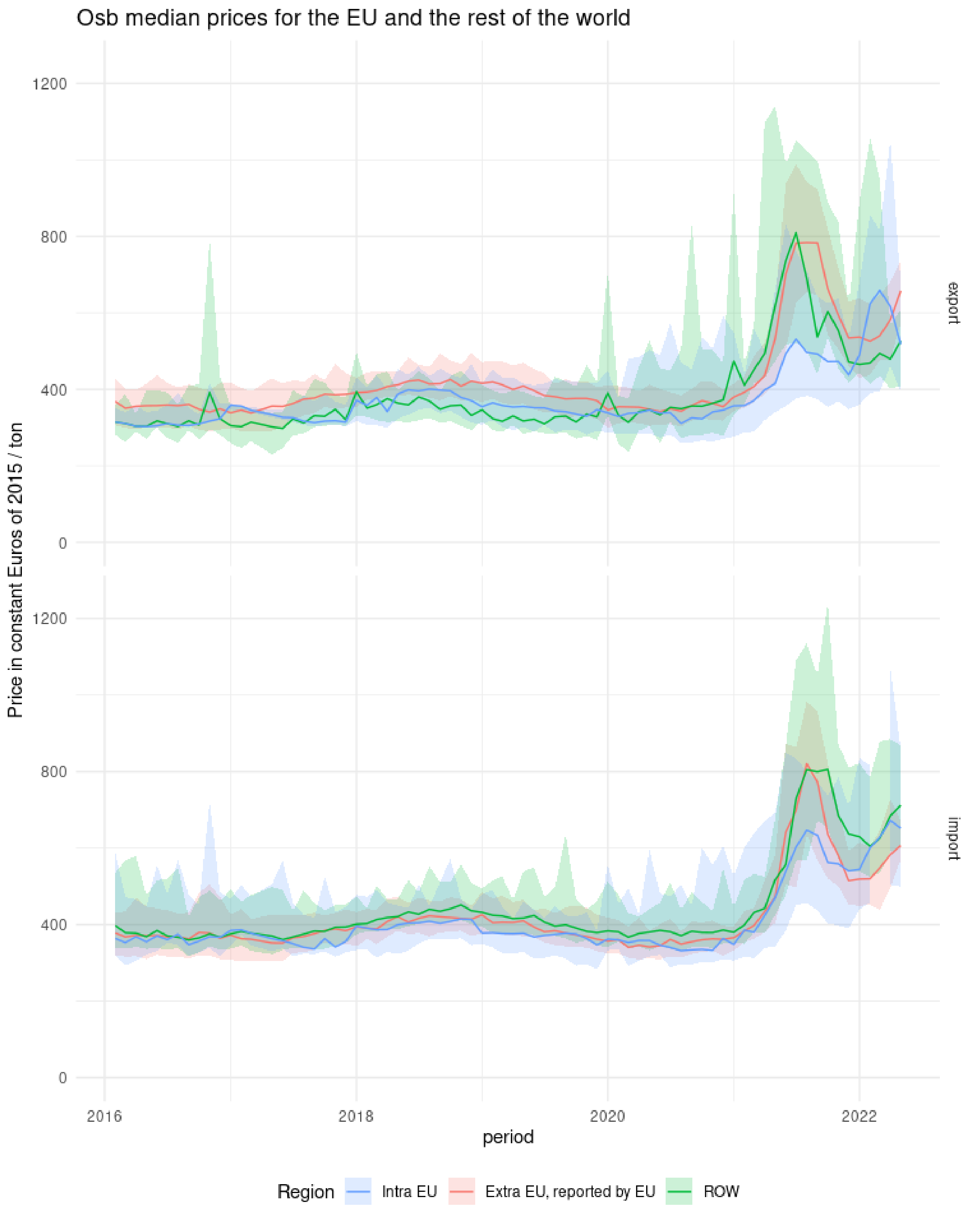
Annex 8.2 Intra and extra EU plywood non coniferous prices



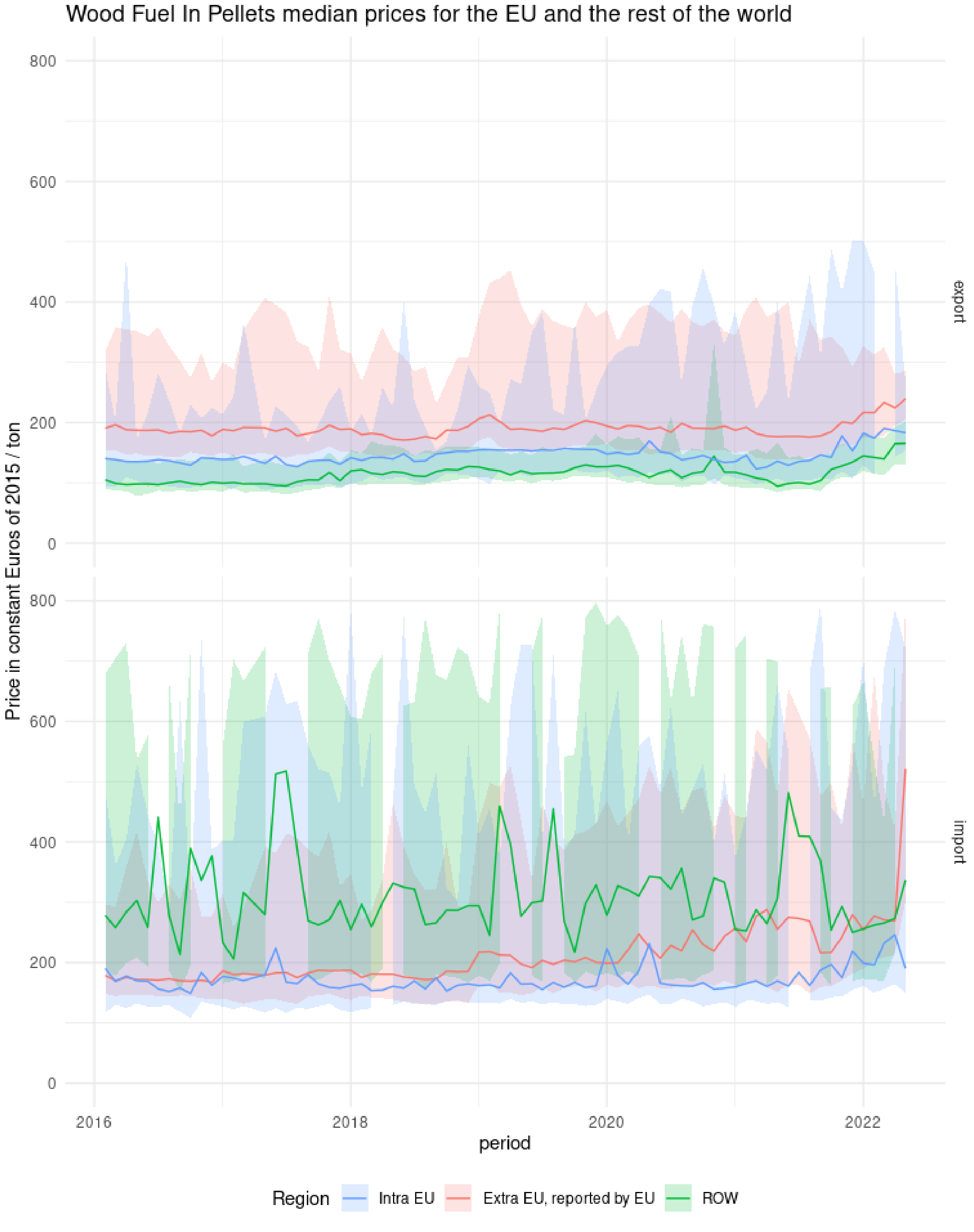
Annex 8.3 Intra and extra EU plywood coniferous prices



Annex 8.4. Intra and extra EU Oriented Strand Board (OSB) prices



Annex 8.5. Intra and extra EU pellets price



Annex to Chapter 9

Biowaste estimations from waste statistics

1. Details to compute the biowaste components of waste in dry matter

The first step is to calculate of biowaste from waste statistics and the second step is to determine the amounts in dry matter.

Step 1. Calculation of amounts of biowaste

The data on waste generation was collected from Eurostat as reported in "Generation of waste by waste category, hazardousness and NACE Rev. 2 activity (env_wasgen)" (Eurostat 2014). The data reported included European totals including all MS, and data from each MS. Statistics on waste generation are provided through a matrix which consists of different waste categories and the activities/source of the waste generation. Relevant data on waste categories that contain biodegradable matter and the source of waste generation (NACE activities) were chosen and are reported in the following sections. The calculations were done for agricultural and industrial biowaste and household biowaste, as explained below.

Agricultural and industrial biowaste

The calculation of agricultural and industrial biowaste considers;

- the amount of each type of waste W072, W073, W075, W076, W091, W092, W093 generated by the NACE activities A, B, C, D, E36_E37_E39, E38, F, G-U_X_G4677, G4677
- the amount of waste W091 by the NACE activities A, C10-C12, and G-U_X_G4677
- the share of each biowaste type in waste code W101 (household and similar waste) generated by the same NACE activities.

For rubber (W073) and textiles (W076) waste, coefficients were used to determine the biodegradable composition as these waste categories consist of a blend of synthetic and natural material.

Coefficients expressing the share of biowaste in W101 reported by each NACE activity were obtained from specific waste composition analysis of municipal solid waste (i.e. "household and similar waste" reported by EP_HH). Since no waste composition analysis studies of "household and similar waste" reported under the other NACE activities were found, we assumed it to be the same as for EP_HH.

The agricultural and industrial biowaste was calculated using the following equations:

Paper and cardboard wastes = $\sum_{Nace\_i} W072_{Nace\_i} + Coef_p \sum_{Nace\_i} W101_{Nace\_i}$

Rubber wastes = $Coef_{bior} \sum_{Nace_i} W073_{Nace_i} + \frac{Coef_{r,t,l}}{3} \sum_{Nace_i} W101_{Nace_i}$

Wood wastes = $\sum_{Nace\_i} W075_{Nace\_i} + Coef_w \sum_{Nace\_i} W101_{Nace\_i}$

Textiles wastes = $Coef_{biot} \sum_{Nace\_i} W076_{Nace\_i} + \frac{Coef_{r,t,l}}{3} \sum_{Nace\_i} W101_{Nace\_i}$

Vegetal wastes = $\sum_{Nace\_i} W092_{Nace\_i} + Coef_{vw} \sum_{Nace\_i} W101_{Nace\_i}$

Animal Faeces, urine, and manure = $\sum_{Nace\_i} W093_{Nace\_i}$

for NACE_i = A, B, C, D, E36_E37_E39, E38, F, G-U_X_G4677, G4677

And lastly,

Animal and mixed food waste = $\sum_{Nace\_i} W091_{Nace\_i} + Coef_{fw} \sum_{Nace\_i} W101_{Nace\_i}$

for NACE_i = A, C10-C12, and G-U_X_G4677 as these were the NACE activities that could potentially generate food waste according to EUROSTAT (2017).

Where:

$W072_{Nace\_i}$	Amount of waste reported under code W072 (paper and cardboard) by NACE activity i
$W101_{Nace\_i}$	Amount of waste reported under code W101 (Household and similar wastes) by NACE activity i

$Coef_p$	Coefficient that expresses the share of paper waste in waste code W101, equal to 0.1505, obtained from Edjabou et al (2015)
$Coef_{bior}$	Coefficient that expresses the share of natural rubber in rubber waste, equal to 0. 40
$W073_{Nace_i}$	Amount of waste reported under code W073 (rubber wastes) by NACE activity i
$Coef\ _{r,t,l}$	Coefficient that expresses the share of natural rubber, natural textile, and leather waste in waste code W101, equal to 0.014. This value was obtained by multiplying the coefficient given in Edjabou et al (2015) expressing the share of rubber, textile and leather in municipal solid waste (equal to 0.026) by $Coef_{biot}$
$W075_{Nace\_i}$	Amount of waste reported under code W075 (wood wastes) by NACE activity i
$Coef_w$	Coefficient that expresses the share of wood waste in waste code W101, equal to 0.0045, obtained from Edjabou et al (2015)
$Coef_{biot}$	Coefficient that expresses the share of natural textiles in textile waste, equal to 0.5401 (derived from the share of synthetic textile identified in McArthur Foundation (2017), equal to 0.4599)
$W076_{Nace\_i}$	Amount of waste reported under code W076 (textile waste) by NACE activity i
$W091_{Nace\_i}$	Amount of waste reported under code W091 (animal and mixed food waste) by NACE activity i
$Coef_{fw}$	Coefficient that expresses the share of food waste in waste code W101, equal to 0.25, obtained from EUROSTAT (2017)
$W092_{Nace\_i}$	Amount of waste reported under code W092 (vegetable waste) by NACE activity i
$Coef_{vw}$	Coefficient that expresses the share of vegetal waste in waste code W101, equal to 0.04, obtained from Edjabou et al (2015)
$W093_{Nace\_i}$	Amount of waste reported under code W093 (Animal faeces, urine, and manure) by NACE activity i

Household biowaste

The calculation of household biowaste considers:

- the amount of waste type W72, W73, W75, W76, W92, W91 generated by the NACE activity EP_HH
- the share of each biowaste type in the waste "household and similar waste' (W101) generated by the NACE activity EP_HH.

For rubber (W073) and textiles (W076) waste, coefficients were used to determine the biodegradable composition as these waste categories consist of a blend of synthetic and natural material.

Coefficients expressing the share of biowaste in W101 reported by each NACE activity were obtained from specific waste composition analysis (WCA) of Municipal solid waste (i.e. "household and similar waste" reported by EP_HH).

The classes (type) of biowaste at the household were defined according to the categories identified in the WCA studies (Edjabou et al 2015).

The household biowaste was calculated using the following equations:

Paper and cardboard wastes = $W072_{Nace\_EP\_HH} + Coef_p\ W101_{Nace\_EP\_HH}$

Textiles, leather, and rubber =

$$Coef_{bior}W073_{Nace\_EP\_HH} + Coef_{biot}W076_{Nace\_EP\_HH} + Coef_{r,t,l}\ W101_{Nace\_EP\_HH}$$

Untreated wood = $W075_{Nace\_EP\_HH} + Coef_{w}\ W101_{Nace\_EP\_HH}$

Composites, human hygiene waste = $Coef_{c\_hh}\ W101_{Nace\_EP\_HH}$

Gardening waste = $W092_{Nace\_EP\_HH} + Coef_{vw}\ W101_{Nace\_EP\_HH}$

Food waste = $W091_{Nace\_EP\_HH} + Coef_{fw}\ W101_{Nace\_EP\_HH}$

$Coef_{c\_hh}$ Coefficient that expresses the share of composites, human hygiene in waste code W101 equal to 0.0335, obtained from Edjabou et al (2015) and considering the amount the amount of synthetic plastic from Cordella et al (2015)

Step 2. Calculation in dry mass

Eurostat waste statistics provide amounts in wet mass. The quantities derived from the waste statistics were then converted into dry mass by using the coefficients presented in Table A10.1, which provide the moisture content of each waste type.

Table A10.1. Coefficients used to convert the amounts of biowaste calculated in wet mass to dry mass obtained from Universiy of Florida (2020)

Type of waste	Moisture content
Paper	6%
Rubber	2%
Wood	20%
Textiles	10%
Animal and mixed food waste	70% (assumed as food waste)
Vegetal wastes	60%
Animal faeces, urine and manure	80% (Manure 70 -85)*
Food Waste	70%
Composites, human hygiene waste (diapers, tampons,etc.)	6% (assumed as average of textiles and plastic)
Textiles + rubber + leather	8% (average of leather, rubber and textiles)

*this coefficient was obtained from Manitoba (2015)

Annex to Chapter 12

List of representative products

Table A.12.1. List of representative products per sector and product group. From CF = the products taken from the Consumption Footprint project.

Sector	Product group	Representative product	From CF
Agriculture (food); Food Manufacturing	Meat products	Pork meat	x
		Beef meat	x
		Poultry meat	x
	Dairy products	Milk	x
		Cheese	x
		Butter	x
	Eggs	Egg	x
	Cereal-based products	Bread	x
		Pasta	x
		Rice	x
		Quinoa	x
	Sugars	Sugar	x
	Oils	Sunflower oil	x
		Olive oil	x
		Rapeseed oil	x
		Soybean oil	x
		Palm oil	x
	Tubers	Potato	x
	Vegetables	Tomato	x
		Broccoli	x
		Carrot	x
	Legumes	Bean	x
		Chickpea	x
		Lentils	x
	Legume products	Tofu	x
		Soy drink	x
	Fruits and berries	Apple	x
		Orange	x
		Banana	x
		Avocado	x
		Strawberry	x
	Nuts	Almond	x
		Cashew	x
	Drinks	Coffee	x
		Tea	x
		Mineral water	x
		Beer	x

		Wine	x
	Confectionery products	Biscuits	x
		Chocolate	x
	Pre-prepared food	Meat-based dish	x
Fishing and aquaculture; Food manufacturing	Fish products	Salmon	x
		Cod	x
		Tuna	x
		Shrimps	x
Agriculture (non-food)	Bioethanol feedstock	Maize	
		Cereals	
		Sugar beet	
	Biodiesel feedstock	Rapeseed	
		Soy beans	
		Oil palm	
	Textile feedstock	Cotton	
Forestry	Wood for paper production	Hardwood from EU	
		Softwood from EU	
		Hardwood - imported	
		Softwood - imported	
	Wood for production of other products	Hardwood from EU	
		Softwood from EU	
		Hardwood – imported	
		Softwood – imported	
Manufacturing of textiles	Bio-based textiles	T-shirt	x
		Jeans	x
Manufacturing of wood-based products	Furniture	Wardrobe	x
		Sofa	x
		Wooden seat	x
		Wooden table	x
Manufacturing of paper	Paper products	Newspaper	x
		Book	x
		Toilet paper	x
		Breast pad	x
Manufacturing of bio-based chemicals and pharmaceutical, plastic and rubber	Bio-based plastics	Bio-plastic bag	
Biofuels	Biogasoline	Biogasoline from corn	
		Biogasoline from cereals	
		Biogasoline from sugar beet	
		Biogasoline from cellulosic materials	
	Biodiesel	Biodiesel from rapeseed	
		Biodiesel from oil palm	
		Biodiesel from UCO, animal fats and other residues	

		Biodiesel from soybean	
Energy production	Bio-based electricity	Electricity from solid biomass (wood)	
		Electricity from biogas	
		Electricity from waste incineration	
	Bio-based heat	Heat from solid biofuels, CHP	
		Heat from solid biofuels, only heat	
		Heat from wood pellets	
		Heat from waste	
		Heat from biogas, CHP	
		Heat from biogas, only heat	
	Rapeseed oil used for power and heat	Rapeseed oil	
	Biomethane used in transport, household and industries	Biomethane	

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