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9.- Circular Economy in Agriculture and Rural Areas

Reading 1

Circular nutrient and biomass flows

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

First results from an integrated assessment

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Executive summary

This report illustrates part of the results from the first two years of JRC biomass study, carried out in the context of the mandate on the provision to EC services of data and analysis on biomass flow, supply and demand on a long-term basis.

The JRC biomass study has a wide scope and is a long-term endeavour, not having a pre-defined duration. Here we refer to the results after the first two years, with a focus on the assessments of the biomass produced in the EU, how much is being used and for what uses, and how to assess the related environmental impacts. We report quantitative estimates on current EU biomass production, uses and flows for the sectors agriculture, forestry, fisheries and aquaculture, and algae. The document contains the best estimates we had been able to attain from available data and our current knowledge, yet highlighting the remaining gaps and underlying uncertainties.

In addition, results for all sectors examined are presented with an integrated perspective and using cross-sectorial biomass flows diagrams. The methodological framework to assess the environmental impacts of biomass supply chains is also introduced.

The total agricultural biomass produced annually in the EU was estimated at 956 Mt of dry matter per year (excluding pastures) of which 54% economic production, that is grains, fruits, roots, tubers, i.e. the reason why the crop is cultivated. The remaining 46% is above ground biomass from by-products and residues such as leaves and stems, which may also have an economic value (for instance when used for animal bedding or for bioenergy production), and are also important for ecosystem services such as maintaining organic carbon levels in soil or preventing soil erosion.

The total above ground woody biomass of EU-28 forests was estimated at 18 600 Mt of dry matter, of which 68% of stemwood, the remaining 32% being branches, stumps and tops altogether referred to as other wood components (OWC). We estimated the net annual increment of EU-28 forests available for wood supply as 444 Mt/yr, of which 349 Mt stemwood and 95 Mt OWC. The average annual harvest level in the EU is about 63% of this increment. However reported removals have been shown to be underestimated up to 20%, which would correspond to a harvest-to-increment ratio approximately 12% higher. With this harvest level, harvest would still not exceed the annual increment, resulting in the increase through time of forest biomass stock, thus in EU forest acting as carbon sink.

Overall, the average annual biomass produced in the land-based sectors (agriculture and forestry) of the EU is 1466 Mt in dry matter (956 Mt agriculture, 510 Mt forestry). Not all the biomass produced is harvested and used, part of it remains in the field to maintain the carbon sink and the other ecosystem services. The biomass harvested and used in 2013 from the EU agricultural and forestry sectors was estimated as 805 Mt dry matter (578 Mt from agriculture, 227 Mt from forestry). In addition, 119 Mt were grazed in pastures.

Production from fisheries and aquaculture by the EU-28 Member States equalled 6.05 Mt wet mass (roughly corresponding to 1.5 Mt dry weight) in 2013, representing 3.17% of total global production. Total production of both macro- and micro algae was 0.23 Mt wet mass in 2015 (roughly corresponding to 0.027 Mt dry weight).

Comprehensive cross-sectorial biomass flow diagrams (Sankey diagrams) representing in a unique view the flows of biomass of different sectors of the bioeconomy, from supply to uses including trade, have been developed. The diagrams, which can be considered a first release subject to future refinements and expansion, link the data from the supply to the uses, and integrate agriculture, forestry, aquaculture and fisheries biomass flows. The biomass flow diagrams are the bases to frame the future analysis of cross-sectorial competitions and synergies.

Biomass balance sheets of supply and uses for the forest-based and agricultural sectors have been compiled with consolidated numbers detailed at MS and EU-28 levels. With reference to 2013, the EU agricultural biomass supply was composed of harvested crop production (478 Mt), collected crop residues (100 Mt), grazed biomass (119 Mt) and

imports of bio-based products (121 Mt of vegetal biomass equivalents). Agricultural biomass has been further disaggregated into content in proteins, fats, sugar and starch, cellulose and other components. Concerning biomass uses, around 80% of the agricultural biomass supply was used as food and feed (15% directly consumed as plant-based food and 65% as animal feed, mostly for the production of animal-based food). Around 98 Mt dry matter of vegetal biomass equivalents were exported, the rest was used as either biofuel, biomaterial or waste.

Biomass flows diagrams for the forest-based sector have been developed illustrating cascade uses, the competition and synergies as well as the importance of different sub-sectors. We have made evident and discussed data gaps and existing inconsistencies among data sources, which in the prosecution of the study in 2018 will be further addressed.

In the forest-based sector in 2013, EU-28 reported biomass sources were in total about 354 Mt dry weight, summing primary (242 Mt), secondary (95 Mt) and post-consumer (17 Mt) sources. Total known uses of woody biomass summed to around 399 Mt dry weight of Solid Wood Equivalents (SWE), consequently, there is a gap of 45 Mt between the reported sources and uses of wood (the latter being higher). Regarding the share of energy and material uses, 52% of wood primary and secondary sources were used for materials while 48% for energy.

Biomass flows within the seafood supply chain have been reconstructed through the development and first known attempt of adaptation to seafood of a Multi Region Input-Output model (MRIO). We have reconstructed the basic technical coefficients and trade matrixes, which represent the core of the model, reconstructing global seafood biomass flows, thus providing for the first time the possibility to distinguish, for each subsector separately, the proportions of supply that are satisfied domestically and traded internationally. Further testing of model assumptions and assigning monetary values to biomass flows are activities foreseen for 2018.

Global supply, demand and trade for macro and microalgae biomass and derived products have been framed based on critical analysis of existing statistics.

A methodological framework for the analysis of environmental impacts of biomass supply chains has been developed. This framework is quite flexible, can cover all biomass uses, all environmental impacts and beyond and can accommodate the needs of different Tasks in the Biomass mandate. Firstly, the study aimed at defining a detailed guidance on when and how various Life Cycle Assessment (LCA) modelling approaches (Attributional (A-LCA), Consequential (C-LCA) and intermediate setups) should be applied. It highlighted the importance of consistency between the stated goal of the study and the methodology used. In the first phase of the study, a database was compiled to gather all the A-LCA results calculated or assembled by the JRC for multiple bio-based commodities. This database focuses on supply-chains impacts and it currently consists of more than 380 pathways. Additional commodities or pathways can be added anytime. The bulk of the database comprises bioenergy commodities mainly and focuses on Greenhouse Gas (GHG) emissions. However, the database contains numerous non-energy datasets as well, such as some bio-based materials, waste and food products. It is being further expanded. Finally, a comprehensive set of environmental impact indicators, beyond climate change impact, has been proposed to be added to the modelling framework.

1 Introduction

Biomass is at the core of the bioeconomy and the key societal challenges it addresses. The demand for biomass is increasing worldwide, consequently, there is a growing need to assess and better understand how much biomass is available and can be mobilized sustainably, how much is being used and for which purposes, what are the biomass flows in the economy and how the increased pressure on natural resources can be reconciled with environmental, economic and social sustainability in Europe and globally.

Many sectorial policies deal – directly or indirectly – with biomass supply and demand and with the impacts of biomass harvest and uses from quite diverse, and at times contrasting, perspectives. Recognising the need for a balanced and scientifically robust approach to assessing the status and trends of biomass, a number of European Commission (EC) services have given the Joint Research Centre (JRC) a mandate to provide data, models and analyses on EU and global biomass supply and demand and its sustainability (environmental, social and economic), on a long-term basis[1]. The envisaged work, initiated in 2015, covers all sources of biomass - agricultural, forest, fisheries, aquaculture, algae - and includes an assessment of the impacts of the production and use of biomass, and the competition and the synergies between sectors for biomass resources. This assessment is designed to support the implementation of policy measures, and to develop and analyse scenarios for biomass supply and demand with short–term (2020), medium-term (2030) and long-term (2050) perspectives.

More detail on the request can be can be found in the *Mandate on the provision of data and analysis on biomass* flow, *supply and demand by JRC on a long-term basis* (hereafter referred to as the "Biomass mandate")[2].

The activities are being carried out by JRC through the setting up of the overarching study on biomass (hereafter referred to as the JRC biomass study) and coordinated with the policy Directorate-Generals (DGs) of the European Commission that have agreed to the Biomass mandate.

The overall approach of the inception phase of the study was to gather information on the state-of-the-art knowledge and databases on biomass resources in the different sectors as well as to establish the basis for ex-ante assessments using computer-based simulations to support biomass-related policies. This phase included a focus on in-depth literature reviews as well as reviews of available datasets, as outlined in the mandate

The first two years have laid the foundations of a framework for the development of a robust scientific knowledge base and modelling capacity that can support policy making on biomass-related issues. Initial steps have focused on:

1. the stocktaking of existing studies on biomass supply and demand, complemented by JRC data collection and in-house capacity,
2. the development of a knowledge base on biomass-related issues, identifying gaps, and uncertainties.
3. the projection of future forest-based and agriculture biomass supply and demand, and the related environmental impacts.

This report summarizes part of the work carried out within the JRC biomass study, particularly regarding the biomass produced in the EU, the quantities being supplied and used for food, feed, material and energy purposes, the development of a methodological framework to assess the environmental impacts of biomass supply chains. It thus reports quantitative estimates on current EU biomass production, uses and flows for the sectors agriculture, forestry, fisheries and aquaculture, and algae, providing the best estimates we

[1] Biomass mandate agreed by the Directorate Generals Agriculture and Development (AGRI), Climate Action (CLIMA), International Cooperation and Development (DEVCO), Energy (ENER), Environment (ENV), Internal Market, Industry, Entrepreneurship and SMEs (GROW), Maritime Affairs and Fisheries (MARE), Mobility and Transport (MOVE), Regional and Urban Policy (REGIO), Research and Innovation (RTD), Secretariat-General (SG) and Trade (TRADE).

[2] See https://biobs.jrc.ec.europa.eu/biomass-assessment-study-jrc

had been able to attain from available data and current knowledge, yet highlighting the remaining gaps and underlying uncertainties. In addition, results for all sectors examined are presented with an integrated perspective and using cross-sectorial biomass flows diagrams. The modelling work within the Biomass study to develop forward looking scenarios of biomass supply and demand is not part of this report.

2 Biomass from agriculture

Agriculture occupies half of the land area of the European Union. Although it occupies only 4.5% of the EU-28 working population (Eurostat), it supplies the European economy with a diversity of essential products and services such as food, feed, material, and energy. The economic value of the primary crop products such as grains and fruits, roots and tubers is the principle motivation for crop cultivation. A large part of the crop biomass that is grown, i.e. the residues, is left in the field, although this may also generate farm income, for instance when used for animal bedding (e.g. straw). Residues are also essential for other uses, including ecosystem services such as maintaining organic carbon levels in soil or preventing soil erosion. With the development of the bioeconomy, the demand for these secondary products is likely to increase, changing the economic conditions of production. While meeting the demand for food and feed products remains the main objective of the agricultural sector, the increased demand of residue biomass for material and energy uses calls for a comprehensive assessment of biomass production from agriculture. This chapter presents an estimation of the total agricultural biomass produced, the current uses, and the potential supply of additional quantities of residue biomass produced in the European Union given current management and intensification levels. To ensure a sustainable use of residues, only a certain part of this total can be removed from the field.

2.1 Production

Agriculture supplies food, feed, fibre and energy as well as ecosystem services. This section provides the knowledge base on the current production of agricultural biomass. The assessment distinguishes the production related to the primary economic reason to cultivate a crop (e.g. grains, fruits, roots, tubers) and the production of residues (e.g. straw).

The production estimates account for all crop groups, including cereals, crops harvested green, sugar and starchy crops, oil-bearing crops, permanent crops, vegetables, pulses and industrial crops. Animal products (meat, dairy products) are excluded from this analysis to avoid double counting since these products result from the transformation of the feed and fodder biomass (e.g. cereals, grasses) into animal biomass.

In this Chapter, agricultural biomass production is thus distinguished by economic and residue production.

2.1.1 Methods, data sources and boundary conditions

Collection of statistics

The estimation of economic and residue production, at EU level requires a complete dataset with crop statistics for all EU Member States (MS). Production and harvested crop area from 1998 to 2015 were collected from the Eurostat database, which contains crop statistics at NUTS level 0 and – for some MS – also NUTS level 1 and/or 2.

Additionally, crop area and production data were collected by contacting the National Statistical Institutes from the MS, which provided crop statistics at the highest NUTS level available from 1998 to 2012. The statistical data collected from the MS were, when necessary, harmonized with the Eurostat standards used for crop definitions and administrative units. The crop/varieties provided by the MS were matched with those from Eurostat, sometimes grouping individual crops reported by MS (e.g. summing rapeseed and turnip rape statistics from MS to produce an equivalent to "rapeseed and turnip rape" reported in Eurostat).

Regarding the administrative units, in some countries there were changes in the boundaries and/or names of regions during the reference period. In specific cases (e.g. a few regions in Germany, Sweden, Italy and Romania), it was necessary to aggregate statistics to match the NUTS system. In other cases such as Ireland, UK and Finland, it was necessary to disaggregate some regions to the NUTS3 level using as weight the arable land area from the Corine land cover map (Buttner et al., 2004). Once statistics from the

MS and Eurostat were harmonized, a complete statistical dataset at all NUTS levels was generated using a post-processing algorithm with regional weights.

Estimation of economic and residue production

As explained above, a consistent economic production dataset for all commodities for the EU-28 across all administrative levels (NUTS 0 to 3) was generated by using crop production statistics from Eurostat and MS.

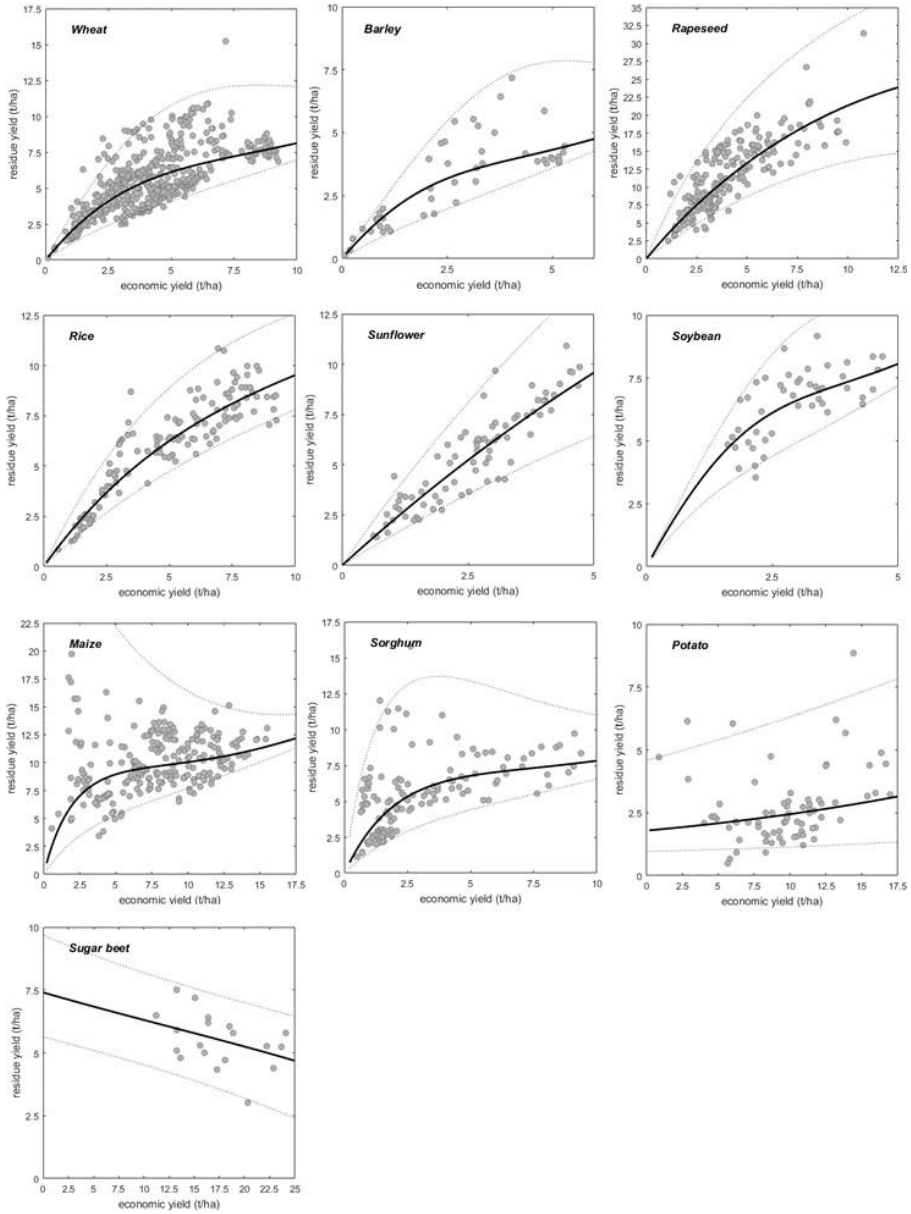
Residue yield (R) was inferred from economic yield (Y), relying on the relationship between the biomass allocated in the economic products, in most cases crop storage organs (e.g. grains, roots, tubers) and residues that often correspond to vegetative organs (e.g. leaves, stems), through the harvest index HI expressed as:

$$R = \frac{Y}{HI} - Y$$

These relationships were formalized for every crop through newly derived empirical models for the main crops grown in the EU (Figure 2.1). The models were constructed from an extensive dataset of experimental observations collected from scientific literature. The different relationships between economic and residue yield that can be observed in Figure 2.1, relate to crop-specific physiological characteristics of biomass partitioning (c.f. wheat and maize, López-Lozano et al., 2017). Using these models, residue yield R (expressed in tonnes of dry matter per hectare) for every NUTS 3 region was calculated using economic yield (Y, in tonnes of dry matter per hectare) as predictor. The economic yield was obtained from the statistical crop production dataset developed previously.

For spatial representation and analysis, the estimations of residue production at NUTS 3-level were disaggregated to 25 km grid cells using several land cover classes from the CORINE land cover map (see Figure 2.7).

Figure 2.1. Empirical models for the estimation of residue yield for the crops studied



Solid lines represent the model estimations and dashed lines are the confidence intervals at 95%. Dots are the observed values from scientific literature.

2.1.2 Results

2.1.2.1 Total production in the European Union

The total agricultural biomass produced annually in the European Union is estimated at 956 Mt of dry matter, as averaged from 2006 to 2015 (García-Condado et al., 2017). Out of this total, 514 Mt (or 54%) are produced in the form of the primary products (biomass produced as grains, fruits, roots, tubers) with an intrinsic economic value – the reason for which the crop is cultivated– and is thus referred to as economic production[3].

The remaining fraction of the biomass (442 Mt or 46%), which is not the primary aim of the production process (e.g. dry biomass from leaves, stems), is referred to as residue production, although sometimes residues may generate farm income (e.g. animal bedding,

[3] In order to avoid biased calculation because of the absence of reporting for some crops and some years, the values presented here refer to the sum of the average annual production by crop at Member State level from 2006-2015 for those years that had reported values.

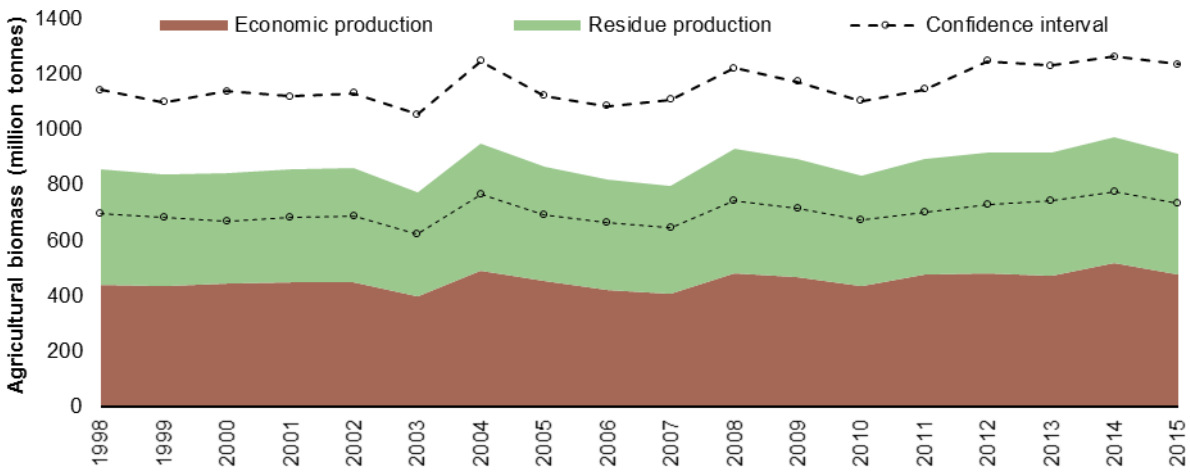
production of bio-energy). Residues are also essential for other uses including ecosystem services such as maintaining soil organic carbon levels in the soil or preventing soil erosion.

Total residue biomass from agriculture in the EU has increased slightly over the last 17 years (1998-2015), as shown in Figure 2.2. The growth in both economic and residue production is explained by a positive trend that is the result of a progressive increase in the yields of the main cereals (e.g. maize) due to improvements in agro-management, and a general expansion of area cultivated with oil-seeds.

The inter-annual variability of biomass production – both economic production and residues – is largely determined by weather conditions. Adverse weather extremes affected cereal growth in the main producing countries in 2003 – characterized by an extremely cold winter and a long heat wave in summer – and in 2007 – due to a severe drought in Eastern Europe. It explains the reduced biomass production in these two years (Figure 2.2). Conversely, 2004 and 2014 are the years with the highest agricultural production, as beneficial weather conditions prevailed along the growing season in most Member States.

The production of agricultural residues is estimated from empirical models (see the Methodology section) and the confidence intervals in Figure 2.2 represent the uncertainties, inherent to the model used. These uncertainties are relatively large – especially the upper interval – indicating the need for future improvements in the models used to estimate agricultural residue production.

Figure 2.2. Evolution of agricultural biomass production (economic production and residues in Mt dry matter per year) in the EU-28 from 1998 to 2015



Source: JRC, Eurostat, 2017[4]
Dashed lines represent the confidence intervals of the residue production in the EU-28 at 95%.

2.1.2.2 Contribution from crops

The breakdown of economic and residue production per crop group and crop is given in Figure 2.3 and Figure 2.4. Cereals and plants harvested green (258 Mt/yr and 156 Mt/yr, respectively) dominate economic production, accounting for about 80% of the total. The next important crop groups are sugar and starchy crops, and oil-bearing crops (resp. 40 Mt/yr and 27 Mt/yr). Dedicated energy crops (crops grown exclusively for energy production, not included in any of the other crop groups as Eurostat does not report the share of food or fodder crops, e.g. maize or rapeseed used for the production of energy) represent only a minor fraction (<0.1%) of the total biomass production.

[4] This figure relies on annual data reported by Member States with some missing values for some crops and years. The total production is slightly underestimated.

Regarding individual crops, wheat, grain maize and barley sum altogether to 225 Mt/yr, about 45% of total agricultural economic production. Maize harvested green and grasses – both used for fodder – account for 123 Mt/yr or 24%. Other crops, such as sugar beet (5%) and rapeseed (4%) also provide a relevant contribution to the total economic production.

Regarding residue production, cereals represent 74% of total agricultural residue production (329 Mt/yr), while oil-bearing crops is the second group of importance with 17% (73 Mt/yr). In these two main crop groups, the biomass of residues is higher than the economic production (Fig. 3), since the proportion of grain to total above ground biomass – also known as harvest index – in these crops typically ranges from 20% to 55%.

As far as residues are concerned, wheat (149 Mt/yr), grain maize (80 Mt/yr), rapeseed (54 Mt/yr), and barley (50 Mt/yr), contribute most to EU-28 production, together constituting 75% of the total. It is important to note that the relevance of maize among cereals in the production of residue biomass is significantly higher than in the production of grains. According to experimental data, biomass formation in leaves and stems in maize can be high even in conditions of moderate water stress, which makes this crop an important source of residue biomass.

Other relevant crops for the production of residues are olive trees (residues mainly coming from pruned biomass), sunflower or triticale, each of them producing around 15 Mt/yr. The contribution of sugar beet (9 Mt/yr) and potato (4 Mt/yr) is low – especially if compared to their contribution to the economic production – as the harvest index of both crops is rather high, close to 75%.

Figure 2.3. Breakdown of EU-28 economic production by crop group (top pane) and crops by crop group (bottom pane), expressed in Mt of dry matter per year. Averages values over the reference period 2006-2015

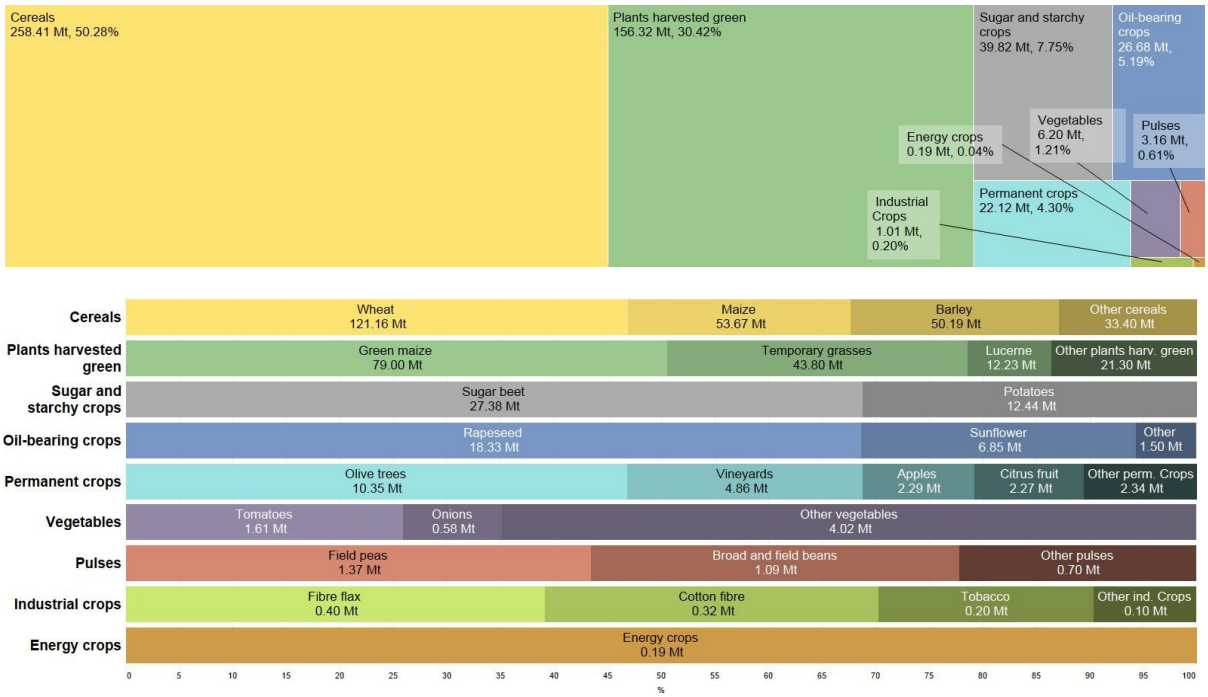
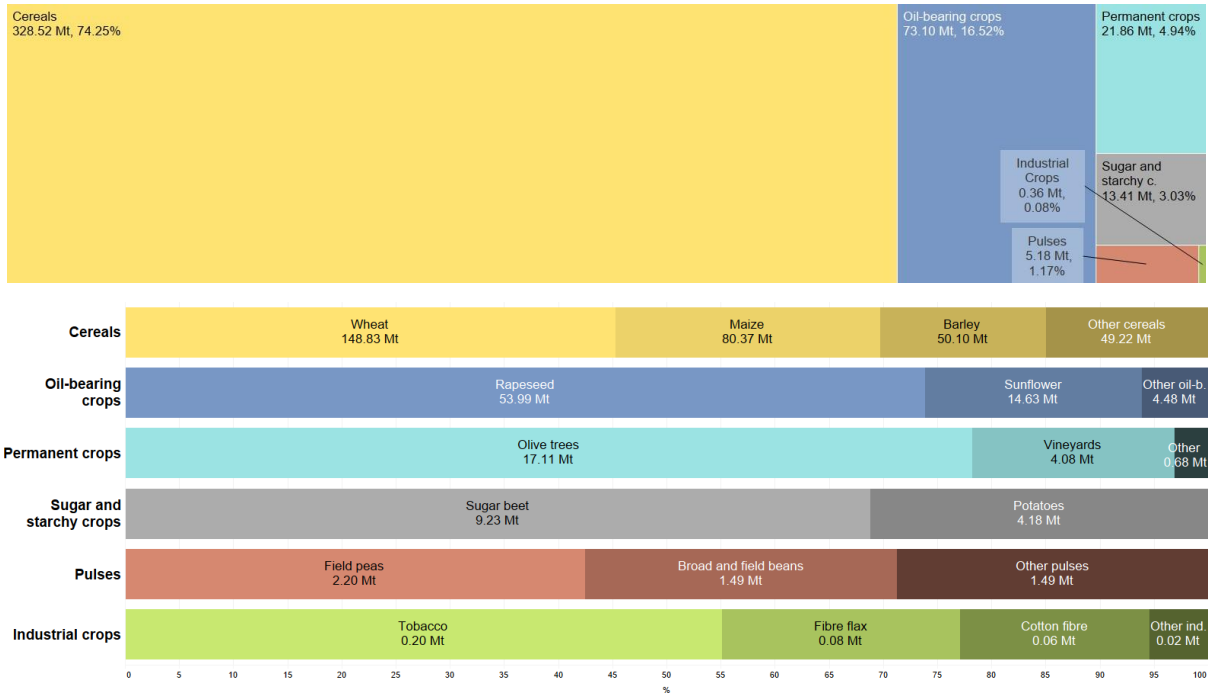


Figure 2.4. Breakdown of EU-28 residue production by crop group (top pane) and crops by crop group (bottom pane), expressed in Mt of dry matter per year. Averages values over the reference period 2006-2015

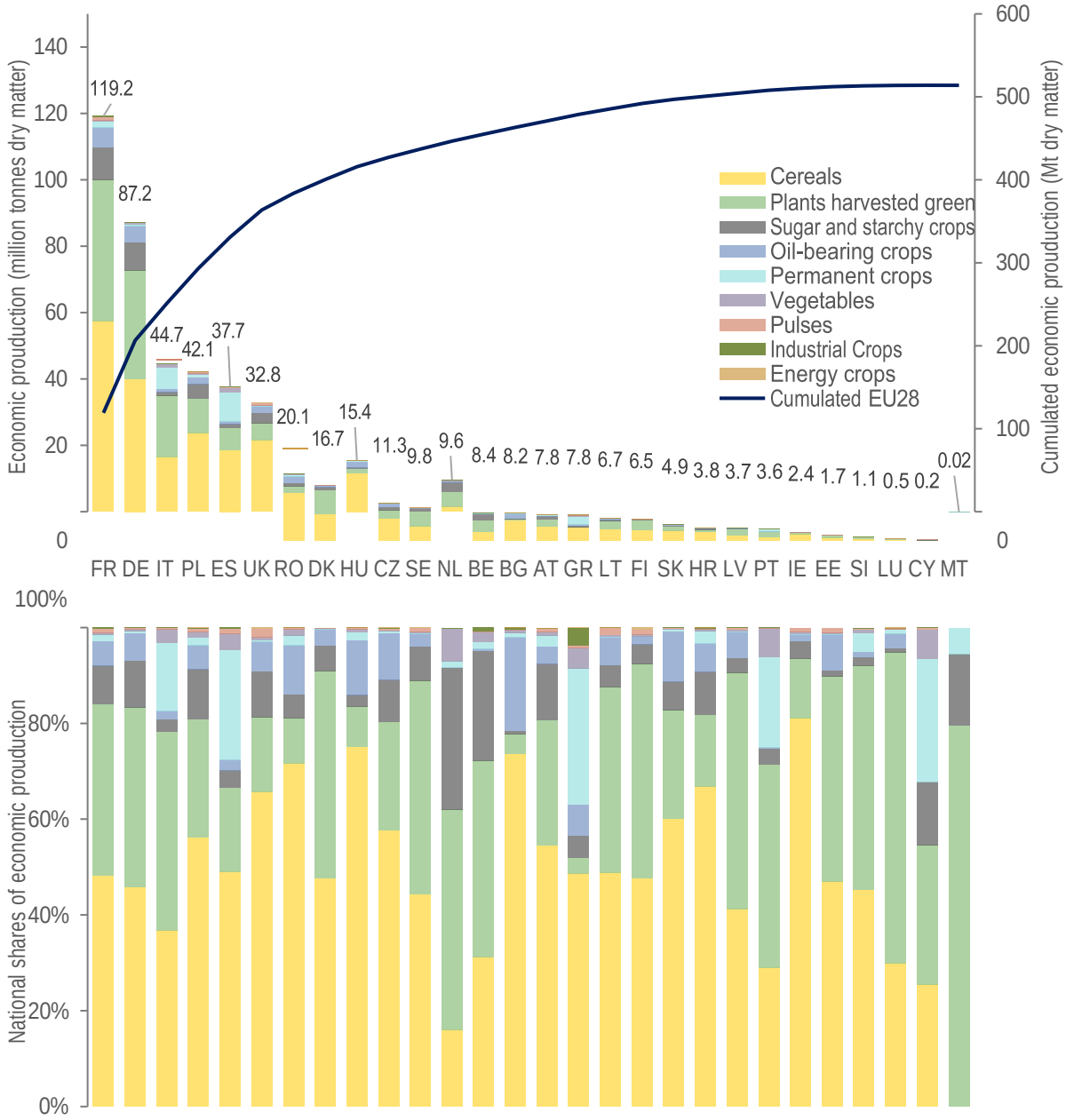


2.1.2.3 Distribution by Member States

The distribution of economic and residue production across the Member States is shown per crop group in Figure 2.5 and Figure 2.6. The top-7 countries – France, Germany, Poland, Italy, Spain, the UK and Romania – make up about 75% of the economic (384 Mt/yr) and residue production (323 Mt/yr).

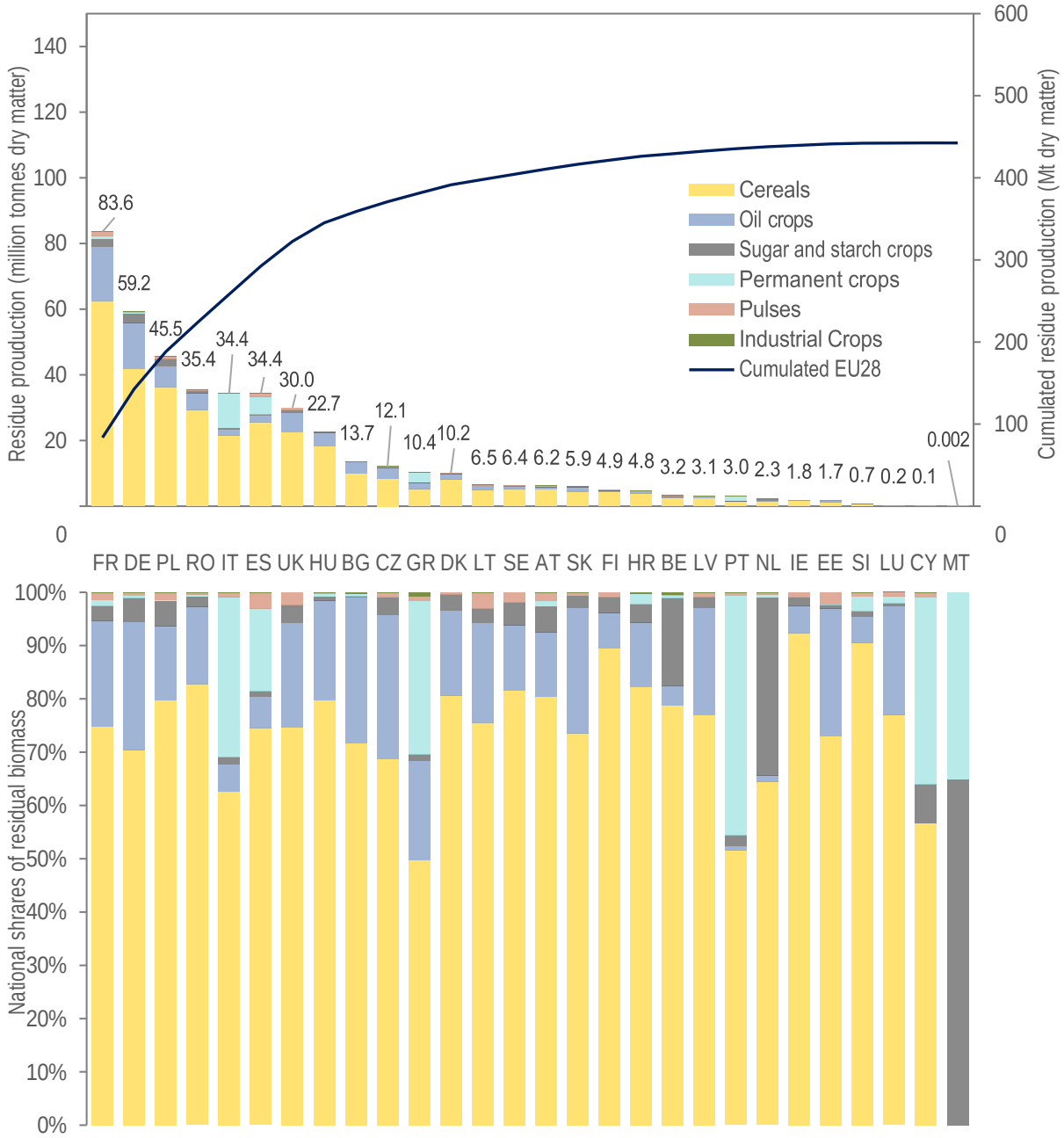
France and Germany are, respectively, the first and second largest producers. In both countries cereals are the main contributors to the total economic production – 57 Mt/yr and 40 Mt/yr for France and Germany, respectively – followed closely by plants harvested green – 43 Mt/yr and 33 Mt/yr, respectively. In France, the production of fodder biomass mainly comes from temporary grasses, whereas in Germany green maize provides 80% of fodder production. Italy is the third country in terms of economic production, with fodder crops contributing most to the total national figure, and a substantial contribution from permanent crops. Poland and Spain follow, characterized by different crop distributions: in Poland cereals and fodder crops dominate, whereas in Spain the production from permanent crops – mainly olive trees – is substantial.

Figure 2.5. Economic production (top pane) from the main crop groups per member state, expressed in Mt of dry matter per year; and the shares at national level (bottom pane). Average values over the reference period 2006-2015.



Cumulated values are referenced to the secondary (right hand side) axis.

Figure 2.6. Residue production (top pane) from the main crop groups per member state, expressed in Mt of dry matter per year; and the shares at national level (bottom pane). Average values over the reference period 2006-2015.



Cumulated values are referenced to the secondary (right hand side) axis.

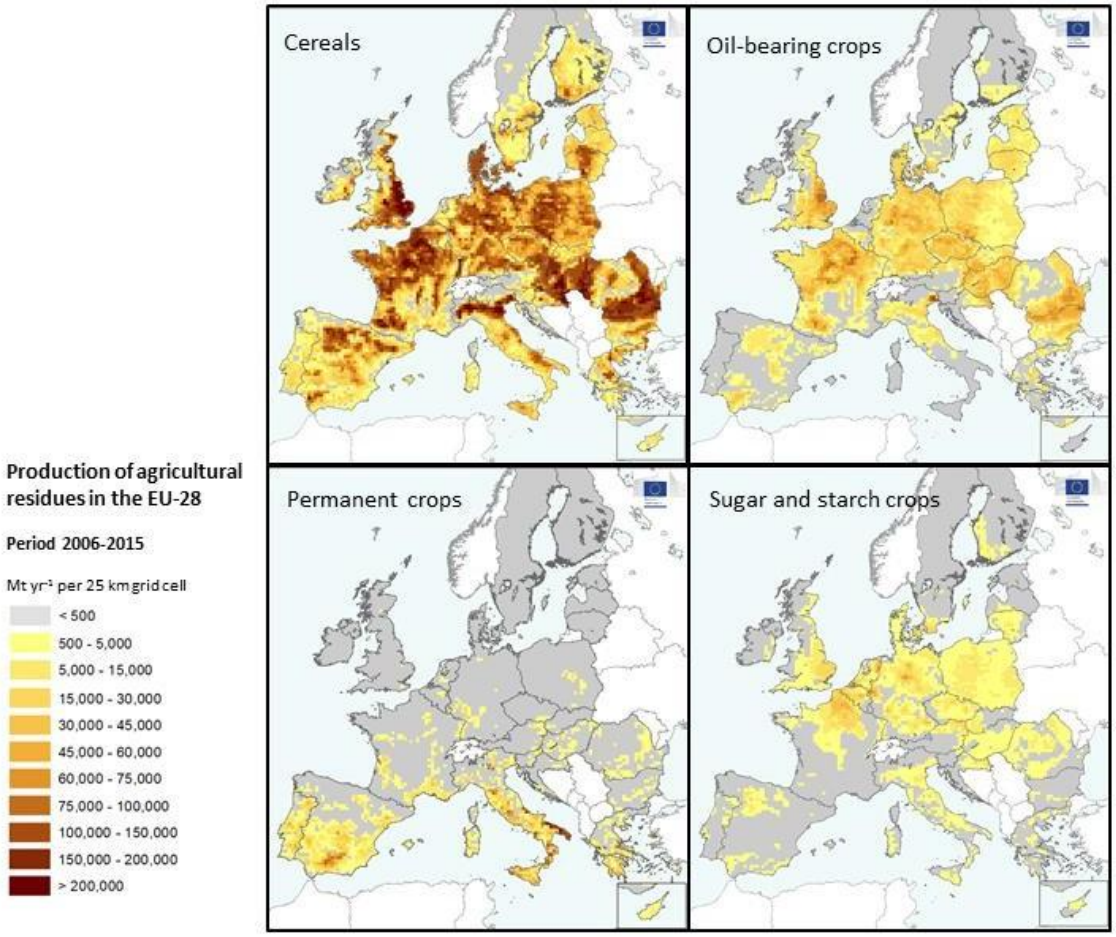
Regarding the production of residues, France and Germany are the two main EU producers with respectively 84 Mt/yr and 60 Mt/yr. In both countries, cereals – with an important contribution from wheat – represent 70-75%, followed by oilseeds.

Poland and Romania are placed in the third and fourth position, respectively. The contribution of cereals reaches 80% of total residue production in both countries, followed by oilseeds with about 15%. In Poland – a top EU producer of triticale and rye –, most of the residue production comes from winter cereals. In the case of Romania, maize is the most relevant crop. As indicated in the previous section, maize produces high amounts of biomass in leaves and stems, and thus becomes a crop of major importance for the production of residues, and this explains why Romania is the fourth contributor to EU-28

residues production whereas it only occupies the seventh place in terms of economic production.

One of the main factors determining a possible economic use of agricultural residues –e.g. for bioenergy production – are the transport costs. Thus, studying the spatial distribution of agricultural residue production over EU-28 territory becomes crucial to assess the economic efficiency of using this source of biomass. Figure 2.7 shows the results of a first attempt to spatialize the distribution of agricultural residues production, based on the spatial disaggregation of estimates in residue production. The northern half of France, East Anglia, central Germany, the Po valley, and the Danube basin are the main producing areas of agricultural residues within the EU-28, mostly coming from cereals and oilseeds. Pruning residues are also relevant, especially in Andalucía (Spain) and Puglia (Italy) due to the presence of olive trees.

Figure 2.7. Distribution across EU-28 of residue production for the reference period 2006-2015 in the main crop groups: cereals, oil-bearing crops, permanent crops and sugar and starch crops



Values are expressed in Mt/yr of dry matter per 25 km grid cell.

2.1.3 Gaps, uncertainties and future developments

Several knowledge gaps need addressing to improve this assessment of agricultural biomass production. No systematic figures of residue production are available in agricultural statistics. Therefore, residue production is deduced from economic production using empirical models that describe, for each individual crop, the relationship between

biomass cumulated in plant storage organs and biomass produced in other aboveground organs (e.g. leaves, stems, etc.).

Although relationships exist for most crops, estimating residue production solely from economic production is an over-simplification, as genetic factors (varietal differences), agro-climatic conditions, and agro-management practices (e.g. irrigation, fertilizing) influence the relationship. As a result, the uncertainties can be large in most of the model estimates for specific yield intervals. The use of crop growth simulation models can help to overcome the simplicity of empirical models based on economic yield. Further research should investigate the potential of crop models to predict changes, not only on economic yield, but also in the HI, and use them as tools to improve the estimation of crop residues over large areas. Similarly, canopy models driven by Earth Observation data using satellite and weather observations can support the quantification of the total biomass over croplands. Biophysical modelling makes it possible to simulate the physiological processes determining crop biomass partitioning into yield or residues with a higher precision compared to simple empirical models. Actually, the use of remote sensing data to drive the model should reduce the uncertainty on residue biomass estimates, as remote sensing products constitute a useful observation of the formation of green biomass, and vegetative organs in particular (leaves, stems).

A further evaluation on the use of agricultural residues requires data on current collection practices and the technical capabilities in harvesting the residue from the field. Moreover, an assessment on the residue biomass needed to satisfy sustainability criteria – e.g. to prevent soil erosion and/or increase soil organic carbon – would be necessary to quantify the amount of produced residues available for other competitive uses. Such a sustainability criterion could be a minimum percentage of residues that needs to be left in the field to maintain e.g. soil organic matter.

2.2 Supply, uses and flows

The EU agricultural biomass *supply* comprises the EU agricultural economic production[5] (primary products), the collected part of crop residues (secondary products), the grazed biomass and imports of bio-based products.

The *uses* of agricultural biomass (food and feed, bioenergy and bio-based materials) have been quantified separately from supplies of agricultural biomass for the main reason that the available data supporting calculations also belong to distinct sources. *Flows* have been quantified in a third step.

Due to the limited information available for the quantification of agricultural biomass uses and flows, these items are estimated for the EU and each EU Member State (NUTS 0) between 1998 and 2015 (same time period as for section 2.1) with no breakdown at crop type level.

2.2.1 Methods and data sources

The estimation of the EU agricultural economic production and crop residue production is described in section 2.1.1. The present section briefly describes how the other components of the EU agricultural biomass supplies, i.e. the collected part of crop residues (secondary products), the grazed biomass and imports of bio-based products are estimated. It also reports on the quantification of the uses of agricultural biomass in Europe, mainly in the form of food and animal feed, but also in bioenergy (e.g. biofuels) and bio-based material (e.g. bio-based textile). Exports are considered as a form of "use".

Estimation of the collected part of crop residue (Biomass supply element)

Either crop residues can remain *in situ* to fulfil a diversity of ecosystem services (e.g. soil conservation, prevention from soil erosion) or they can be collected and used in the

[5] Defined in section 2.1

bioeconomy value chains as animal bedding and feed products, as bio-based materials or as bioenergy carriers. Our quantification of agricultural biomass supply only considers the fraction of crop residues which is collected and enters bioeconomy value chains. This fraction is inferred from the total crop residues production calculated in section 2.1.1, applying the crop-type residue collection coefficients presented in Table 2.1.

Table 2.1. Share of collected residues for the crop types considered in section 2.1

Crop type	Share of collected crop residues
Cereals	25%
Fruit trees and berry plantations	10%
Vineyards	10%
Cotton fibre	0%
Fibre flax	0%
Hemp	0%
Other fibre crops n.e.c.	0%
Hops	10%
Tobacco	10%
Olive trees	10%
Oil-bearing crops	10%
Pulses	0%
Potatoes	10%
Nuts	10%
Vegetables, melons and strawberries	10%
Plants harvested green	0%
Sugar beet	50%

Source: Jölli and Giljum (2005) and Piotrowski et al (2015).

Estimation of grazed biomass (Biomass supply element)

The grazed biomass is barely reported in official statistics. Nevertheless, it represents a significant amount of biomass and it can partly substitute other types of animal feed biomass. Therefore, we considered important to bring it into the broad picture even though in a very approximate way.

Grazed biomass is considered as proportional to pasture and meadows land area reported in FAOSTAT land (1.8 tdm/ha, with tdm standing for tonnes of dry matter).

Estimation of agricultural biomass trade (imports as biomass supply element and exports as biomass use element)

The trade of agricultural biomass is inferred from the Eurostat – Comext data, converted in dry matter of vegetal biomass equivalent. A differentiated approach is followed for the four product types below:

- raw vegetal biomass: trade of crop products (e.g. cereal grains, vegetables and fruits, etc.). Those products are fully made of vegetal biomass and do not undergo any processing. The only transformation of Comext data is the conversion from fresh to dry matter (see Annex 1).
- plant-based food: trade of processed vegetal biomass as a food product (e.g. bread, flour, vegetal oil, etc.). Those products are fully made of vegetal biomass but a fraction of the initial raw vegetal biomass is lost in the process (e.g. wheat bran in the wheat flour processing[6]). In addition to the conversion of Comext data into dry matter, an additional coefficient is applied to measure the full quantity of vegetal biomass entering

[6] The manufacture of one tonne of bread makes use of 1.3 tonnes of cereals.

the transformation process. Coefficients are defined by food product type, as reported by EC DG Agriculture and Rural Development[7].

- animal-based food: trade of processed animal biomass as a food product (e.g. meat, dairy and cheese products, etc.). Those products are converted into their feed equivalent (i.e. vegetal biomass equivalent) following Piotrowski et al.'s methodology (2015a). From this study, the European conversion efficiency of feed to animal products is applied to European exports of animal-based food products (i.e. 8.34%), the global one is applied to imports (i.e. 3.69%).
- bio-based products: trade of processed agricultural biomass as (part of) a bio-based material (e.g. bio-based textile, bio-based chemicals, etc.). The biomass origin of those products is defined (e.g. oilseeds, starchy crops etc.) and thus Comext data is transformed using processing coefficients from Piotrowski et al. (2015b) to take into account the biomass lost in the transformation process.

Estimation of feed and food uses (biomass use element)

Feed and food uses are made of agricultural biomass and in a lesser extent of aquatic biomass. They are split into: (i) aquatic food, (ii) plant-based food, (iii) animal-based food) and (iv) animal feed and bedding. The estimation of aquatic food uses is presented in section 4. The quantification of plant-based food as well as animal-based food is derived from the "Total Food Supply" reported in the FAOSTAT Food Balance Sheets (in fresh matter). This source reports the plant-based food in vegetal biomass equivalents (i.e. taking into accounts losses at processing stages) but animal-based food is not converted to feed equivalents.

Therefore, we apply two kinds of transformations to FAOSTAT Food Balance Sheets data:
- Conversion from fresh matter to dry matter,
- Conversion of animal-based food (excluding aquatic) back to feed equivalents.

Calculation steps are given in Annex 2. They include the disaggregation of food supply data into their carbohydrate, fat and protein content. This disaggregation is extra information for the study, as it does not directly serve the quantification of food uses *per se*. We kept it in Annex 2 for the sake of transparency.

Estimation of biofuel uses (biomass use element)

The Renewable Energy Directive requests EU Member States to report on their biomass supply for transport, including both domestic and imported raw material. This data is compiled in the NREAP[8] database from which we extract the biofuel supply from "common arable crops" per Member State. This has the advantage of being the official data on biofuel use at Member State level, but the drawback is that only biofuels that fulfil the criteria of sustainability as specified in Article 17 (2) to (6) of the Renewable Energy Directive are reported. In other words, by excluding the biofuel supply that does not comply with sustainability criteria, our quantification of biofuel use is thus underestimated.

Estimation of bio-based material uses of agricultural biomass (biomass use element)

The use of agricultural biomass for the fabrication of bio-based materials remains a major data gap. Therefore, we acknowledge the absence of validated and comprehensive information in this area and do not provide global estimations. The only estimation we included in this study was to consider that all the fibre crop production was dedicated to

[7] https://ec.europa.eu/agriculture/sites/agriculture/files/statistics/trade/2016/products-description.pdf
[8] National Renewable Energy Action Plan (NREAP) data from Member States https://www.eea.europa.eu/data-and-maps/figures/national-renewable-energy-action-plan#tab-additional-information

bio-based material uses. Other bio-based material uses are not quantified here, in particular the use of agricultural biomass in the manufacture of bio-based chemicals and bio-based plastics. Although we are missing precious information, we believe that the quantity of biomass at stake is small. Therefore, ignoring this flux of biomass does not distort significantly the very broad picture of inter-sectorial biomass flows. Refining the figures on the manufacture of bio-based chemicals and bio-based plastics is an area for further research.

Flows analysis and estimations

Estimation of the flows to "animal feed and bedding uses"

Animal feed and bedding uses being quantified, it is considered that they are sourced from (i) grazed biomass, (ii) collected crop residues and (iii) crop supplies (economic production and imports).

The following rules have been considered:

- all the grazed biomass (see estimation above) is used as animal feed and bedding,
- 33% of collected crop residues are used as animal feed and bedding (based on Scarlat, Martinov et al. 2010, Piotrowski et al. 2015b, Bentsen et al. 2014 and Ericsson and Nilsson 2006),
- The remaining animal feed and bedding uses are sourced from crop supplies.

Estimation of the flow to "plant-based food uses"

All the plant-based food uses (incl. exports) are sourced from crop supplies (i.e. domestic production and imports).

Estimation of the flow to "biofuel uses"

All the biofuel uses are sourced from crop supplies.

Estimation of the flow to "bio-based materials"

Only the fraction of crop supplies corresponding to fibre crops is attributed to bio-based material uses. We already mentioned that other kinds of bio-based material uses of agricultural biomass are not quantified so far.

2.2.2 Results

In this section, the supply, uses and flows of biomass are commented for the year 2013. Thus, numbers related with agricultural biomass domestic production are slightly different from section 2.1.2 where they are expressed as a 2006-2015 average.

2.2.2.1 The European agricultural biomass total supply

The European agricultural biomass total supply in 2013 (in full trade figures) amounts to approximately 818 million tonnes (Mt) of dry matter of vegetal biomass equivalents. It is composed of crop economic production (or crop harvested production), collected crop residues, grazed biomass and imports of bio-based products.

- The crop economic production is estimated at 478 Mt in the EU-28 for the year 2013[9] (i.e. approximately 1 billion tonnes of fresh biomass).
- Collected crop residues provide additional 100 Mt of biomass.

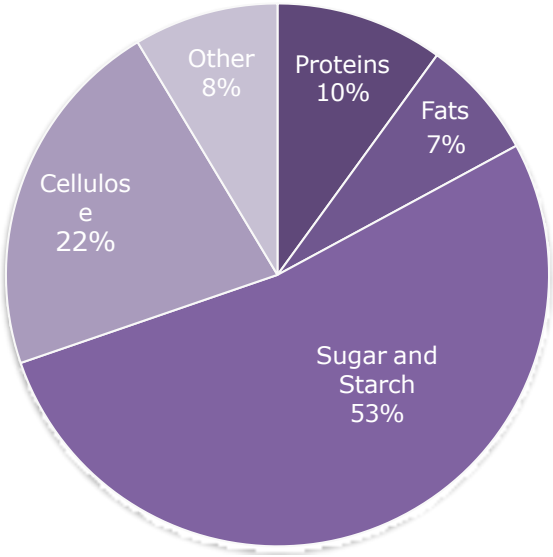
[9] This value is estimated for the reference year 2013, based on data reported by MS for each crop and crop group with some missing information. These values differ slightly from the ones reported in section 2.1, which correspond to the 2006-2015 average, correcting for missing values.

— 119 Mt of biomass are grazed in pastures and meadows.

— Around 121 Mt of vegetal biomass equivalents are imported, 60% in the form of food products, 30% in the form of crop products (non-manufactured) and the rest in the form of bio-based material products (ca. 10%).

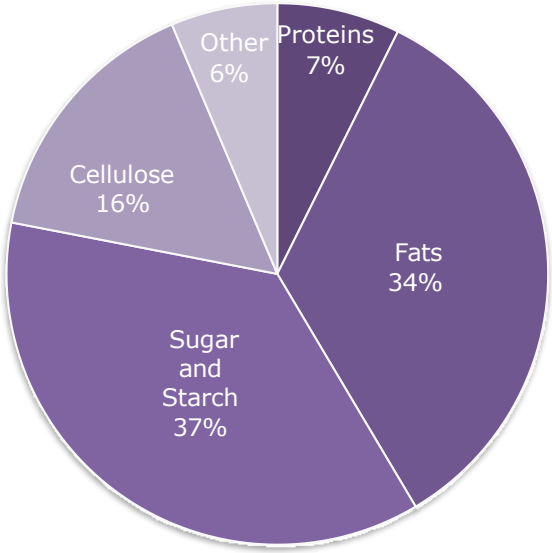
The EU biomass supply (in vegetal biomass equivalents) is mainly composed of carbohydrates (sugar and starch) and cellulose coming from cereals, fodder crops and grazed biomass. The comparison between Figure 2.8 and Figure 2.9 highlights the importance of the fat and protein components in EU imports (oilseed imports in particular).

Figure 2.8. Composition of EU-28 domestic production vegetal biomass (2013, crop residues included, grazed biomass excluded)



Total: 578 Mt of dry vegetal biomass equivalents

Figure 2.9. Composition of EU-28 imports of vegetal biomass (2013)



Total: 121 Mt of dry vegetal biomass equivalents

2.2.2.2 Uses of agricultural biomass in the EU

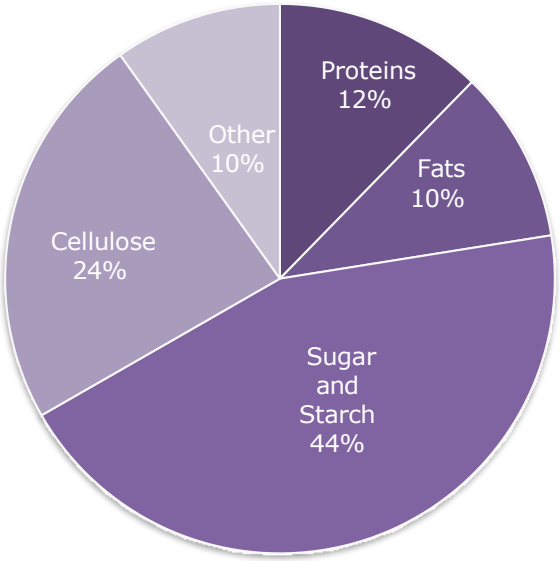
Supplies and uses do not balance in our current version of calculations for the main reason that we are not able to quantify all bio-based material and bioenergy uses of agricultural biomass. While European biomass supplies are estimated at around 818 Mt of vegetal dry matter equivalent in 2013, our quantified uses (including exports) of biomass only add up to around 730 Mt of vegetal dry matter equivalent. The difference between supplies and uses cannot be fully attributed to the underestimation of uses: misalignment between the diverse data sources used, as well as the margin of uncertainty of the data and conversion factors used also prevent from achieving a balance.

The agricultural biomass is mainly used as animal feed and food (around 75% in vegetal biomass equivalents) and around 12% is exported. The conversion of animal-based food in vegetal biomass equivalents emphasizes their importance in the total food uses: animal-based food accounts for nearly one quarter of the food uses if not converted into vegetal biomass equivalents (i.e. feed eq.) but it accounts to approximately 80% of food use when expressed in vegetal biomass equivalents (note that food uses include food waste). The other 20% is made of plant-based and aquatic-based food consumed and wasted.

Finally the comparison between the compositions of EU imports (Figure 2.9) and the one of exports (Figure 2.10) illustrates the EU position as a net importer of fats (and in a less

extent in proteins) and as a net exporter of carbohydrates and cellulose (mainly from cereals).

Figure 2.10. Composition of EU-28 exports (2013, vegetal biomass equivalents)



Total: 98 Mt of dry vegetal biomass equivalents

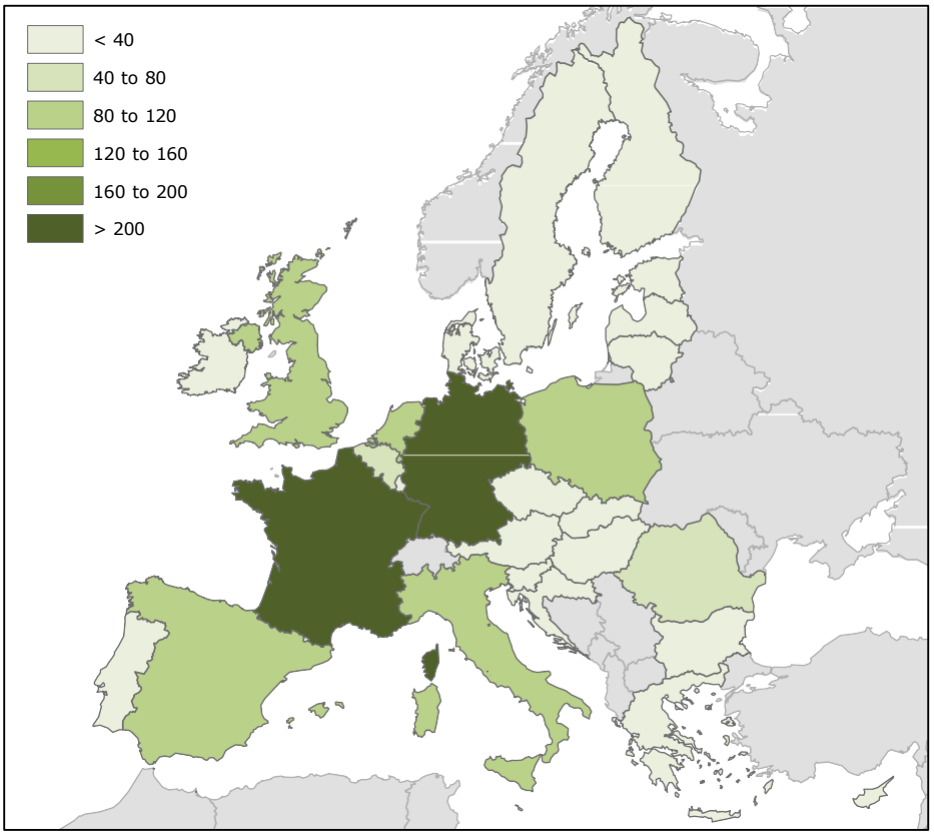
2.2.2.3 Distribution by Member States

France and Germany are the major agricultural biomass suppliers and exporters in the EU-28 (Figure 2.11). However compared to France, Germany imports a large fraction of its biomass in the form of animal products. They weigh high in the German balance of trade (especially because of their conversion to animal feed equivalents). As a result, Germany is a net importer of biomass (in vegetal equivalent) while France is net exporter (Figure 2.12).

The United Kingdom, Italy, the Netherlands, Spain and Poland are the next bigger EU biomass suppliers. Among them only Poland presents a positive balance of trade, the other four Member States being net importers of biomass (in vegetal biomass equivalents). Again, imports of animal products are particularly important in the Italian and Britannic balance of trade.

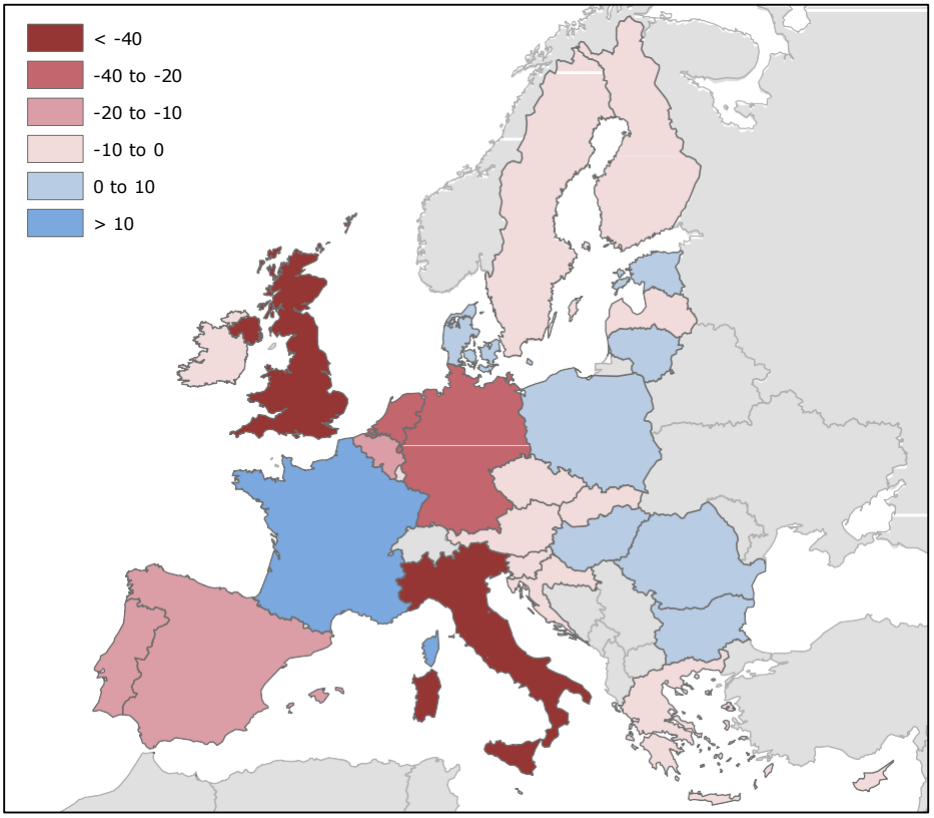
Most of the 21 remaining Member States rely on biomass imports to fulfil their biomass uses, showing a negative balance of trade. Out of these 21 Member States, only Bulgaria, Hungary, Romania, Denmark, Lithuania and Estonia are net exporters of biomass (in vegetal biomass equivalents).

Figure 2.11. Distribution of agricultural biomass supply across EU Member States in 2013



In Mt dry matter of vegetal biomass equivalents

Figure 2.12. Net trade of agricultural biomass in EU Member States in 2013



In Mt dry matter of vegetal biomass equivalents. Positives values (blue) correspond to net exports whereas negative values (red) correspond to net imports

2.2.3 Gaps, uncertainties and future developments

At this stage, the quantification of biomass supply, use and flows suffers from a lack of accuracy arising from the lack of statistics on crop residue production (see section 2.1.3) on one side, but even more from the lack of data on the use of agricultural biomass as bioenergy and as bio-based materials (bio-based chemicals, bio-based handicraft, etc.). In the case of bio-based energy, only biofuels complying with sustainability criteria are officially reported. Unfortunately, official data are not complete in terms of time and Member State coverage. Bio-based energy uses are also made of biogas and bioelectricity for which no comprehensive dataset is currently available. The same occurs in the case of bio-based chemicals and other bio-based materials derived from agricultural biomass (note that bio-based textile uses are currently approximated with the supply of fibre crops).

Data come from various data sources not harmonised among each other. Moreover, the conversion of pasture area into grazed biomass, and of fresh matter into dry matter of vegetal biomass equivalent are based on rough conversion factors (factors are set for the EU and for a selection of product groups). Therefore, mismatches are hard to correct.

More accuracy could be achieved by refining the conversion factors in use. However, filling data gaps remains a real challenge, especially in the case of manufacturing uses of biomass. Confidentiality issues are often associated with industry data. Therefore quantifying the use of biomass in the manufacturing of bio-based chemicals for instance can only stem from rough estimations based on scattered literature sources. However, it is important to note that food and feed uses are by far the main type of utilisation of agricultural biomass (in quantity). Being currently captured, the overall picture of agricultural biomass flows is already informative. Missing uses represent a very small fraction of agricultural biomass uses when measured in quantity, although they may represent a larger fraction of biomass uses when measured in economic value.

Key messages

- European Union total annual aboveground agricultural biomass production amounts to 956 million tonnes (Mt) per year from 2006-2015. 54% of this is economic production (grains, fruit, fodder biomass, etc.), 46% are residues.
- Wheat and maize residue production (149 Mt and 80 Mt per year respectively) account for half of the total EU crop residue production.
- About 75% of the EU-28 economic and residue production comes from seven countries: FR, DE, IT, PL, ES, RO, and the UK.
- Agricultural biomass flows are estimated for the EU-28 and EU Member States from 1980 to 2015.
- They are represented in the form of dynamic Sankey diagrams. Sankey diagrams enable fast comparison over time and across Member States.
- Further research is needed for the estimation of bio-based material and bioenergy use of biomass.
- Uncertainties associated with residue production estimates are still relatively large.
- To quantify the actual availability of residues for competitive uses, environmental sustainability requirements (e.g. soil conservation and biodiversity) need to be accounted for.
- EU-28 domestic production vegetal biomass is mainly composed of sugar and starch (53%) and cellulose (22%) whereas imported vegetal biomass is mainly composed of sugar and starch (37%) and fats (34%, figures of 2013).
- France and Germany contribute 32% of the total EU-28 agricultural biomass supply.
- Italy and the UK are the main net importers of agricultural biomass, whereas France is the main net exporter.

3 Biomass from forestry

Forests occupy 38% of EU land and provide a wide range of ecosystem services such as carbon storage and sequestration, habitat provision, water regulation (quality, quantity, flow), regulation of air quality, soil erosion control, recreation, wood and non-wood products. Forest ecosystems are quite diverse in many respects; site conditions, soil, age structure, species composition (70% of forests are made up of two or more tree species) make forest growth significantly different across EU. Sustainable forest management principles, the diversity of EU forests and the services they can provide drive forest management activities, thus affecting the potential supply of woody biomass to meet the demand of wood-based products and bioenergy.

Other factors significantly affect wood mobilization within the EU, the main ones being forest ownership combined with demographic changes (60% of forests belong to private owners living less and less in rural areas), fragmentation of forest lands (16 million private forest owners) and economic profitability of forest management.

In this chapter, we focus on woody biomass supply from EU forests, wood-based products and markets. It is worth recalling that biomass from forestry encompasses also non-wood forest products that have an important role in the bioeconomy of many EU regions.

3.1 Production

This section provides the knowledge base on the current production and supply of woody biomass from EU forests. It has a special focus on the portion of the forest land considered available for wood supply and does not include estimates of woody biomass in land not classified as forest, such as other wooded land or trees outside forest.

The assessment considers dimensions such as the forest area, the woody biomass stocked, the annual production of wood (forest growth) and the harvesting of wood, providing both a static snapshot in time and an analysis of trends in the past years.

The focus of the assessment is the total above ground biomass of living trees, distinguishing the main stem from the other tree compartments.

3.1.1 Methods, data sources and boundary conditions

Forest is defined as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ (FAO 2001). The land covered with small trees and shrubs not reaching minimum tree height, density and extent to qualify as forest, is referred to as other wooded land. Woody biomass is additionally found in trees outside forest. Here we focus on woody biomass from forest, thus not counting other wooded land and trees outside forest.

The main data source for forest biomass data are National Forest Inventories (NFIs), which are designed and carried out based on country specific definitions and specifications. Harmonization efforts—also supported by COST and H2020 programmes—have been undertaken by the countries in the context of international reporting obligations. Significant progress has been made, however, in many instances comparability of national statistics is still an issue. The uncertainties and differences among countries origin from a number of factors:

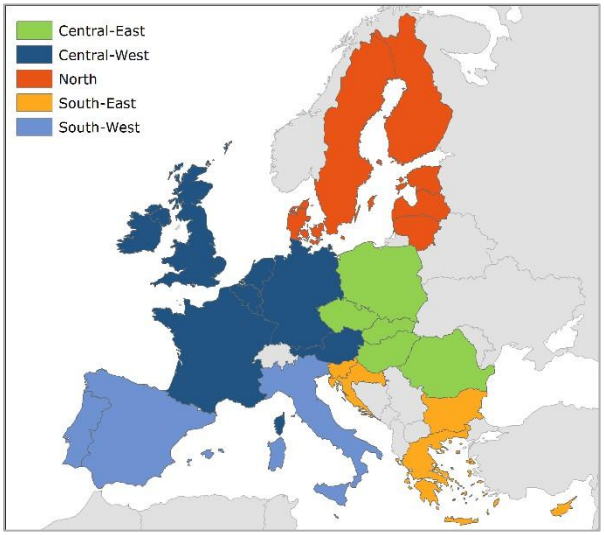
- The woody biomass assessed by the NFIs may or may not include different tree compartments depending on the country: stem with or without minimum diameter, branches, stump, tree tops, smaller trees.
- The estimation of the increment of trees (the growth rate of the forest), which is in most cases focused on the stem increment, is carried out using different methods. The resulting estimates are thus not fully comparable across countries.

- Forest inventories are carried out with different frequencies, often following multi-annual cycles. As a consequence, the estimates are not aligned in time across countries, and for the EU member states this is quite a wide range (from 1985 to 2013).
- Despite the common definition of Forest Available for Wood Supply (FAWS) — established in international reporting as the "forest where any legal, economic or specific environmental restrictions do not have a significant impact on the supply of wood" (FAO 2001)—criteria for concretely determining FAWS can differ significantly among countries.

Forest production figures found in statistics commonly refer to wood from the stem, which is the principal merchantable component of the tree, whose volume estimate is called growing stock[10]. The rest of the woody biomass, including all branches, stumps and tree tops, here referred to as other wood components (OWC), is often not accounted for. In this chapter we provide our best estimate of the total above ground living biomass (AGB) for EU-28, including both stemwood and OWC estimates, as derived from National Forest Inventories (NFI) data sources.

To harmonize the values across countries, we have addressed the main sources of uncertainties and differences in the biomass assessment, analysing a vast amount of available data in depth. The work has been carried out also in cooperation with organizations in charge of the NFIs, whose support was essential to derive harmonised biomass estimates.

We have also used modelling techniques, e.g. to reconstruct time series and align data in time. Clearly, despite the efforts undertaken to derive accurate figures, the values provided are subject to uncertainties. What is presented is therefore best EU level estimates attainable given our current knowledge. Since the data were processed using models and correction factors, the estimates provided may differ from national statistics.



To highlight regional differences, some results in the following sections will be presented broken down according to the regions shown in Figure 3.1, which follows country grouping adopted in Forest Europe (2015).

Figure 3.1. Regions in the EU applied in this chapter to summarize forest-based sector data

[10] The exact definition of growing stock may differ according to the country considered.

3.1.2 Results

3.1.2.1 Forest area

The total EU-28 forest area in 2015 amounted to 161 Mha (Forest Europe, 2015), covering 38% of the land. Of this area, 134 Mha (84%) are considered as forests available for wood supply (FAWS), see Figure 3.2.

Figure 3.2. Where woody biomass is mostly found in EU-28.

Source: Forest Europe 2015.

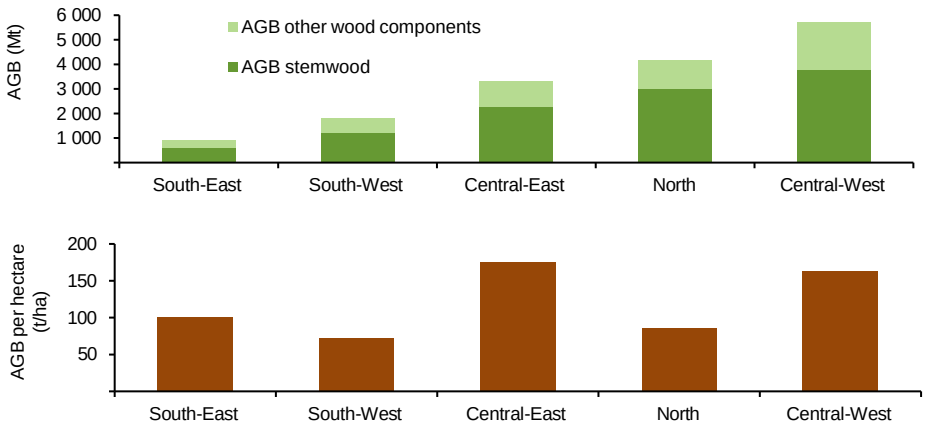
From 2000 to 2015, forest area in EU-28 has been expanding by roughly 413 000 ha per year (6.2 Mha in total), corresponding to an average rate of expansion of 0.26% per year. However, from 2010 to 2015 the average expansion rate slowed down to 339 000 ha per year, thus lower than the 15-year average.

3.1.2.2 Above ground biomass

The total above ground biomass (AGB) of EU-28 forests is estimated in 2013 to be 18 600 Mt dry weight[11]. Considering only forests available for wood supply (FAWS), the total AGB is 16 000 Mt of which 10 900 Mt (68%) is stemwood, the remaining 5 100 Mt (32%) being OWC.

Countries in Central-West Europe account for a large share of AGB (36% of EU-28), while the region of North Europe comes second (see Figure 3.3). The latter has on average lower biomass stock per hectare, mostly due to ecological factors, but also to forest management practices.

Figure 3.3. Above ground living biomass (AGB) and average AGB per hectare in the EU regions shown in Figure 3.1.



Source: JRC estimates based on NFI data.

[11] All estimates related to forest biomass are presented in oven-dry metric ton (t).

Since 2000, the stock of AGB in EU-28 forest has been increasing by 223 Mt per year on average, which corresponds to an annual rate of increase of 1.3%. AGB stock increase is key for climate change mitigation as it constitutes a significant part of the carbon sink of EU forests.

3.1.2.3 Net annual increment

The net annual increment (NAI) is defined as the wood produced in the forest annually minus losses due to natural mortality of trees, and it may be estimated using different approaches. NAI is typically reported as the increment of the stem volume in FAWS. Adapting this definition to biomass, and modelling a time series from NFI data sources, we estimated the 10-year average (2004-2013) of NAI of EU-28 forests as 349 Mt/yr. Together with the annual increment of OWC (95 Mt/yr), the NAI of the total biomass in FAWS equals 444 Mt/yr.

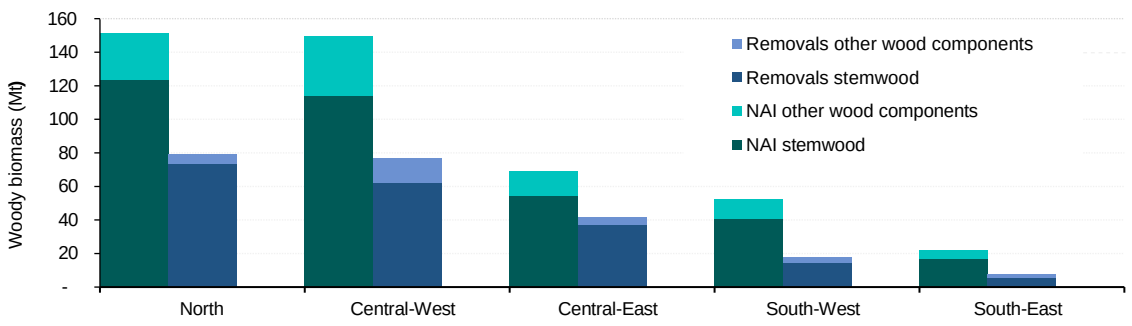
Considering the NAI of all EU-28 forests, the 10-year average for the total above ground biomas (stemwood and OWC) is 510 Mt/yr, thus additional 66 Mt/yr are produced in forests which are not available for wood supply.

Since the year 2000, the average NAI per hectare of EU-28 has been slightly decreasing. The NAI in total biomass went from 3.33 t/ha/yr in 2000 to 3.25 t/ha/yr in 2013, according to our estimates. A declining trend in the NAI was already registered by Nabuurs et al. (2013), attributed to a combination of ageing of EU forests and high growing stocks, especially in Central-Western Europe. More detailed explanations about this process were provided in Pilli et al. (2017). Concerning over-mature forests, they tend to be more prone to pests and in general are more vulnerable to natural disturbances.

The NAI indicates the amount of woody biomass added to the AGB per year. If the harvested living biomass exceeds the NAI, the stock of living biomass will decrease. However, in order to be conclusive, such a comparison should be made on a multi-annual basis.

Figure 3.4 shows NAI in EU regions compared to removals (10-year averages, 2004-2013). Northern and Central-Western European countries together account for two thirds of the EU-28 NAI (68%). At EU-28 level, the increment of stemwood is 79% of the total NAI.

Figure 3.4. NAI and removals in the European regions; FAWS, 10-year averages 2004-2013, woody biomass in Mt.



Source: Removals, JRC calculation form Eurostat; NAI, JRC calculation from NFI data.

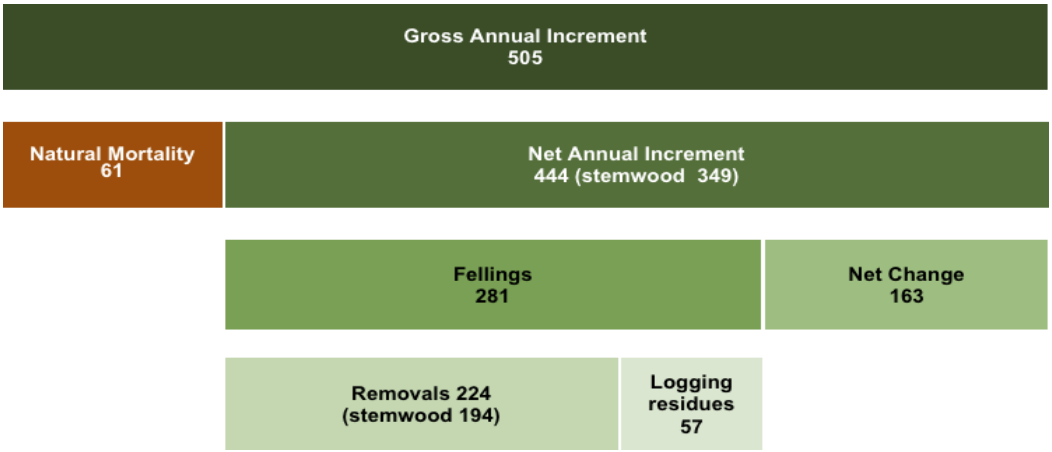
3.1.2.4 Removals

Only part of the biomass from felled trees is removed from the forest during harvesting operations, the remainder being left on the ground as primary logging residues. This is an important management practice. Excess removal of residues from forest sites implies removal of nutrients and organic matter, affecting soil and, indirectly, influencing competing vegetation and soil microclimate. This in turn may alter soil physical properties,

reduce soil carbon and forest productivity, and may also adversely affect biodiversity (Vance et al., 2018). However, effects are highly variable and site-dependent, thus limiting the possibility of generalized conclusions about potential impacts. For example, in fire prone areas a more intense removal of residues is a positive management practice, since it reduces the fuel load thus lowering fire hazard.

Figure 3.5 presents the relationship between different terms used for growth, fellings and removals[12], together with EU-28 estimates (2004-2013 yearly averages). Starting from removals as reported by Eurostat, we estimated that, on average, 281 Mt were felled each year, of which 224 Mt were removed, while 57 Mt, that is 20%, were left in the forest as logging residues. Removals comprise 194 Mt stemwood (87%) and 30 Mt OWC (13%). The NAI not felled corresponds to the net annual change in living biomass in EU-28 forests and equals 163 Mt.

Figure 3.5. Increment, fellings and removals in EU-28 forest area available for wood supply; average values in Mt/yr for the period 2004-2013.



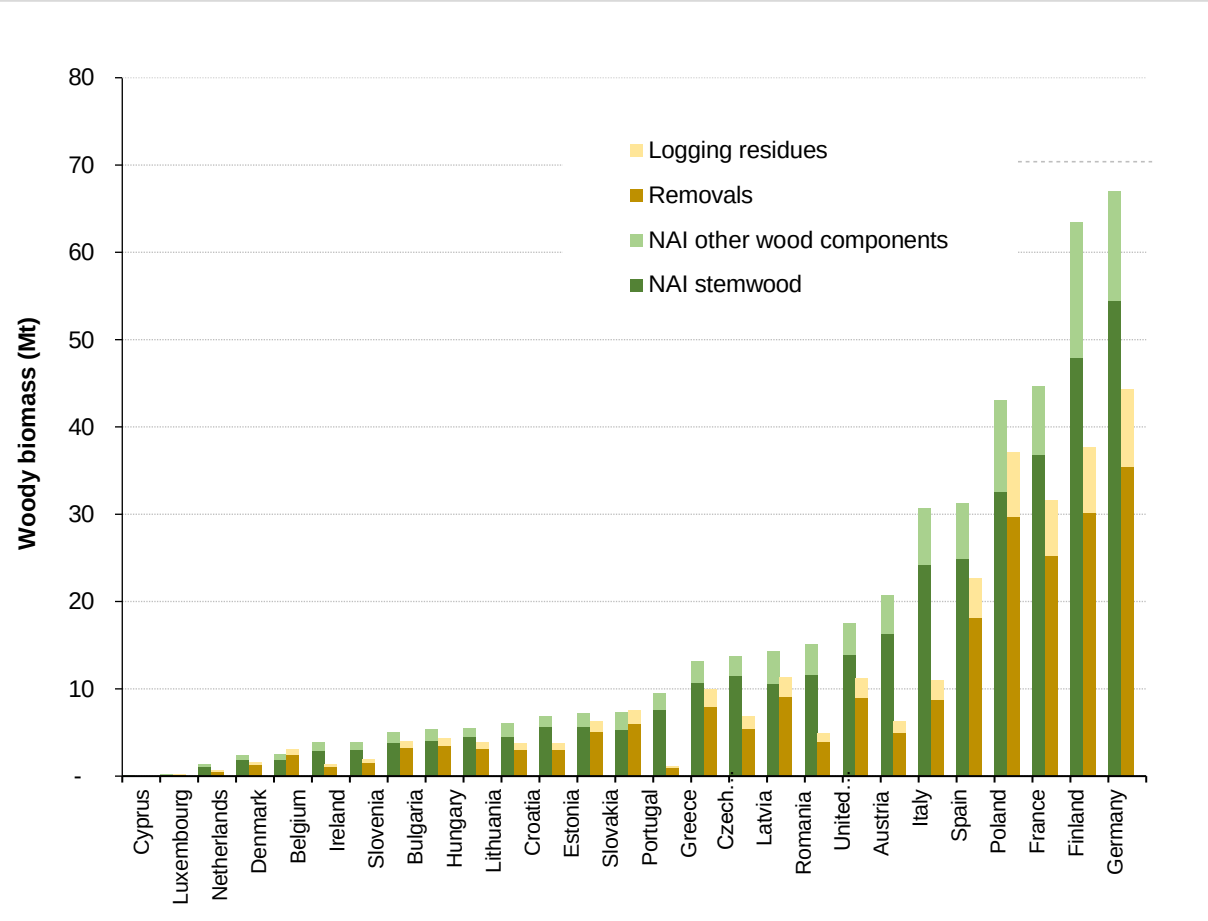
Source: JRC calculations from Eurostat and NFI data.

We estimated natural mortality using modelling as described in Pilli et al. (2017). Mortality refers to the death of forest trees due to the natural turnover rate, thus excluding disturbances such as wildfires or storms. Gross Annual Increment was estimated summing natural mortality and NAI.

The fellings-to-NAI ratio, of harvesting ratio, is an indicator of forest management intensity. When felling and NAI are estimated based on total biomass (stemwood plus OWC), the average harvesting ratio for EU-28 is 63%. However, marked differences exist among countries (see Figure 3.6)

[12] Fellings refer to the cutting down of trees, removals refer to the wood actually removed from the forest.

Figure 3.6. Harvesting and net annual increment in EU MS (10-year annual averages 2004-2013); woody biomass in Mt dry weight



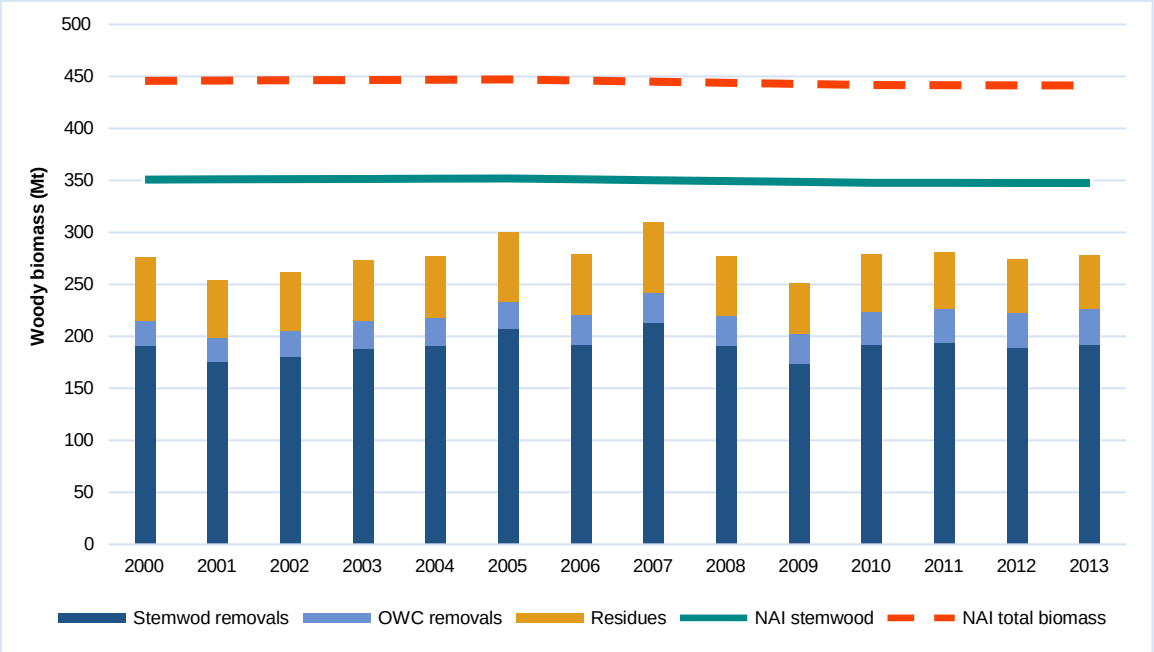
Source: Removals, JRC calculation form Eurostat; NAI, JRC calculation from NFI data.

It is important to note that fellings and removals statistics are subject to high uncertainties. NAI is estimated with high uncertainty too, however its difference from the true value can be either positive or negative while, according to our analysis illustrated in the second part of this chapter, removals at EU-28 level are significantly underestimated (up to 20% as an EU level conservative estimate, although with large differences among countries). Consequently, the actual EU harvesting ratio is likely to be at least 12% higher[13]. Nevertheless, this still implies a EU harvesting ratio below 100%, resulting in a steady increase of forest biomass stock, although with significant differences among MS and from year to year. Because of the increase in biomass stock, EU forests are overall acting as a carbon sink.

Figure 3.7 depicts the time series of annual removals and increments. At EU-28 level, removals have consistently been lower than increment. This fact, together with the expansion in forest area, has resulted in increasing woody biomass stocks in the forest over time. The chart shows minimum removals in 2009, clearly due to the 2008 economic crisis. The slight decline of NAI over time is barely visible.

[13] A major reason behind this underestimation is underreporting. In many instances small-scale informal loggings (and subsequent use) are not reported in the national statistics (e.g., fuelwood harvesting).

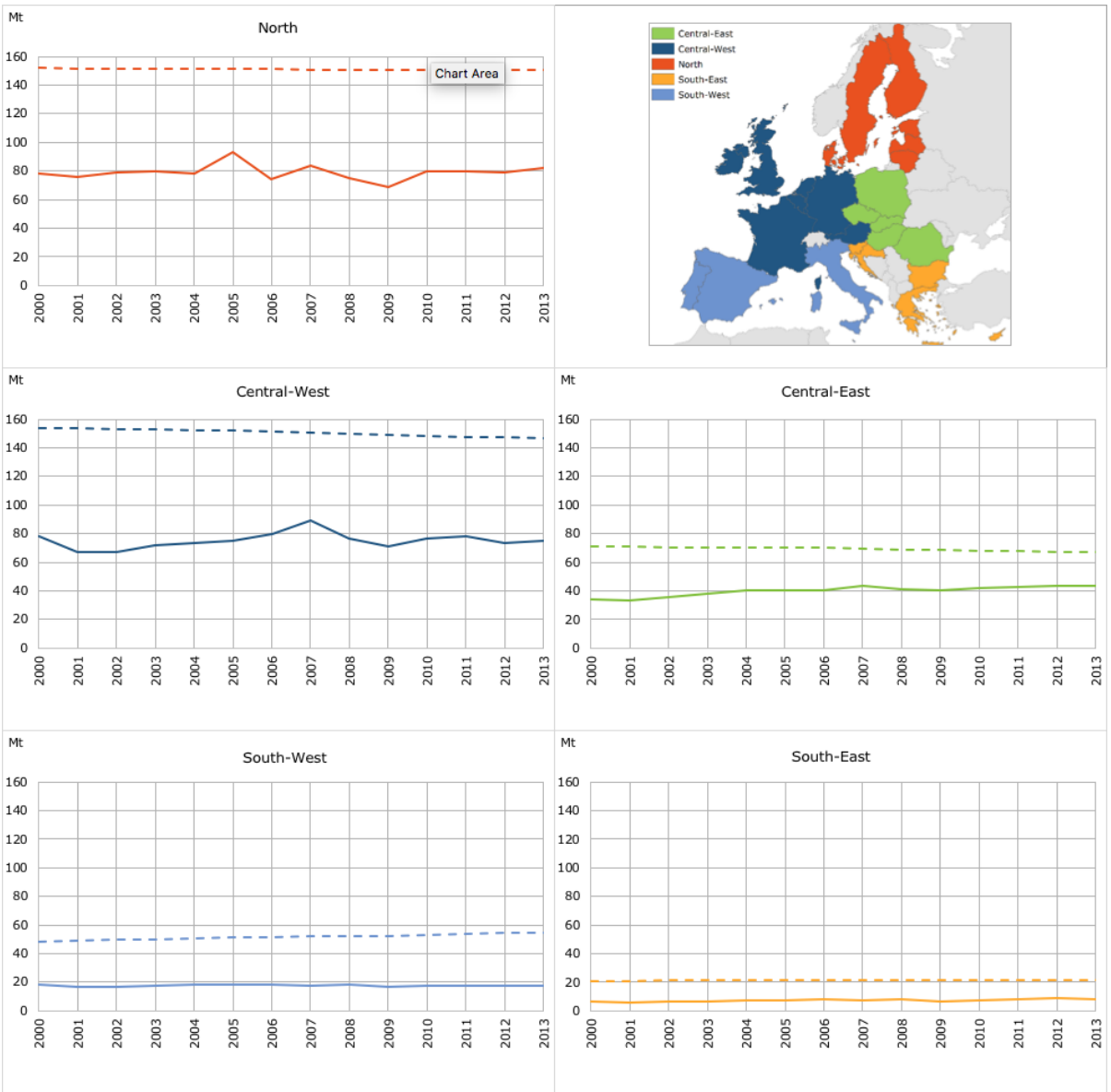
Figure 3.7. Harvesting and net annual increment of EU-28 forest area available for wood supply; woody biomass in Mt dry weight.



Source: Removals, JRC calculation form Eurostat; NAI, JRC calculation from NFI data.

Time series for the five regions of EU (Figure 3.8) show that NAI is substantially larger than fellings in all regions and years considered. NAI is on the increase in South-West EU (while removals here show no clear trend). In all other regions NAI is either decreasing over time or showing no clear trend (South-East EU). This might turn out to be problematic in the longer term, as the harvest level is not declining. On the contrary, it seems to be on the rise again after the slump following the financial crisis. On the other hand, where the decline in NAI is mainly due to ageing of the forest, harvesting may favour an increase through rejuvenation of forest stands.

Figure 3.8. Removals (stemwood and OWC, continuous lines) and NAI (total biomass, dashed lines) in EU regions



Source: Removals, JRC calculation form Eurostat; NAI, JRC calculation from NFI data.

3.1.3 Gaps, uncertainties and future developments

Efforts to harmonize forest inventory estimates have been pursued since the first international reporting exercises in the 1990s; however lacking comparability of national statistics is still an issue today. In addition, although a common definition of forest available for wood supply is shared, the way it is applied in practice differs significantly between countries. JRC is working, also collaborating with the NFI organizations, towards improving the harmonized assessments of forest resources.

The highest uncertainties are associated to reported wood removals, which are likely to be underestimated, and to NAI. Although there are marked differences among countries regarding data precision and accuracy, at the EU level the reporting of wood removals in both quality and quantity should be improved.

JRC will continue collaborating with NFIs to support the efforts towards harmonization of estimates, particularly addressing the more critical aspects indicated in this report. A concrete attempt to derive an analytical definition of the forest area not available for wood supply to be reported as a GIS layer across EU is on-going, identifying, quantifying and mapping the environmental, social or economic restrictions that have a significant impact on the supply of wood.

We are also working to complement NFI derived statistics with remote sensing assessments of forest biomass. Maps of aboveground forest biomass have been produced using satellite data calibrated with ground observations. However, the accuracy assessment of the existing maps is limited by the lack of reference data consistent over the study region and the uncertainty in their reliability is a severe limit to their operational use. Current advances are reported by Avitabile and Camia (2018).

Despite the recognized challenges, the advantages of complementing NFI data with spatially explicit assessments of biomass are remarkable for the enhanced analysis it would make possible, for example enabling the analytical assessment of cost supply curves or the integrated analysis of potential wood supply with the provision of other ecosystem services, thus supporting sustainable forest management.

3.2 Supply, uses and flows

Forest-based biomass supply chains comprise the provision of primary products (roundwood and biomass from other tree compartments), industrial transformations, and the consumption of wood-based products and energy. The description of physical flows relies on comprehensive datasets covering EU member states over reasonably long time. These datasets provide information on the provision of primary products, industrial conversion as regards semi-finished wood-based products and wood pellets, and, to a lesser extent, primary and secondary wood energy supply. In addition, international trade of large volume wood-based commodities is covered by comprehensive data sets, both in quantity and monetary terms.

3.2.1 Methods and data sources

The analysis of supply, uses and flows in the forest-based sector relied on two groups of comprehensive—in terms of reasonably long time-series—international datasets. The first one entails information concerning traditional, semi-finished wood-based products (i.e., sawnwood, wood-based panels, and paper and paperboard) and, to some extent, wood pellets, as regards production and trade (from the Joint Forest Sector Questionnaire (JFSQ)) and conversion factors and input-output coefficients (from Infro). The second group of data sets concerns the main raw materials or partly processed (intermediate) products used for the production of wood-based products and wood pellets—roundwood removals and trade, wood pulp production and trade, industrial residues production and trade, recovered paper production and trade (JFSQ). For energy uses of wood, data availability is scarcer. The main data source here is the Joint Wood Energy Enquiry (JWEE), which also provides conversion factors and input coefficients for wood pellets production. The JWEE is complemented with data form the national renewable energy action plans (NREAPs).

Data source	Organization	Data
Joint Forest Sector Questionnaire (JFSQ)[14]	Eurostat, UNECE, FAO, ITTO	Production, imports and exports of forest products and removals
Resource shares	Infro (Mantau 2016)	input/output coefficients for wood products
Forest product conversion factors for the UNECE region[15]	UNECE, FAO	Bark correction factor
Joint Wood Energy Enquiry (JWEE)[16]	UNECE/FAO Forestry and Timber Section	Energy use of wood, input coefficients, conversion factors
NREAPs and Progress Reports Data Portal[17]	JRC	Energy use of wood

Using these data sets, we first discern trends in production, consumption and trade of wood-based commodities, and relate production and consumption patterns to forest resource endowments. The same data allow us to set up Wood Resource Balances (WRBs). The WRB, a balance sheet for woody biomass, is useful for providing an overview over

[14] https://www.unece.org/forests/forestsfpmonlinedata/jfsq.html
[15] http://www.unece.org/fileadmin/DAM/timber/publications/DP-49.pdf
[16] http://www.unece.org/forests/jwee.html
[17] https://ec.europa.eu/jrc/en/scientific-tool/nreap-data-portal

sources and uses of woody biomass—and, most importantly, highlight data gaps and inconsistencies. As for any balance sheet, the two sides should balance, were all data reported correctly. The WRB summarises all flows of woody biomass from the forest to wood-based industries and wood-based energy uses. The left side of the balance sheet presents the sources of woody-biomass; primary (from forests and other wooded land) and secondary (industrial by-and co-products and post-consumer wood), whereas the right side of the balance sheet show in which sectors the woody biomass is used, all in a common measurement unit (see, e.g., Mantau 2010). The WRB takes into account the fact that wood is a highly versatile material, which can be used and reused in many different processes, so-called cascading. Further detailing where different woody-biomass sources are used, one can construct flow charts over woody biomass flows. These Sankey Diagrams depict particularly well the re-use of woody biomass, i.e., the cascade uses of woody biomass, as well as potential synergies and competition between different uses of biomass.

In this section data and estimates will mainly be presented in measurement units used in international reporting on wood-based products. Reference to corresponding oven-dry weight will be provided where appropriate.

3.2.2 Results

Forest endowment is apparently positively correlated not only to the production of wood-based commodities, but also to the consumption thereof, in particular solid-wood products —an aggregation of sawnwood and wood-based panels (see Figure 3.9 and Figure 3.10). To a large extent, this can be explained by a long tradition of using wood as a construction material in forest rich countries. As an example, in Finland and Sweden wood account for between 85 to 95% of the single-family housing market (Prokofieva et al. 2015). This type of cultural characteristics is important to consider when assessing future uptake of, e.g., wood-frame construction (Jonsson 2009).

Figure 3.9. Growing stock per capita in EU Member States (m^3/capita), 2013

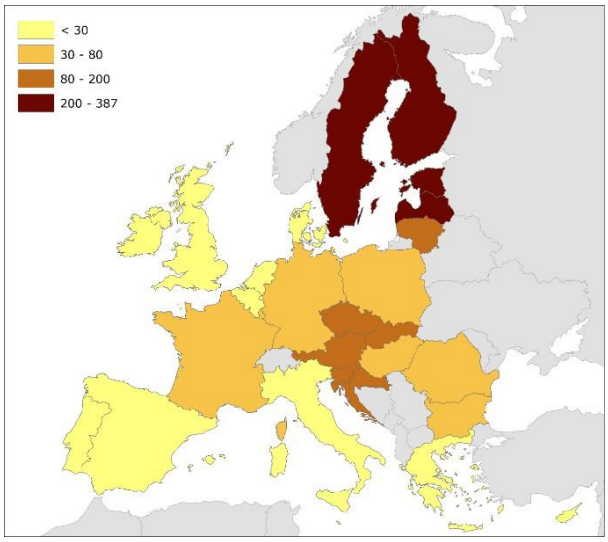
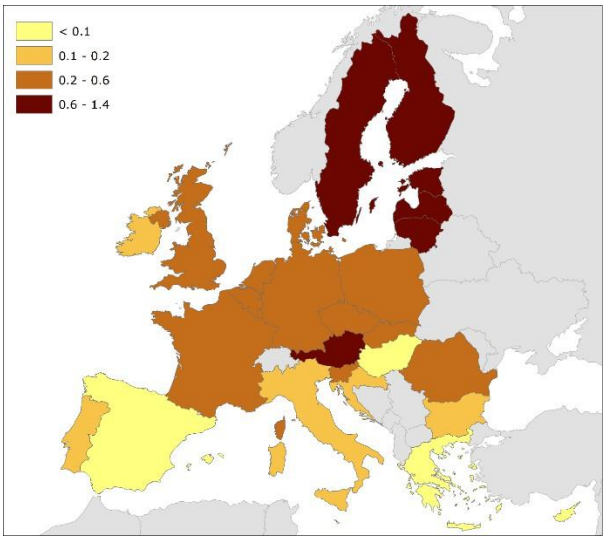


Figure 3.10. Consumption of solid-wood products (sawnwood and wood-based panels) per capita (m^3/capita), 2013

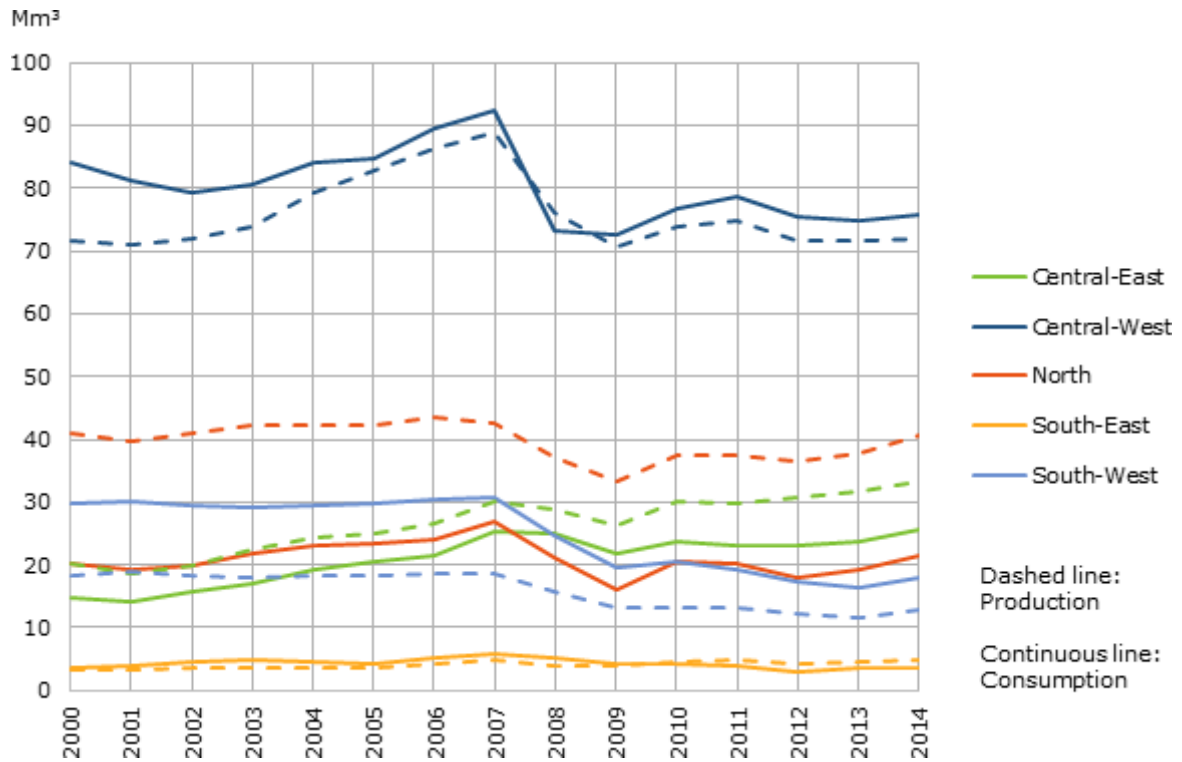


Production and consumption of solid-wood products over time for the five sub-regions of EU used in this report to summarize the results are depicted in Figure 3.11.

All regions show a marked drop in production at the time of the financial crisis of 2008-2009, which had a strong impact on final demand. Of particular importance was the drop in housing starts and ensuing fall in the demand for construction timber (Prokofieva et al. 2015). Since then there has been somewhat of a recovery. However, only the region of Central-East EU has surpassed pre-crisis production levels by 2014. The largest producer

in absolute terms, Central-West EU, does not show any consistent increasing trend since 2009 and production in 2014 is still only some 80% of its peak level in 2007. Consumption patterns are largely the same (Figure 3.11). The EU as a whole is a net-exporter of solid-wood-products and since consumption contracted more than production during the financial crisis, net-exports have increased.

Figure 3.11. Solid-wood products production and consumption for five sub-regions of the EU (in Mm^3)



For paper and paperboard—an aggregation of all paper grades—the decrease in production, and, above all, consumption in all sub-regions of the EU in the aftermath of the financial crisis is aggravated by the structural downturn caused by electronic communication and information technology (ICT) increasingly substituting for printed media (Jonsson et al. 2017). Thus, after an initial recovery, none of the sub-regions, except Central-East EU—the only sub-region that has surpassed pre-crisis production and consumption levels by 2014—shows any consistent increases in production and consumption of paper (Figure 3.12). EU as a whole is a net-exporter of paper and paperboard, and net-exports are on the increase as consumption is falling more than production.

Figure 3.12. Paper and paperboard production and consumption for the five sub-regions of the EU (in Mt, dry weight)

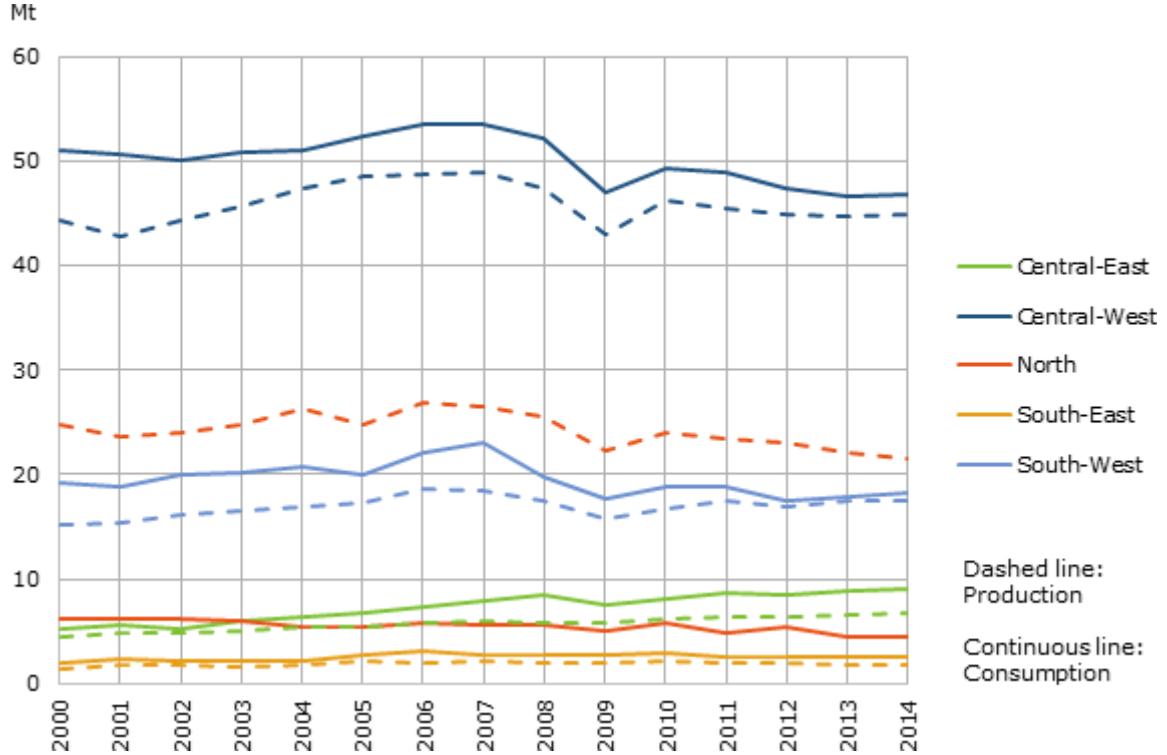


Table 3.1 presents the summaries of EU member States WRBs and the EU level aggregate, i.e., the sum of member states' WRBs. Comparing the sum of reported sources on the left-hand side with the sum of reported uses on the right-hand side, one arrives at over 98 million cubic meters (Mm^3) of solid wood equivalents (SWE) of 'missing sources'. Given instances where information on uses of woody biomass are missing, or remarkably low values reported, the absolute unbalance is even larger. It is more than reasonable to assume that a considerable part of these unaccounted for, or 'missing', sources consist of un(der)-reported removals. Not the least fuelwood removals constitute considerable sources of uncertainty. The poor quality of data for fuelwood—a heterogeneous commodity in statistics comprising not only roundwood but also tree tops and branches—is to a large extent the consequence of considerable quantities never being marketed, e.g., being harvested and used by non-industrial private forest owners themselves. Assuming most of the estimated 'missing' sources consist of unreported removals, actual fellings would be up to 20% higher, which in turn implies an increase in forest management intensity by some 12%.

Energy accounts for almost half (48%) of total reported uses of woody biomass on EU-28 level. This share of energy use is higher than previous estimates of 43% for 2010 (Mantau 2010) and 42% for 2005 (Steierer 2010). Bearing in mind that energy uses are underreported, the energy share of woody biomass uses should reasonably be even higher. Indeed, targets for renewable energy set by the EU have resulted in a surge in the consumption of woody biomass. Reported fuelwood removals—underestimated as already discussed—increased from around 70 Mm^3 to about 99 Mm^3 between years 2000 and 2015, while consumption increased from about 69 Mm^3 to around 99 Mm^3. Wood pellets has experienced even stronger relative consumption growth, from 14.3 Mt in 2012 (data are only available from 2012) to 20.5 Mt by 2015. During the same period, EU production increased from 11 to 14.2 Mt. Hence, imports have been growing rapidly. Imported solid biofuels, mainly composed of wood pellets, accounted for around 7% of all primary energy production from solid biofuels in the EU-28 in 2013 (Eurostat).

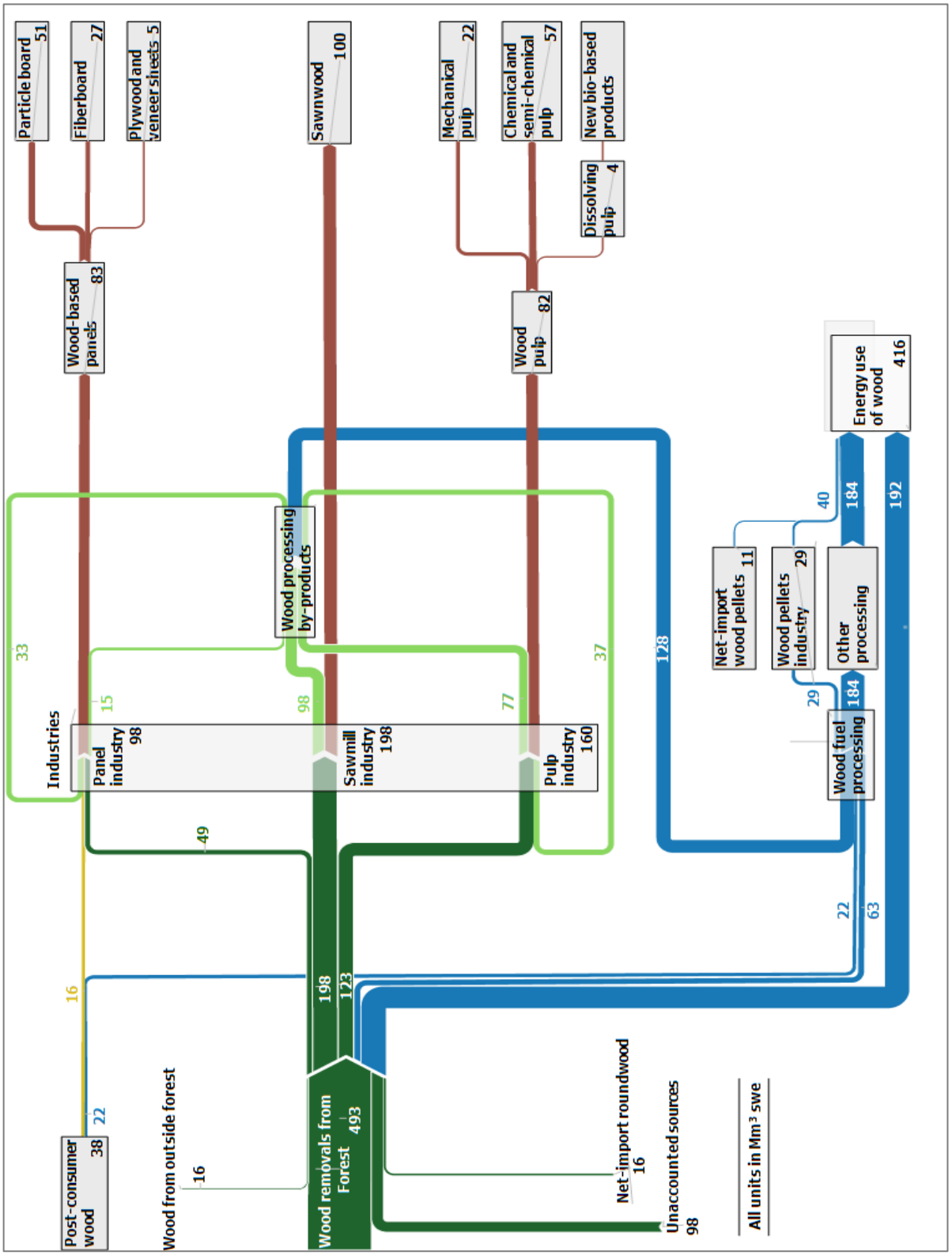
Table 3.1. EU-28 Wood Resource Balances in 2013 (thousands of m^3 of solid wood equivalents - last row in Mt dry weight)

1000 m^3 SWE	Sources			Uses		Balance
Member State	**Primary**	**Secondary**	**Post-consumer wood**	**Material**	**Energy**	**(Uses - Sources)**
Austria	29,946	13,912	1,163	30,069	23,656	8,704
Belgium	10,331	5,449	1,749	9,146	12,143	3,760
Bulgaria	5,889	1,056	0	3,837	NA	-3,108
Croatia	4,805	327	243	3,105	2,113	-157
Cyprus	22	4	0	4	88	66
Czech Republic	17,106	4,865	43	12,530	10,415	931
Denmark	4,142	5,458	566	1,601	10,685	2,120
Estonia	6,255	1,480	35	5,746	4,972	2,949
Finland	71,452	33,813	560	65,302	38,662	-1,861
France	59,481	11,841	5,278	32,016	46,627	2,043
Germany	71,806	24,559	15,172	69,045	65,911	23,418
Greece	2,231	295	18	819	2,327	601
Hungary	5,698	191	0	1,100	2,617	-2,171
Ireland	3,022	1,074	356	3,037	1,688	273
Italy	12,821	8,889	3,376	10,180	56,113	41,208
Latvia	10,455	1,653	0	10,783	NA	-1,325
Lithuania	6,127	1,629	0	4,333	1	-3,422
Luxembourg	579	318	69	1,098	399	532
Malta	2	2	0	0	8	5
Netherlands	1,596	1,417	1,086	1,046	4,135	1,082
Poland	43,401	9,049	1,121	28,659	11,134	-13,779
Portugal	13,295	8,463	206	17,346	13	-4,605
Romania	17,863	5,891	1,868	19,553	35,295	29,226
Slovakia	6,434	2,520	37	6,595	6,556	4,160
Slovenia	3,042	861	25	2,111	2,890	1,072
Spain	17,300	7,418	517	17,354	12,878	4,995
Sweden	87,334	43,222	1,839	83,835	50,514	1,955
United Kingdom	12,787	11,916	2,228	13,339	13,364	-228
EU-28	**525,222**	**207,571**	**37,556**	**453,589**	**415,203**	**98,443**
EU-28 (Mt)	**241.6**	**95.5**	**17.3**	**208.6**	**191.0**	**45.2**

Figure 3.13 depicts a woody biomass flow chart for EU-28, a so-called Sankey Diagram. The importance of the sawnwood industry is clearly visible. Sawmilling within EU is at the same time the largest industrial user of woody biomass and the main source of secondary wood fibres, used by wood-based panel and pulp industries as well as for energy. Further, as sawlogs represent the economically most valuable part of trees, the sawmill industry is key in mobilising woody biomass from forest owners (Prokofieva et al. 2015). The cascade uses of woody biomass within the wood-based economy is evident, as are synergies and competition. The energy sector is by far the largest user of EU internal wood processing residues and by-products. The panel industry is likewise largely based on EU wood processing residues and by-products. Considering also post-consumer wood, secondary wood fibres produced within the EU make up half of the wood resources used for panel production, making panel industry the second largest user of EU-28 secondary fibre after energy generation. The pulp industry is also a major user of recycled fibres; this feedstock accounts for nearly a quarter of woody biomass use. Thus, the energy sector, wood-based panel and pulp industries are all synergic to the demand for sawnwood, at the same time as they compete for the same feedstocks. The paper production focus of the EU-28 pulp industry is apparent, dissolving pulp making up less than five percent of the output. About 74% of dissolving pulp is used for viscose production (and further to textiles), the remaining 26 % comprise more than ten different product categories, including plastics,

explosives, food industry, pharmaceuticals, cosmetics, and glues, aggregated as New bio-based products in the Sankey Diagram.

Figure 3.13. Woody biomass flows in EU-28 (2013, values in Mm^3 SWE)



3.2.3 Gaps, uncertainties and future developments

As already hinted at, there are numerous uncertainties in the data. The most critical concerns harvest levels and removals of woody biomass from EU forests. Another major uncertainty relates to energy uses, values are often underestimated or at times outright missing. A particular challenge is household use of fuelwood, oftentimes a non-marketed good. Data uncertainties obviously hinder efficient analysis.

The current analyses do not deal with so-called emerging wood-based products. There is a plethora of such products, encompassing areas such as construction components, fuels, chemicals, plastics, and textile fibres. As it is impossible to consider all (potential) products and conversion pathways, ongoing work first entails a pre-selection of products, based on criteria such as, e.g., technical readiness, biomass utilization efficiency, sustainability, volume of wood use, etc. Then it is necessary to identify the main production pathways for each product (which, e.g. can be a platform chemical), main substitutes/competing products, market share of the bio-based product, and the market share of the wood-based pathway (value-chain) inside the bio-based market. Further work will be geared to acquire information as to product price, and, as far as possible, production costs.

The flow analysis developed so far concerns the links between the supplies of primary products and the provision of secondary products as well as the eventual reuse. However, it reveals only parts of the economic activities that rely on the supply of woody biomass. To provide a more detailed picture of the economic role of the wood-based sectors, the forest-based value chains will be further developed to include wood-based consumer products—products directly bought by households, corporate sectors, and the government for its own use—such as, e.g., paper for home and office printing and furniture. To capture the trajectory of wood trough the economy, from the forest to consumer products, we will track the supply and use of forest-based products by main sectors as reported in supply-use and input-output tables. The work will focus on the contribution of the forest-based sector to the value-added as well as employment.

Key messages

The total stock of the aboveground biomass in EU-28 forests has been increasing since year 2000 at a rate of approximately 1.3% per year, although the forest growth rate (net annual increment) has been slightly declining overall, mostly due to ageing of forests.

The average annual harvest level – 281 Mt (of which 224 Mt are removed from the forest) – amounts to 63% of the growth rate (net annual increment) of EU-28 forests – 444 Mt per year. However, WRB analysis confirms that removals are under-reported to a considerable degree. Since reported removals are underestimated, the actual forest management intensity at EU level is likely to be up to 12% higher. Even so, harvest is still not exceeding the annual increment, thus not depleting the growing stock. Efforts to improve the current assessments should be pursued.

Consumption patterns as regards wood-based products—in particular, solid-wood products—are related to forest endowment. Thus, forest rich countries have a long tradition of using wood in construction. These differences in traditions and culture are important to consider when assessing the possible uptake of wooden construction.

Production and consumption of solid wood products decreased as a result of the financial crisis and the resulting downturn of housing starts. Since then, most regions of EU show some recovery, though only Eastern member states have surpassed pre-crisis consumption levels by year 2015. As consumption contracted more than production, EU net-exports have increased.

For paper and paperboard, the decrease in production and consumption in the EU caused by the financial crisis is aggravated by a structural downturn caused by electronic ICT substituting for printed media. Since consumption has fallen more than production, net-exports are on the increase

A wood resource balance (WRB) indicates that for the EU as a whole there are some 98 Mm^3 of 'missing' sources. To a considerable extent, they are the result of unreported fellings.

On EU level, reported data indicate that energy accounts for nearly half (48 %) of the total use of woody biomass, the remaining 52% being material uses. Energy use of wood has been increasing, not the least wood pellets consumption.

A Sankey diagram of woody biomass flows highlights the crucial role of the sawmill industry, as the largest industrial user of woody biomass as well as the main supplier of by-and co-products used in wood-based panel and pulp industries as well as for energy generation.

WRBs also highlight data uncertainties related to energy uses of woody-biomass, at times not captured in official data. Household use of fuelwood poses a major challenge here, as it oftentimes is not registered through official market channels.

Intensifying the cascade use of woody-biomass—making even more efficient use of industrial by- and co-products—and increasing the use of waste-wood would increase the supply base and reduce the pressure on EU forests.

This assessment has not dealt with so-called emerging wood-based products. For these products, data availability is scarcer and scattered compared to the traditional, large-volume flows analysed here. This necessitates alternative forms of data gathering and analysis. Work to this end has started, in collaboration with the European Forest Institute.

Further, indicators of employment and value added in the forest-based sector will be developed, to allow a more comprehensive assessment of the wood-based bioeconomy.

4 Biomass from fisheries and aquaculture

Fisheries and aquaculture are important sources of food, nutrition and income and support the livelihoods of hundreds of millions of people around the world (FAO 2016). World fish supply per capita reached a new record high of 20 kg in 2014 and fish continues to be one of the most-traded food commodities worldwide. Both fisheries and aquaculture have the potential to make a significant contribution to food security and adequate nutrition levels for a global population expected to reach 9.7 billion by 2050 (FAO 2016).

Production from fisheries and aquaculture by the EU-28 Member States reached 6.8 Mt live weight in 2014 representing 3.2% of global production (EU 2016), indicating that in global terms the EU is a relatively small player. In 2014, approximately 5.5 Mt (81%) were produced from wild fisheries and 1.28 Mt (19%) from aquaculture.

Trade figures for 2013 indicate that the EU is a net importer of fisheries and aquaculture products. Imports into the EU-28 from third countries in 2013 totalled 5.95 Mt, with a value of almost 21 million euros, while exports amounted to 2.15 Mt with a value of 4.3 million euros (EU 2016).

The share of world fish production utilized for direct human consumption has increased significantly in recent decades, reaching 87%, or more than 146 Mt, in 2014 (FAO 2016). Almost all of the remaining 21 Mt was destined for non-food products, with 76% (15.8 Mt) reduced to fishmeal and fish oil. The rest was largely utilized as fish for ornamental purposes, culture (fingerlings, fry, etc.), bait, pharmaceutical uses, and as raw material for direct feeding in aquaculture, for livestock and for fur animals (FAO 2016).

4.1 Production

Management of wild capture fisheries varies in different parts of the world but in general, management instruments are designed to control exploitation rates in an attempt to achieve objectives related to fish stock biomass. Fisheries Management in the EU is carried out under the provisions of the Common Fisheries Policy (CFP, EU 2013), which aims to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens. Article 2 of the CFP lists more specific objectives and targets for EU fisheries management, notably the aim to ensure that the exploitation of living marine biological resources takes place in sustainable conditions. This approach implies the need to maintain and/or restore populations of harvested species above levels that can produce the maximum sustainable yield (MSY). MSY is defined as *'the highest theoretical equilibrium yield that can be continuously taken on average from a stock under existing average environmental conditions without significantly affecting the reproduction process'*. Furthermore, in order to reach the objective of progressively restoring and maintaining populations of fish stocks above biomass levels capable of producing maximum sustainable yield, the maximum sustainable yield exploitation rate (F_{MSY}) shall be reached by 2015 where possible and, on a progressive incremental basis, at the latest by 2020 for all stocks.

According to FAO (2016a), in 2013, 31.4% of fish stocks were estimated as fished at a biologically unsustainable level and were therefore overfished, while 58.1% were being fully utilised and 10.5% were considered underfished. Such estimates indicate considerable potential to increase the biomass production from global fish populations by increasing the exploitation rate on underfished stocks. Furthermore, reducing the exploitation rate on those that are currently overfished will also lead to an increase in stock biomass, thereby increasing in the short and medium term the potential production from those stocks.

4.1.1 Methods, data sources and boundary conditions

Assessing the world's biomass of wild fish stocks is not straightforward. In contrast to terrestrial ecosystems based on a direct management control (agriculture, forest, etc.), the fish population in the oceans must be estimated on the basis of catch data and/or surveys.

Other sources of uncertainty in estimating the biomass of wild fish stocks include the allocation of catches to the relevant stock. Fish populations are not restricted to management area boundaries and some species are highly migratory and are caught in mixed-stock fisheries. Furthermore, in many cases, estimates of fish stock biomass are available only for spawning stock biomass (the mature part of the stock) rather than total stock biomass or that part of the stock that can be fished by the fleets exploiting it (exploitable stock biomass).

A further complication when estimating fish biomass is the issue of discards. Incidental and unwanted catches occur in many of the world's fisheries and such catches are commonly returned to the sea, very often dead. Discards are not only undesirable from a management point of view; they also represent a waste of biological resources. On average, some 8% (6.8 Mt) of the total catch by weight of marine organisms caught by fishing boats worldwide is discarded every year, of which about 1.3 Mt is discarded in the fisheries of the Northeast Atlantic, mostly in EU waters (Kelleher 2005).

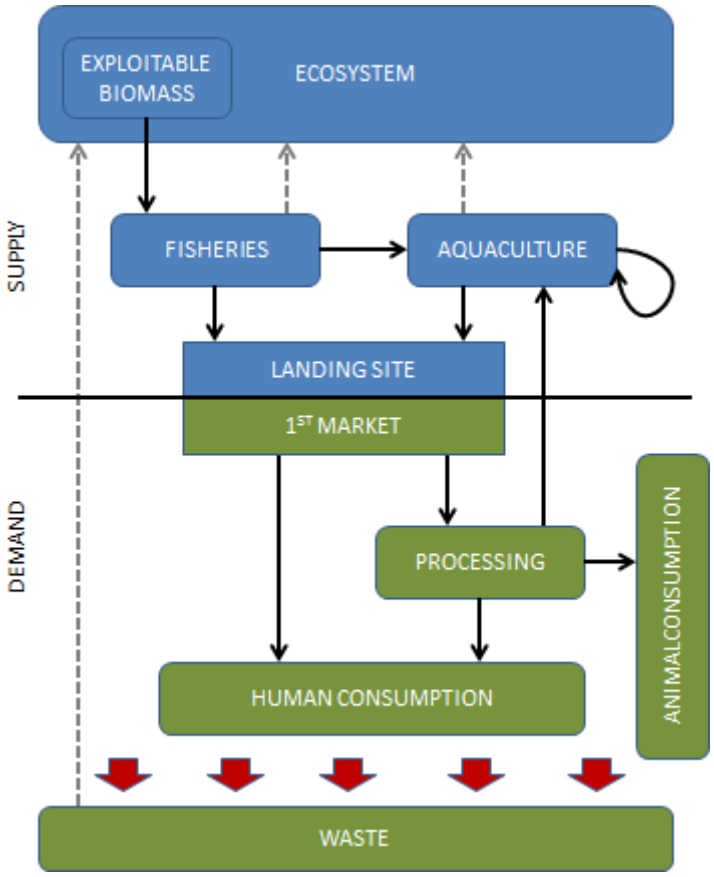
Under the current CFP (EU 2013), and in an attempt to reduce this wasteful practice, the EU has introduced an obligation to land all catches. The so-called "landing obligation" is being phased in on a fishery by fishery basis with the aim of eliminating discarding in most fisheries by 2019.

In the context of the JRC Biomass study, the current and future technical potential of biomass from marine fisheries was assessed. The categories assessed are the supply of biomass from marine fisheries and its utility in terms of food for human consumption and animal feed, as well as the resulting waste.

Figure 4.1 depicts the simplified model of production and flow of marine biomass from fisheries and aquaculture. The boxes represent the elements of a two-component supply and demand system. Arrows indicate the flows between the different elements.

The blue boxes represent those elements that can be considered as part of the marine biomass supply system. The marine ecosystem contains the exploitable biomass, which is utilised by the fisheries and aquaculture sectors, and their production is conveyed to the demand system through a landing site and point of first sale (first market). The green boxes indicate the flow of the marine production biomass through the demand system either through the processing industry or directly for human consumption. Biomass fed through the processing industry can flow to human consumption, to animal consumption or back to aquaculture. Waste is generated at all stages in the overall system.

Figure 4.1. Model of marine biomass production and flows from fisheries and aquaculture



With regard to fisheries, the technical potential biomass (TPB) concept refers to the biomass that is available to the EU Member States in a form that can be used to benefit society. It results from the interaction between Member States' fishing capacity and the biomass available for harvesting, the "exploitable biomass". TPB is thus defined and computed as the long or medium-term average landings in weight of all species aggregated.

The TPB may not entirely be used for human consumption due to market dynamics, regulations like the CFP landing obligation, poor quality, etc. and inevitably part of the TPB will be lost as waste; hence it is considered "potential". TPB represents the flows of biomass from wild capture fisheries through the supply and demand systems. To achieve sustainable exploitation at maximum productivity, as outlined in the Common Fisheries Policy objectives (see above), the MSs' fishing capability should be managed so that the TPB is intended to equate to the maximum sustainable yield (MSY). In the medium-term, this is expected to steer the exploitable biomass to a level close to MSY (B_{MSY}) levels.

Data sources used in this report include the State of World Fisheries and Aquaculture 2016 (FAO 2016), the FAO Global Capture Production database (FAO, 2016b), the Stock assessment data from the RAM Legacy database 3.0[18], ICES (FAO area 27) for the stock assessments for commercial stocks in the NE Atlantic and adjacent seas[19], STECF (FAO area 37) for the stock assessments for commercial stocks in the Mediterranean and Black Seas[20], Nominal Catch (Task I) statistics from the International Commission for the Conservation of Atlantic Tuna (ICCAT)[21].

[18] https://depts.washington.edu/ramlegac/wordpress/databaseVersions/RLSADB_v3.0_(assessment_data_only)_access.zip
[19] http://standardgraphs.ices.dk
[20] https://stecf.jrc.ec.europa.eu/reports/medbs
[21] http://iccat.int/en/t1.asp accessed on 16/Nov/2016

4.1.2 Results

4.1.2.1 Landings

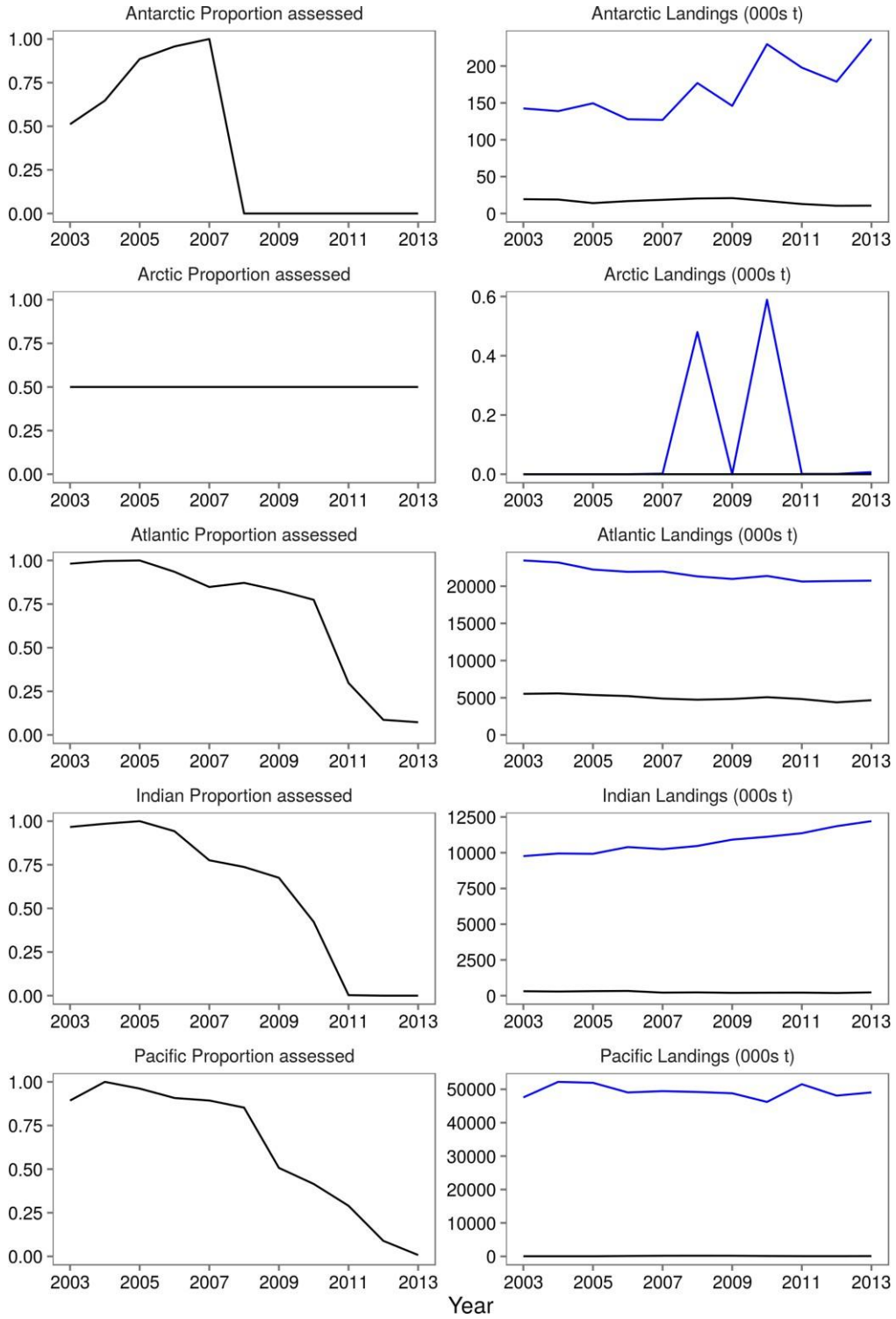
This section presents an overview by ocean, highlighting the landings reported by all European fleets and the fraction of the total landings coming from stocks, which were subject to quantitative stock assessments. Additionally, the exploitation status of such stocks over time is also expressed as the following ratios (i) F/F_{MSY}: ratio between the estimated fishing mortality rate and the theoretical rate of fishing mortality that will deliver the MSY and (ii) B/B_{MSY}: the ratio between biomass estimates and the theoretical biomass that will deliver MSY.

The **Atlantic**, **Indian** and **Pacific** oceans have much higher landings than the **Antarctic** and the **Arctic**, with the Pacific being the highest (Figure 4.2). Total landings from the Indian and Antarctic oceans are increasing over time, whereas it is slightly decreasing in the Atlantic and relatively stable in the Pacific. The total Arctic landings have a high variability over time and also very low values.

The landings attributed to EU Member States are focused on the Atlantic. The removals by Member States from the other oceans are much lower. There are no removals from the Arctic by EU Member States.

The decline in the proportion of assessments over time is a result of the assessment database being currently updated (see section on gap analysis below). There are no reliable assessments in the Arctic.

Figure 4.2. Landing proportion assessed by ocean and landings in live weight (thousand tonnes)

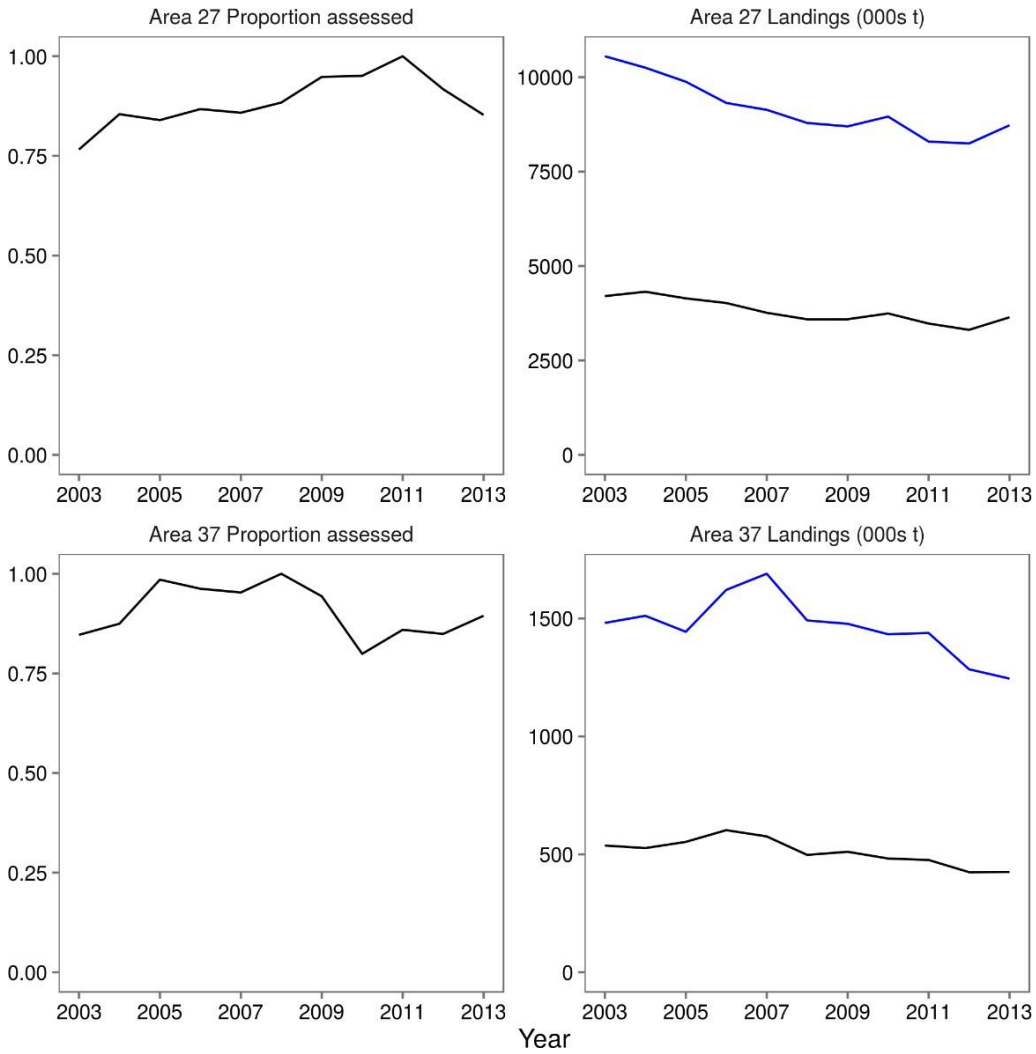


The left-hand panels show the proportion of the total landings that has been assessed by a quantitative stock assessment. The right-hand panels show the total landings from all countries (blue line) and the landings attributed to EU Member States (black line) over the period 2003-2013.

The total landings in **North-East Atlantic** (Area 27) are much higher than in the **Mediterranean** (Area 37). In both areas, there is a declining trend in total landings (Figure 4.3).

The landings attributed to EU Member States are also slightly declining over time. The proportion of the total landings attributed to EU Member States in each area is similar and relatively stable. The proportion of the landings that is assessed in area 37 is relatively stable over time. It is lower than the proportion assessed in area 27, which shows an increase over time apart from the last few years.

Figure 4.3. Landings in live weight (thousand tonnes) and the proportion assessed in FAO areas 27 (North-East Atlantic) and 37 (Mediterranean)



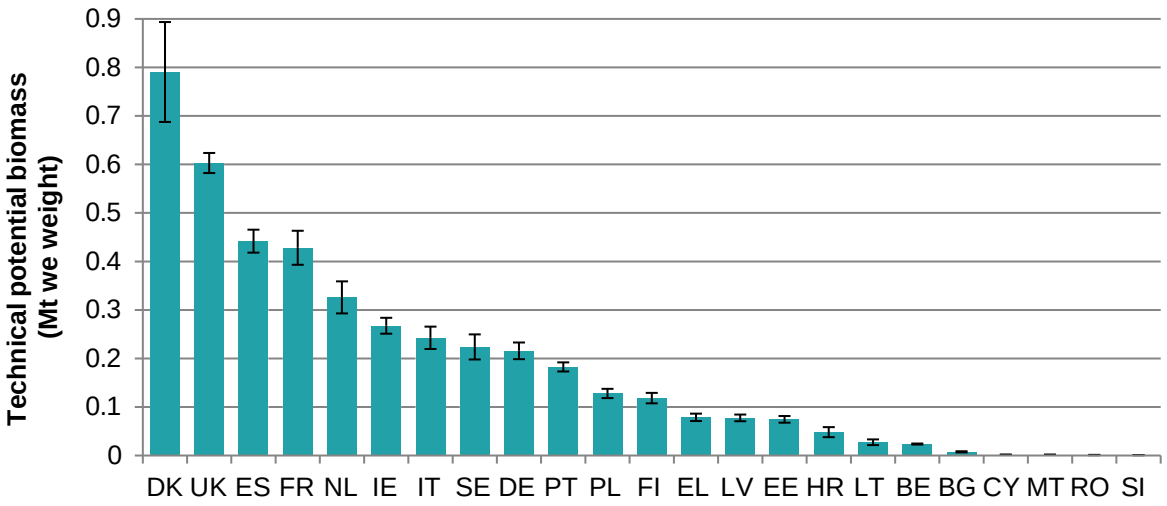
The left-hand panels show the proportion of the total landings that has been assessed by a quantitative stock assessment. The right-hand panels show the total landings from all countries (blue line) and the landings attributed to EU Member States (black line) over the period 2003-2013.

The estimation of the TBP for the EU Member States is presented in Figure 4.4, including its uncertainty in the form of (95%) confidence intervals. Note that the TBP reflects a stable level of biomass available to Member States and is expressed as the average landings over a recent period (2003-2013). Over this period, the technical potential biomass of the EU-28 for the North Atlantic and Mediterranean combined is estimated between 3.9 Mt and 4.7 Mt, with an overall average of 4.3 Mt (wet weight).

The top five EU Member States to which the largest TPB is attributed to are Denmark (791 thousand tonnes), the United Kingdom (603 thousand tonnes), Spain (442 thousand tonnes), France (428 thousand tonnes) and the Netherlands (326 thousand tonnes). The figures do not take into account the composition of the catches. For example, Denmark

has a high proportion of catches for industrial purposes, which have less value than catches for human consumption, whereas the United Kingdom and Spain have a high proportion of catches for human consumption. Some Member States do not catch anything, for example Austria.

Figure 4.4. The Technical Potential Biomass (TPB) attributed to EU Member States in FAO areas 27 and 37 over the years 2003-2013



Error bars show the 95% confidence interval.

The major players in the Northeast (NE) Atlantic are the Spanish, French, British, Portuguese and Irish fleets, with the latter two having the highest dependency on the region for production. The most important species include Atlantic mackerel, horse mackerel, hake and Norway lobster.

In terms of production, the UK, French, Spanish, Portuguese and Irish fleets are the most important and collectively were responsible for 74% of the landed weight and 87% of the value landed in 2015 (JRC 2017). The weight and value of landings generated by the NE Atlantic fleet amounted to approximately 1.4 Mt (-3% less than in 2014) and €2.4 billion (+1%), respectively. Based on the value of landings the French (30% of the regional landings), Spanish (26%) and UK (20%) fisheries have the highest level of landings in the Northeast Atlantic. However, Ireland and Portugal have the highest percentage of national landed value from the Northeast Atlantic at 90% and 75%, respectively.

While effort remained stable, total landings decreased by 2%. Despite the decrease in landings the overall, performance improved, with the majority of Member State fleets generating gross and net profits in 2015.

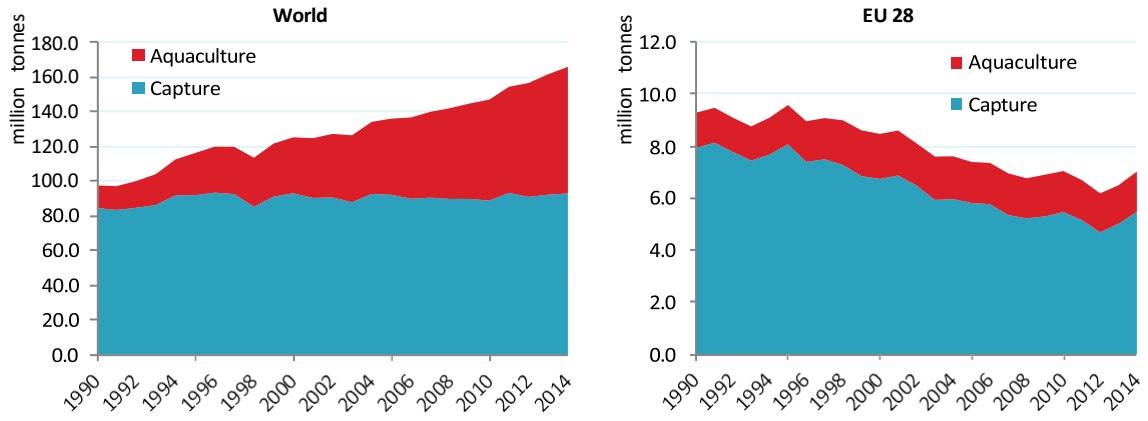
4.1.2.2 Aquaculture

As reported in the Scientific, Technical and Economic Committee for Fisheries Report on the aquaculture sector (JRC Scientific and Policy Report EUR 28356 EN), aquaculture is the fastest growing animal food producing sector in the world and is an increasingly important contributor to global food supply and economic growth. The share of global supply of fish and shellfish (i.e. crustacea and molluscs) increased from 13% in 1990 to 44% in 2014. Aquaculture sector increased by 5.1%, while capture fisheries increased by 0.8%. Production from world capture fisheries of fish and shellfish has been fluctuating around 90 Mt per year during the last two decades. In contrast to this, the global aquaculture production has been increasing, as shown in Figure 4.5, producing 72.9 Mt in 2014.

The sector has increased production 76% since 2004 and more than 4 times since 1990 (see Figure 4.5). However, this growth has primarily been driven by Asian countries

producing 89% of the world aquaculture products. China is the most important producer of aquaculture products in the world, producing 61% of the global fish and shellfish. European aquaculture production represented only 1.7% of the world aquaculture production in terms of weight and 3.2% in value.

Figure 4.5. World and EU-28 seafood production (capture and aquaculture): 1990-2014



Source: FAO, 2016

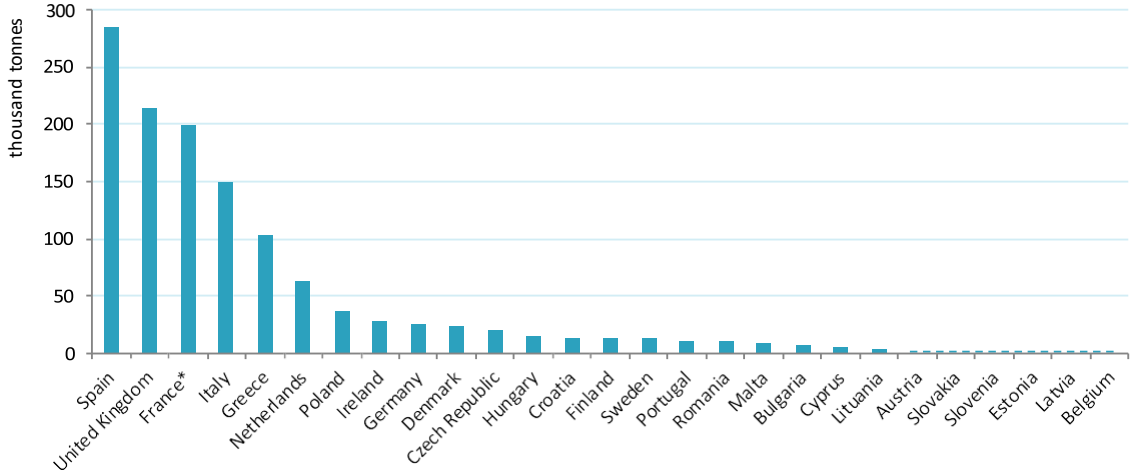
According to FAO (FAO 2016) the production of farmed fish is higher than fisheries. In that group, five major producers are included, such as China, India, Viet Nam, Bangladesh and Egypt. In the other 30 countries, a well established aquaculture is present, - Greece, the Czech Republic and Hungary in Europe and Lao People's Democratic Republic and Nepal in Asia.

The aquaculture production in EU-28 has increased by 15% since 1990. However, since 2004, the production has decreased by 6%. As EU capture fisheries production has been decreasing over the analysed period, aquaculture has become relatively more important to supply the seafood market. In 2014, the aquaculture sector provided 22% of the fish and shellfish supply in EU-28.

EU aquaculture production is mainly concentrated in five countries: Spain, United Kingdom, France, Italy and Greece. Figure 4.6 shows the significance of the Member State's (MS) aquaculture production in the relation to the total EU-28 aquaculture production in weight.

Spain, with 23% of the total EU production in volume, is the largest aquaculture producer in the EU, followed by United Kingdom 17%, France 16%, Italy 12%, and Greece with 8%. These five countries account for 76% of the total EU-28 aquaculture production by weight.

Figure 4.6. Aquaculture production in EU Member States in 2014 (fish live weight equivalents)



* Note: 2013 data is used. Source: Eurostat, 2016

It should be noted that even though Spain has the largest aquaculture production in volume (23%) it is only third in value (12%). This is due to the low market value of mussels, which represented 77% of the Spanish aquaculture production volume, but only 20% of the value.

4.1.3 Gaps, uncertainties and future developments

Major gaps exist in knowledge about fishing potentials and capacities. As mentioned above, assessments of fish abundance are inherently uncertain and hence the results presented here should be viewed with caution. Additional issues relating to data quality and the assumptions that have to be made on fish stock biology and dynamics add as well to the uncertainty.

The JRC biomass study is exploring the proportion of the landings from fish stocks for which an assessment is available. In fact, potential biomass of a fish population equates to the biomass that will deliver the maximum sustainable yield from that population (B_{MSY}), and reliable estimates of B_{MSY} can only be computed for those fish stocks for which a reliable stock assessment is available. In the absence of a stock assessment, it is not possible to judge whether the prevailing biomass is greater or less than the B_{MSY} and hence whether the potential biomass will be greater or lower.

The trends in biomass for global fish populations reported here are based on the results of stock assessments stored in the RAM 3.0 database, which had its most recent full update in 2008. For years subsequent to 2008, assessment results have been added on an ad hoc basis only and the result is that the trends in biomass presented may not be the best representation of the true trends over the time period represented (2003-2013).

For highly migratory species such a tunas and billfishes, the spatial distribution of stocks encompasses multiple fishing regions. At present, there is no reliable means to allocate stock biomasses of highly migratory species to the EU EEZ of FAO regions 27 and 37. Hence the exploitation and conservation status of such stocks were not included in the analyses presented.

Due to a huge diversity of life history traits (short-/long-lived species, high/slow reproduction, pelagic/demersal/benthic, etc.), marine species occupy a diverse range of habitats and geographical scales. Such diversity creates an extremely complex and fluid system with multiple interactions that are impossible to predict with a reliable precision. Hence, the results of forecasting and scenario testing will also be highly uncertain and speculative.

The connection between food products and the biological stock is very difficult to establish, as the trade of such sector makes impossible to trace back fish products to their origin at sea. Linking the impacts of changes in the supply/demand chain to available stock biomasses becomes a many-to-many system, involving huge uncertainties, which are unlikely to be uninformative for policy decision-making.

4.2 Supply, uses and flows

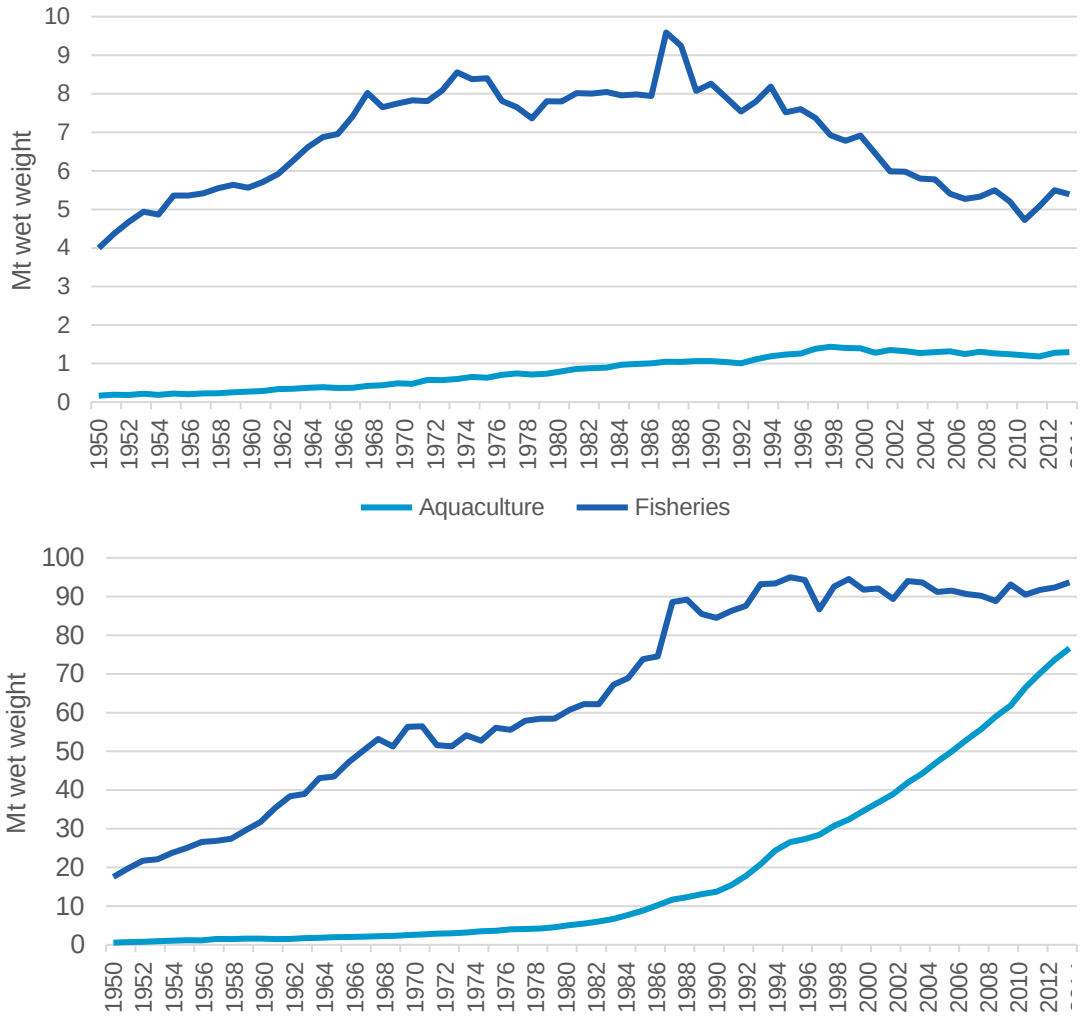
In the sector of fisheries and aquaculture, numerous specific issues must to be taken into consideration in order to have a precise picture of the supply, uses and flows. Namely the practice to use biomass to produce other biomass (which is the case of aquaculture, where aqua-feed is manufactured with the so called "forage fish" to feed farmed carnivorous species) and the very relevant position of seafood in the international trade of commodities.

In fact, according to FAO (2016), around 21 Mt of global fish production were destined for non-direct human consumption purposes in 2014, 76% of which was reduced to fishmeal and fish oil. In addition, about one third of the global fishmeal production was obtained from fish by-products (residues) in 2012. It should also be noted that herring and mackerel in the North Atlantic are examples of drastic change in usage: while most of their harvest was formerly used for fishmeal production, almost all the entire harvest is now directed to human consumption (Alder et al., 2008).

The prevailing key role of fishmeal and fish oil for feeding also has an important effect on operation costs. While fishmeal and fish oil production has declined since 2005, demand has continued to grow pushing prices to record highs in 2014, with maintained expected levels due to sustained demand (FAO 2016). These elevated prices have fostered some structural changes in the fishing sector, boosting low-value capture fisheries; while for aquaculture, this has resulted in an increased production of omnivorous species and growing incentive for research and innovation aimed at minimising aqua-feed consumption which, in turn, has led to reductions in feed conversion ratios (Naylor et al., 2009). In fact, fish production from aquaculture now exceeds the volume from wild capture fisheries required as input (feed) (Naylor et al., 2009). Furthermore, in 2014, half of global aquaculture production in volume and 31% of farmed fish species were produced without fishmeal feeding (FAO, 2016).

As mentioned earlier, another central issue in the analysis of the seafood supply chain is linked to the extensive trade of seafood commodities. The share of the total seafood products being traded internationally is very high and increasing mostly due to the recent globalisation and the geographically uneven increase of aquaculture production (mostly in Asia) and seafood demand (mostly Europe, North America and Asia). In 2012, the share of the total capture fisheries and aquaculture production entering international trade was 37% of the total production (58 Mt, live-weight equivalent) (FAO, 2014b). This share is the highest among food and agricultural commodities, compared for example with around 10% for meat and 7% for milk and dairy products. The seafood market has changed radically in recent decades because of globalisation. Nowadays, it is possible to find seafood from all over the world in almost any developed country (FAO, 2014b).

Figure 4.7. Evolution of the world (graph on top) & EU (graph below) aquaculture and capture production in weight (Mt) for the period (1950-2014)



Source: FAO, 2016

Forecasts on future demand and supply for seafood indicate that aquaculture will continue to fill the growing supply-demand gap resulting from a rapidly increasing population and consumption per capita. In 2014, half of the seafood for human consumption derived from aquaculture (Figure 4.7) and it is estimated that by 2030 this figure will increase to 62% (Msangi et al., 2013).

Aquaculture expansion entails the transfer of an increasing share of seafood supply from capture fisheries to a more conventional farming system, together with a profound transformation of the seafood production systems, which is taking place over a span of a few decades. Considering the dependency of aquaculture on captured fish (used for the production of fishmeal and fish-oil), the sustainability of aquaculture growth greatly depends on whether the aquaculture sector is able to mitigate this dependency (Naylor et al., 2000).

While seafood consumption has increased in the EU in recent decades, seafood production has stagnated or decreased. To meet consumer demand, since 2009 the EU had to source its seafood elsewhere and over time has become dependent on imports (EUMOFA, 2015). Failler (2007) estimated that average per capita consumption by the EU-27 and Norway will move from 22 kg/capita/year in 1998 to 24 kg/capita/year in 2030. These additional two kilograms per capita imply that the net supply will have to increase by 1.6 Mt. The EU aquaculture and capture fisheries growth may not be able to meet this increasing demand;

therefore, imports will likely raise, further intensifying the dependency of Europe on the rest of the world for its seafood products (Failler, 2007).

In global terms, the large population of Asia is clearly the top consumer of seafood in the world with 88 Mt, while the EU-28 is second with 11.6 Mt. The EU is the largest importer of seafood products absorbing 24% of total global imports (JRC, 2014).

According to FAO (2014) also in developing regions the annual per capita seafood consumption increased (from 5.2 kg in 1961 to 17.8 kg in 2010), and the same has been observed in low-income food-deficit countries (from 4.9 kg to 10.9 kg).

The interactions between capture fisheries and aquaculture and the globalisation of the seafood supply chain described above, highlight the need to account for interindustry flows and for international trade when assessing the long-term sustainability of the seafood supply chain.

4.2.1 Methods and data sources

The main data sources on seafood biomass uses at global level are the FAO food and commodity balance sheets. These provide detailed statistics on the use, supply and apparent consumption in each country. However, they do not explicitly reconstruct the detailed biomass flows along the supply chain and through trade. Estimates by FAO indicate that 50% of the seafood consumption was satisfied through aquaculture production in 2014, a symbolic landmark hinting at the profound transformation of the seafood supply chain. The existing data, however, does not allow to describe precisely the proportions of aquaculture in consumption and trade since both the apparent consumption of seafood reported in food supply balance sheets and the trade statistics do not distinguish between those processed products originating from aquaculture versus those from capture fisheries.

Therefore, JRC contributed to redress the above shortcomings on biomass flows within the seafood supply chain using a Multi Region Input-Output model (MRIO) (Lenzen et al., 2004). This model extends the Leontief's input-output analysis (I/O) used in macroeconomics and in national accounting to represent interindustry relations by accounting for relations between different national economies as determined by international trade.

The added value of MRIO model is to provide a more systemic perspective of the sustainability concerns regarding the use of natural resources, which takes into account both the geographical decoupling between production and consumption through trade and the interindustry relations.

In relation to fisheries, several authors have reconstructed the likely origin of seafood consumption of major fishing nations (Swartz et al., 2010). However, the JRC study focuses on the supply from fisheries only and does not take into account interactions between fisheries and aquaculture and aquafeed sectors.

The JRC developed MRIO model for the world seafood supply chain is aimed to explore the interactions between capture fisheries and aquaculture, fishmeal and trade at global level.

4.2.2 Results and discussion

4.2.2.1 World level

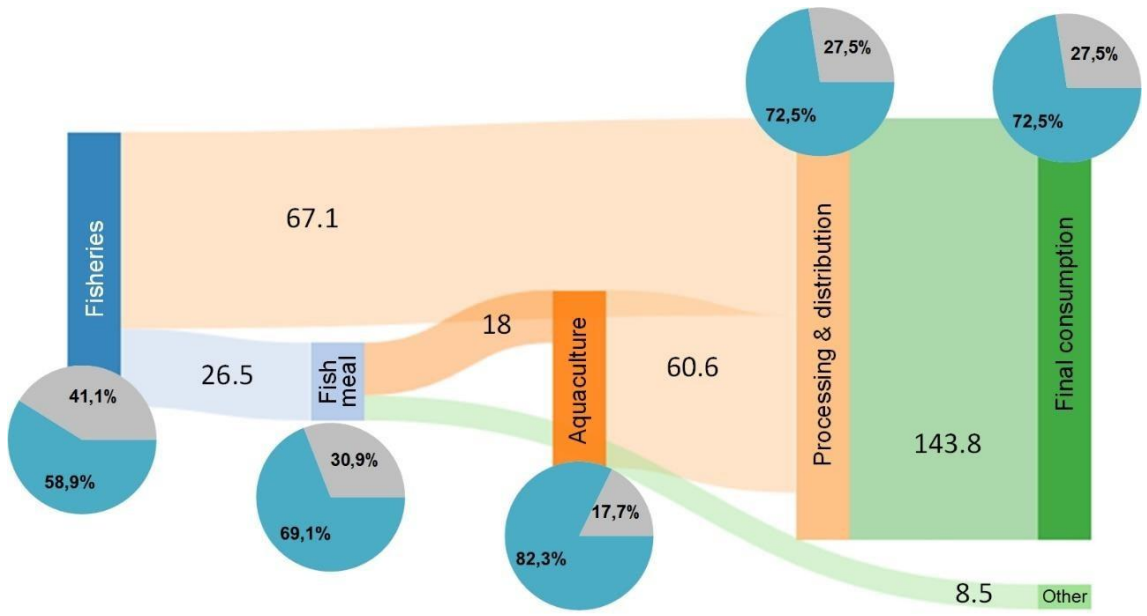
— **Interindustry flows**

Global capture fisheries and aquaculture primary production sectors contribute respectively with 67.1 Mt and 60.6 Mt to the seafood processing industry that, in turn, satisfies a global demand for seafood destined for human consumption of 143.8 Mt[22]. The supply of the

[22] The 16.1 million tonnes difference (11.2% of the global consumption) could be explained by the existence of illegal, unreported and unregulated fishing, under-reporting of production statistics, "seafood consumption" from inland fisheries not properly registered in consumption statistics (global inland fisheries production was 11.1 million tonnes in 2011) and potential double-counting in trade statistics

capture fisheries sectors to the fishmeal industry is 26.5 Mt. Fishmeal expressed as fish biomass live weight equivalent of 18 Mt is destined for the aquaculture sector and for 8.5 Mt for other uses (Figure 4.8), in agreement to a large extent with the findings of Naylor & Burke (2005). The results of our model, however, indicate lower inputs and outputs for the reduction industry to produce fishmeal and fish oil. The results for the baseline scenario at global level are described in Figure 4.8.

Figure 4.8. Global biomass flows of seafood products (in Mt, fish live weight equivalent) showing the interactions between the different sectors and the share of the supply with domestic (blue) or international (grey) origin for 2011



All quantities in Figure 4.8 are expressed in fish live weight equivalents. The slices indicate the proportion of supply sourced domestically (i.e., within each country in blue) in respect and the amount traded (i.e., coming from third countries in grey).

Our analytical reconstruction of the global seafood biomass flows provides for the first time the possibility to distinguish for each sector separately, the proportions of supply that are satisfied domestically and traded internationally. Globally, respectively 41.1% of capture fisheries, 17.6% of aquaculture, 27.5% of seafood processing and 68.6% of aquafeed (fishmeal and fish oil) products come from imports. These results confirm the importance of international trade in particular in the case of fishmeal and indicate a higher relevance of trade in the fisheries in respect of the aquaculture sector.

The detailed reconstruction of seafood biomass flows in the supply chain also allows to carry out (at country level) the calculation of national footprints based on the country's role as consumer rather than producers and the analysis of the footprint by sector.

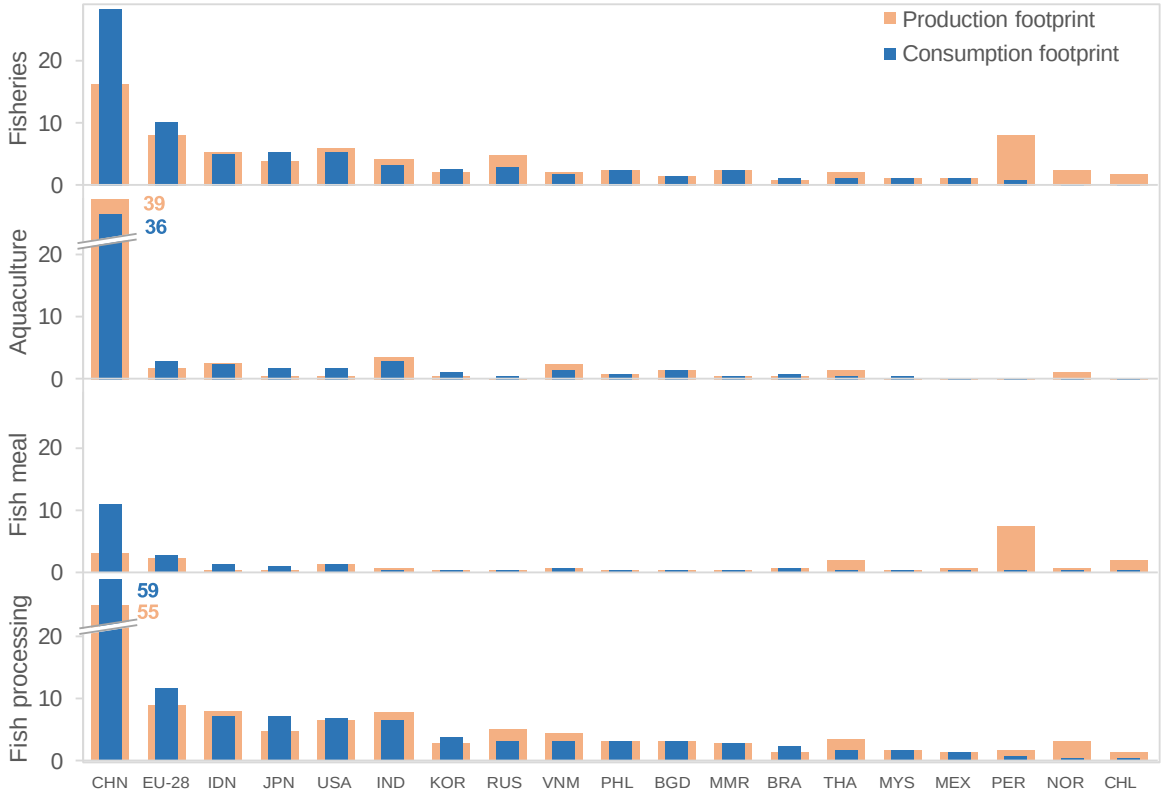
— Consumption- versus production-based footprint

In our model, the consumption-based footprint represents the production needed by all countries to satisfy the demand of one specific country only (country-specific simulations) while the production-based footprint corresponds to the supply produced by each country to satisfy the global demand (baseline scenario).

Using the consumption-based footprint, the global interdependencies and relations between aquaculture, fishmeal and capture fisheries sectors can be estimated, while they cannot be appreciated by simply looking at the amount of production in each sector and country in isolation.

Figure 4.9 shows both types of footprint for the top 20 countries ranked on the basis of their consumption footprint. The EU is presented in aggregate.

Figure 4.9. Production and consumption footprint for the top 20 countries ranked on their consumption (in Mt) for 2011



Note: aquaculture is combined from fresh and marine waters as defined in the present report.

What emerges from the comparison between the absolute values of production and consumption footprints, is the predominant role of China, as it is largely auto sufficient when considering the aquaculture sectors alone and in this case the difference between the consumption and production footprints is small. On the contrary, China has a higher footprint as consumer than as producer in the case of capture fisheries and fishmeal.

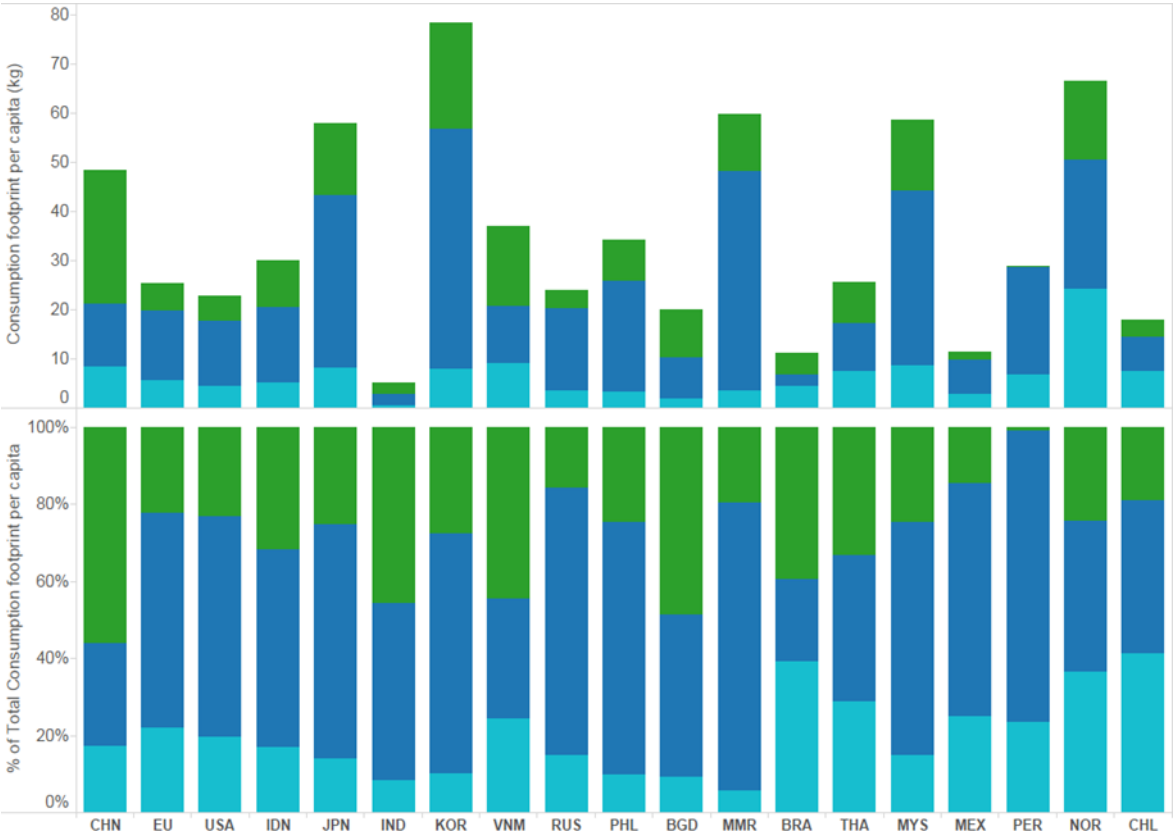
The consumption based footprint helps to appreciate how fishmeal use is highly sensitive to international markets independent of its destination to the aquaculture of herbivorous or carnivorous species. Although aquaculture production in China is mainly based on carp farming, the high consumption footprint for aquaculture is reflected in an equally high consumption footprint for fishmeal due to inter-industrial linkages between the two sectors (i.e., capture fisheries and aquaculture). The high consumption footprint for fishmeal in some countries in transferred through trade to the capture fisheries sectors in Peru and Chile which in fact are characterised by predominant production footprints compared to their consumption footprints.

Although many discussions concerning the sustainability of aquaculture development have been centred on the role of carnivorous species or so-called tigers of the sea, that is production at high trophic levels (see e.g. EASAC-JRC, 2016), our results indicate that the largest impacts at global level may be determined by uses of fishmeal in other sectors including herbivorous species like carps.

— Consumption footprint by sector

Figure 4.10 represents the per capita consumption footprint for the aquaculture, capture fisheries and fishmeal sectors in absolute terms and as proportions of the total consumption footprint. Results for the fishmeal sector are expressed as before as fish live weight equivalents whereas the capture fisheries sector, also expressed as live weight equivalents, includes the component destined to human use only.

Figure 4.10. Per capita consumption footprint for the aquaculture (marine and fresh water origin, light blue), capture fisheries (dark blue) and fishmeal (green) sectors in absolute terms and as proportions of the total consumption footprint for 2011



As previously, the EU is represented in aggregate and the chart lists the top 20 consumer countries.

The absolute values of the consumption footprint are determined by the final consumption of seafood in the population and reflect the typical diet in each country (i.e., preference for wild capture or aquaculture products). In respect of the FAO supply balance sheets, which also provide this type of information, the modelling of the biomass flows across sectors allows distinguishing between the aquaculture and capture fisheries origin. In addition, capture fisheries production can be accounted for separately based on its direct use as food or indirect use for the production of fishmeal.

The global consumption per capita footprint in 2011 estimated from our model is of 27 kg, which compares to 18.6 kg of consumption reported in FAO statistics for the same year. The value estimated in our model is higher since it accounts for the indirect uses of capture fisheries production by the fishmeal sector. The global footprint comprises 41.4% of consumption associated with the aquaculture sector, 41.6% of consumption associated with capture fisheries for direct use as food and 17% of capture fisheries for indirect use through the production of fishmeal.

The countries with the highest per capita consumption footprint are Korea with 76 kg of seafood per capita followed by Norway with 66 kg; Japan, Mauritius and Myanmar follow

with about 60 kg. The share of aquaculture has the highest value of 56% in China, 48% in Bangladesh and 46% in India. Compared to China, the EU has a relatively low footprint for aquaculture of 22% but a relatively higher share of the capture fisheries component related to the production of fishmeal.

4.2.2.2 European Union level

— **Trade dependencies**

In the case of the EU, this study shows that around 21% of the production of processed seafood is domestically sourced within each EU MS, 35% is coming from other EU MS and 44% from third countries. From these figures, the level of self-sufficiency for the entire EU can be estimated at around 56%.

Figure 4.11. Origin of the seafood consumption by sector in the EU disaggregated by domestic (national) and imported (from other EU countries and from third countries) in absolute (Mt) and relative values

This estimate of EU trade dependency confirms a previous EUMOFA (2015) results that the EU self-sufficiency rate for seafood was about 45% in 2012 and is lower than what previously calculated by comparing the volume of trade to domestic production.

Other estimates of the level of self-sufficiency for the EU were reporting values of 75% due to re-export) calculated as the ratio between apparent consumption and domestic production. Both approaches present some problems. In trade statistics, it is impossible to trace the products along subsequent commercial relations and transformations in the

supply chain and it produces consequently a double counting of some of the quantities. In our case, we reconstructed the entire global supply chain and, by isolating the consumption of a single country or a group of countries like in the case above for the EU, we calculated more precisely, which countries and sectors contributed to satisfying their given final demand.

The map in Figure 4.12 shows the geographical distribution of the primary production of aquaculture and fisheries in third countries needed to satisfy the EU demand. It depicts how much the major EU suppliers contribute to EU supply in absolute terms and as a percentage of their total supply in 2011. In other words, it shows the dependency of the EU seafood consumption by supplier. Results indicate that Norway is the main supplier for seafood products with a capture fisheries origin and China for seafood products with an aquaculture origin.

Figure 4.12. Main EU suppliers of seafood products shown in absolute terms (size of the circle) and as a percentage of their total supply from fisheries (orange) and aquaculture (blue; note: aquaculture includes fresh and marine water supplies) in 2011

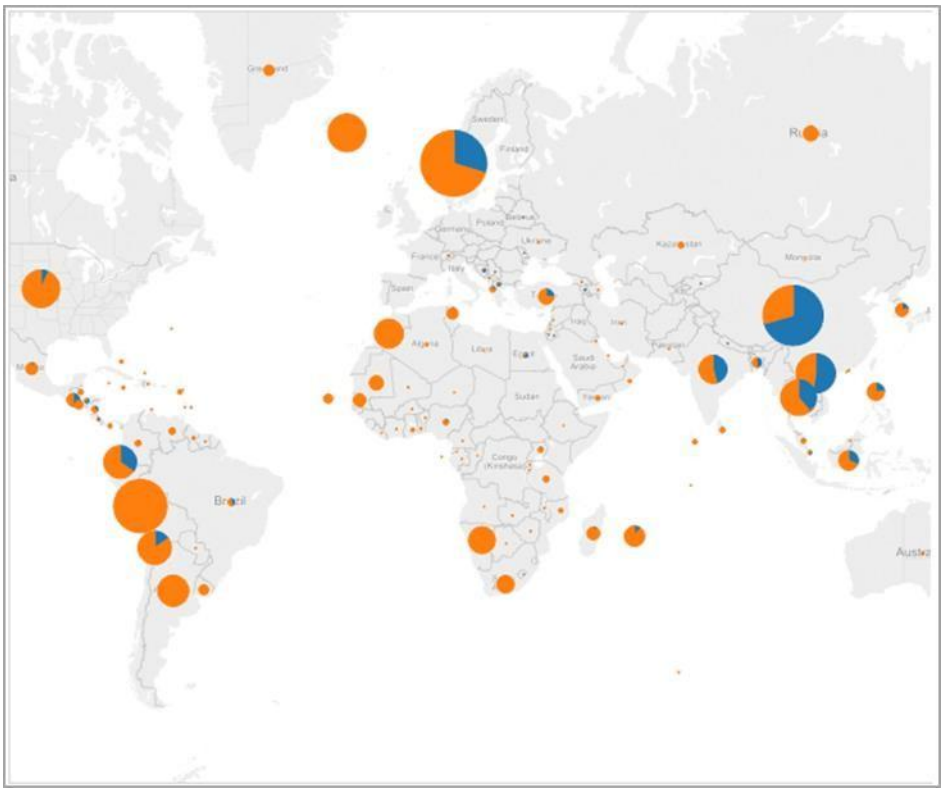
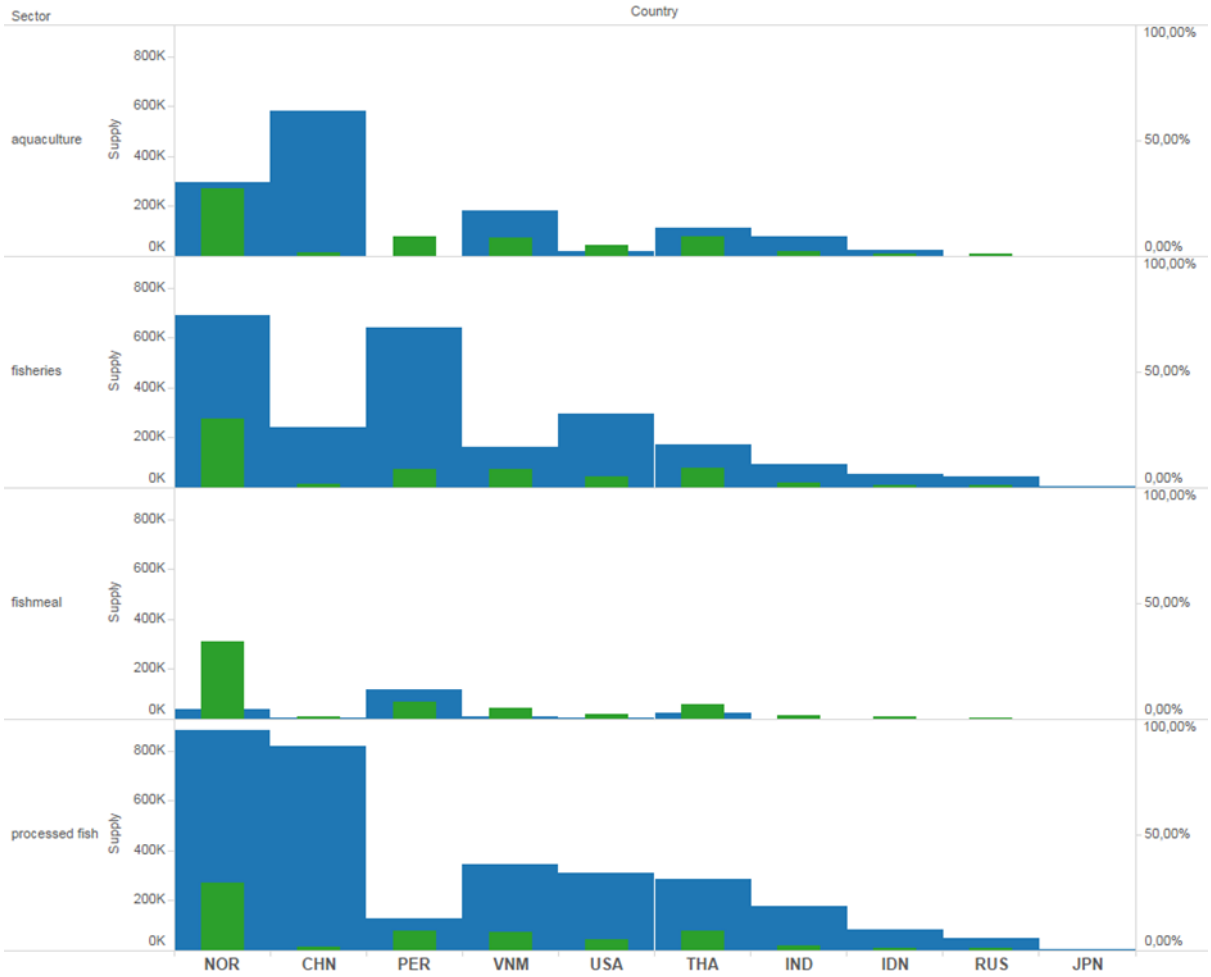


Figure 4.13 details the contribution for the top 10 EU seafood suppliers by sector (capture fisheries, aquaculture, fishmeal and processed fish) and the relative importance of this supply for the supplier country.

Figure 4.13. Main 10 EU seafood products suppliers by sector (in thousand tonnes)



The top 10 countries exporting to the EU-28 of the main commercial species consumed are Norway, China, Iceland, Vietnam, the United States, Peru, Morocco, Ecuador, Faroe Islands, and Thailand. Not surprisingly, Norway is the main country exporting to the EU-28, selling salmon, cod, herring, mackerel, mussels and scallops. China provides cod, hake, herring, mackerel, mussels, sardines and scallops. Viet Nam on the other hand makes into the top 10 exporters predominantly due to tropical shrimp, and to a lesser degree cod. Peru, in addition to hake, sardines, tropical shrimp, sardines, and scallops is also the main exporter of fishmeal and fish oil to the EU (EUMOFA, 2015).

Figure 4.13 shows that Norwegian exports to the EU represent about 25% of the total Norwegian supply, while for China, which is the second seafood supplier, seafood exports to the EU represent a minimal part of their supply.

4.2.3 Conclusions

The sustainability of seafood supply is often assessed only at national level. Analyses generally focus on whether the supply from capture fisheries and aquaculture practices is sustainable in the long-term, taking into account biological, ecological, social and economic objectives. However, many nations are reliant on imports to meet national demands for seafood products. Hence, seafood sustainability assessments need to take account of domestic production and imports, which are driven by national consumption demands. Therefore, it is also important to know if imported seafood is sourced from sustainable

capture fisheries and sustainable aquaculture practices in their countries of origin. Furthermore, at the supranational level, it is important to understand the different production and trade flows of seafood at global scale in order to assess food and income security issues.

The JRC multi-region input-output model investigated the impact of seafood consumption over national boundaries. In other words, it estimated the seafood consumption footprint. The key concept is that sustainability of the seafood supply is primarily determined by the consumption demands of nations as opposed to their production of seafood. Hence, nations should be accountable for what they consume rather than what they produce.

The seafood consumption footprint offers a clear image of the requirements to satisfy national seafood consumption in terms of domestic seafood production (capture fisheries, aquaculture, aquafeed and processing) and supplied from international markets. Sustainability of seafood consumption goes therefore beyond the national borders of seafood production.

The importance of the seafood consumption footprint is highlighted because the overall fisheries sector and the seafood market are very dynamic (Anderson and Fong, 1997). The seafood market has changed radically in recent decades. Nowadays, fisheries products are the most widely traded food and feed commodity in the world (FAO, 2014b). Our results show that the share of international supply from aquaculture products (17.6%) is significantly lower than that from capture fisheries (41.1%). Nevertheless, aquaculture has a positive influence through development of new markets and promotion of seafood consumption in general (Valderrama and Anderson, 2008).

Our results also confirm the high share of international trade in aquafeed products from fishmeal and fish oil (68.6% of aquafeed products enter international trade). The use of fishmeal and fish oil in competing feed industries and as alternative raw ingredients in compound feed is probably more driven by prices than by technological aspects. Therefore, the long-term sustainability of aquaculture in relation to its impact on captured seafood resources has to be put into a global market and systemic context, considering dependencies between seafood demand, capture fisheries, aquaculture, livestock and feed industries.

The aquaculture sector tried to substitute part of the aquafeed inputs by cheaper products from vegetable origin (e.g. soybean meal). Indeed, Norwegian salmonid production increased by 30% between 2010 and 2013, but due to a reduction in the proportion of marine ingredients in the diet and an increase in the proportion of alternative ingredients (e.g. plants, insects, algae), the total amount of marine ingredients used for salmon feed production was reduced by 14% (from 544,000 to 466,000 tonnes, Ytrestøyl et al., 2015).

Such changes have led to a decrease in the overall FIFO (Fish in/Fish out ratio, intended as number of units of wild fish needed to produce one unit of farmed fish) from 1.04 in 1995 to 0.63 or 0.52 in 2007, depending on the method of calculation (Naylor et al., 2009, Jackson, 2016). That is, on average, about 1.92 tonnes of harvestable aquaculture product can be derived from every tonne of whole wild fish caught for feed. This implies that aquaculture uses more efficiently seafood resources (i.e. fishmeal) than livestock production as, for example, the feed conversion ratio (FCR)[23] of salmon (1.3) is lower compared to chicken (1.9), pork (2.8) and beef (6 to 9) (Welch et al., 2010).

As a result, today aquaculture allows obtaining more fish and proteins in absolute terms since on average more tonnes of seafood products can be obtained from aquaculture than the fish products required for their production. In this sense, Figure 4.8 shows that aquaculture received 18 Mt of fishmeal and fish oil in live weight equivalents, while it produced 60.6 Mt[24].

[23] Feed conversion ratio is a measure of an animal's efficiency in converting feed (in weight) into increases of the body weight.

[24] However, the aquaculture production figure includes the production of herbivorous and filtering (e.g. mussels) species.

Consequently, growth in aquaculture is currently not limited by the production of fishmeal and fish oil and is less dependent on the capture fisheries than in the past.

Even if seafood production may increase without the strict limitation of fishmeal production, this food supply increase may be diversely distributed across regions or countries. Moreover, as the aquaculture sector production shows signs of slowing down (Asche et al., 2013), forecasts assigning a prominent role to aquaculture to help feed in an increasing world population (9 billion by 2030) may be overoptimistic.

Similarly, an increase in consumption demand for animal products, such as cheap seafood products (World Health Organisation, 2016) was observed together with an increase of income (i.e., GDP per capita) and purchasing power in emerging countries (e.g. China and Brazil). Continued increases in income and urbanisation in developing countries may lead to changes in traditional trade relations and consequently seafood may become scarcer in areas that currently benefit from high imports (e.g. EU, Japan and USA).

Food security is a major concern in many parts of the developing world and increased food production is needed to meet the future demand of an increasing world population. According to FAO (2011), about one-third of food produced for human consumption is lost or wasted globally, amounting to about 1.3 billion tonnes per year. Although a large proportion of seafood is wasted by consumer households, losses in primary seafood production are significant due to discards[25], which are estimated at around 9-15% of marine catches for industrialised regions and 6-8% in developing countries.

The first global assessment identified a total discard of 27 Mt (Alverson et al., 1994) while the latest global study (Kelleher, 2005) suggested that discards have dropped to 7.3 million. This value may be underestimated as the assessment corresponds to a weighted global discard ratio of 8% and large variations exist among fishing methods and regions (Kelleher, 2005). Nonetheless, reductions appeared to be substantial while, additionally, the newly reformed EU's Common Fisheries Policy (CFP) is implementing a ban on discards, which is generally considered as a wasteful misuse of marine resources.

Producing and processing seafood in the EU is still largely dependent on small and medium sized businesses with limited possibilities for economic diversification. Similarly, most of the EU fishing vessels are considered small-scale, the majority of aquaculture enterprises are under 10 employees and fish processing enterprises under 50 employees. In addition, a recent study showed that in 2010 more than a half of fishing jobs were in EU coastal communities that rely on fisheries for employment with a relatively high dependency ratio when compared to general employment in the community (Natale et al., 2013). A large share of this employment (44%) was associated to small-scale vessels, thus with a limited range of fishing grounds to explore.

4.2.4 Gaps and future developments

With globalisation, international trade of seafood products has become very complex and seafood products can come from different sources, having often passed through various stations in the production and supply chain (Anderson and Fong 1997; Guillotreau 2004). This poses many challenges to the already difficult monitoring activities in the whole fisheries sector.

The main gaps in the current analysis are:

— The absence of any differentiation in origin (capture fisheries or aquaculture) of commodity flows in the trade and consumption statistics. The absence of such differentiation represents the main limitation in understanding the relative importance of capture fisheries, aquaculture and trade for satisfying the global demand for fish.

[25] Discards, the proportion of total catch that is returned to the sea (in most cases dead, dying or badly damaged).

- The flows related to the use of trash fish, trimmings and landings of fish unfit for human consumption in the fish meal industry cannot be explicitly modelled due to the lack of reliable data.
- Trade data are sometimes detailed by species and product type (e.g. frozen fillets); however, for other species, trade data may be aggregated by species groups or families. Moreover, trade between sites of the same company may not always be precisely reported.
- Data on final consumption is often very approximate and not disaggregated by species.
- Data on the use of fishmeal and fish oil for aquaculture are not generally available and need to be estimated from the aquaculture production. Considering that it may take some years to grow certain fish species, estimates can only be approximate figures.
- Data on fishmeal and fish oil for other uses (i.e., animal husbandry) are not available and can only be approximated from the husbandry production.
- Estimates on seafood waste along the market chain are not available, except for very approximate global assessments or in very particular cases.
- Finally, data omissions from official statistics (e.g. no data on demand and trade for Taiwan), issues related to the technical coefficients used as parameters in the model which are not able to capture country specificities or to inconsistencies between demand, trade and primary production across the different statistical data sources.

Considering the extent of the currently available outputs, a further analyse is necessary in the near future as well as a further test of the coherence of some of the model assumptions. Additionally, JRC is considering the possibility to assign monetary values to the biomass flows.

Key messages

Marine and freshwater water realms will be crucial to meet the increasing demand for food, jobs and income, caused by a rapidly growing world population.

EU production of seafood by capture fisheries and aquaculture was 6.8 megatonnes (Mt) life weight equivalent in 2014, with 5.5 Mt originating from capture fisheries and 1.3 Mt from aquaculture (FAO, 2016).

Production from fisheries and aquaculture by the EU-28 Member States in 2013 represented 3.2% of global production (Eurostat, EUMOFA and FAO). The level of self-sufficiency for the entire EU can be estimated at around 56% (JRC)

To ensure sustainability of production and supply, the management of exploitation of natural aquatic resources, i.e. fisheries, and the industrial production of fish food, i.e. aquaculture, needs to be put on a solid knowledge base so that management schemes and policy frameworks can be adapted.

Potential environmental impacts of fisheries and aquaculture need to be assessed. Sustainable production systems need to be developed to meet demand for seafood and socio-economic needs while preserving the environment.

5 Biomass from algae

Algae play an important role in marine ecosystems contributing largely to the global primary production and frequently supporting complex food webs in coastal zones. Several algae are structuring species in coastal communities providing habitat, food, reproductive refuge and shelter to a variety of associated organisms from different trophic levels like apex predators, fishes and invertebrates (Reisewitz et al. 2006, Bertocci et al. 2015). These communities provide also several other important ecosystem services to coastal areas like biomass and energy transfer between ecosystems, natural carbon sequestration (Hill et al. 2015), removal of dissolved nutrients decreasing eutrophication of coastal waters and coastal protection from erosion and hazardous waves (Arkema et al. 2013).

Algae biomass has been explored for centuries by coastal communities as a source of fertilizers, cattle feed and human food. This biomass is a valuable resource in the European bio-based economy. It is currently used mainly by the food and chemical industry as raw material for the extraction of hydrocolloids (mainly alginate, carrageenan and agar-agar) and for human nutritional products. Over the last decade, the development of new algae-based applications (feed and food supplements, nutraceuticals, pharmaceuticals, third-generation biofuel and bioremediation) and the rising interest to include high quality seaweeds in western diets increased the demand for algae biomass. Since algae are key organisms in the marine ecosystems influencing the diversity and dynamics of several other species of ecological and economic interests, their sustainable exploitation must be ensured. Management guidelines should consider the impact of exploitation in the context of climate change and anthropogenic pressure affecting marine organisms. Many of the commercially harvested macroalgal species in Europe are canopy species. For these species, widespread losses were documented over recent decades in some regions, due to a multiplicity of stressors such as global warming (Wernberg et al 2010, Fernandez 2011, Brodie et al 2014), increase in storm frequency (Smale and Vance 2016), increase in herbivory pressure (Bekkby et al 2011, Moy & Christie 2012, Steneck et al 2013), excessive harvesting (Christie et al 1998, Lorentsen et al 2010), decline in water quality (Delebecq et al 2013, Strain et al 2014), diseases and introduction of non-native species (Williams and Smith 2007).

Additionally, the sustainability of algae biomass supply relies also on the development of alternative algae biomass production methods in Europe. In this context, an investment in the growth of a sustainable aquaculture sector has become crucial, especially for commercially important species with identified susceptibility to ongoing stressors. In Europe, the algae aquaculture is still at an early phase. It requires further developments at the technological, operational and biological knowledge levels. However, this production source is expected to represent an efficient alternative to increase the European production potential and to supply the algae biomass related market.

The sustainable development of the algae production sector is closely related to several environment and maritime EU policies, strategies and directives. Some examples are the Blue Growth Strategy[26] supporting the sustainable growth in the marine and maritime environment as a whole, the Bioeconomy Strategy and Action plan[27] aiming at reducing fossil fuel dependency and improving the economic and environmental sustainability of primary production and processing industry, the Circular Economy Action plan[28] and the Maritime Spatial Planning directive[29].

[26] https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/swd-2017-128_en.pdf
[27] https://publications.europa.eu/pt/publication-detail/-/publication/1f0d8515-8dc0-4435-ba53-9570e47dbd51
[28] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614
[29] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0089

5.1 Methods and data sources

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 Food and Agriculture Organization of the United Nations (FAO) that include, at the European level, 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 28. 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.

The FishStatJ workspace of the FAO Global Fishery and Aquaculture Statistics was downloaded and analysed including the datasets on global production by production source (species, country, production area, production source and year (1950-2015)), global commodities production and trade referring to quantity (commodity, country, trade flow and year (1976-2013)) and value (species, country, value, year (1976-2013)). Data on economic value are available only for macroalgae aquaculture production and data on trade only consider macroalgae biomass and derived products.

The planned framework of the analysis (Figure 5.1) focused on the algae biomass supply considering biomass production by harvesting and aquaculture (land-based or off-shore) for the seaweed sector and biomass production on land-based production plans in raceway ponds and photo-bioreactors for the microalgae sector. The demand for algae biomass and derived products was also considered and information on the different algae biomass commercial applications was searched.

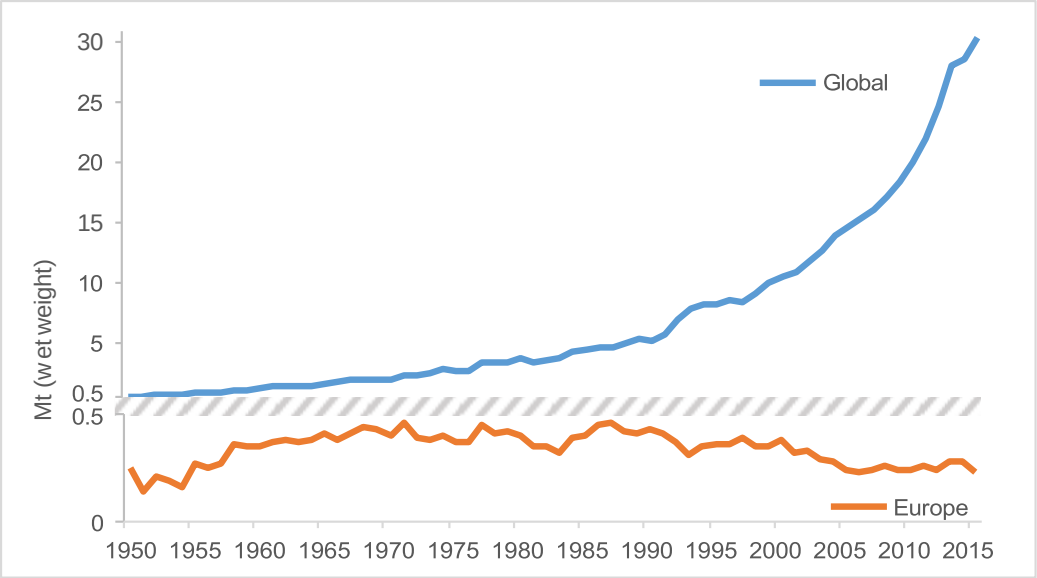
Figure 5.1. Structure of the approach followed in the present study on algae biomass supply and demand

5.2 Production

5.2.1 Results

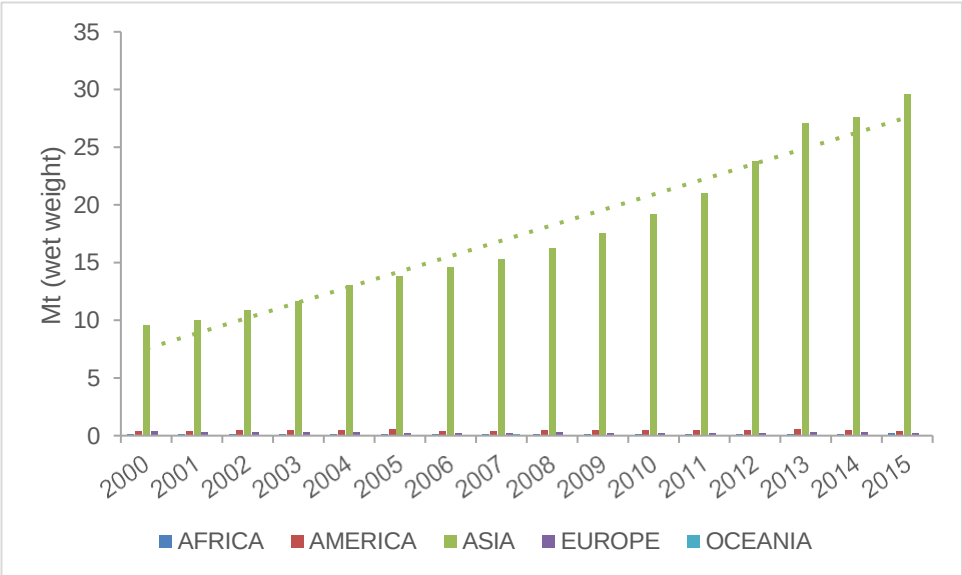
At the global level, annual algae biomass production has gradually increased since 1950, showing a marked growing trend over the last 2 decades, with a production of 10.51 Mt in 2000 and reaching 30.45 Mt in 2015. In Europe, the algae biomass production has remained stable, since 1950, below 0.5 Mt (Figure 5.2).

Figure 5.2. Time series of annual production of algae biomass at the global (blue) scale and in Europe (orange)



At the continental level, Asian countries dominate the algae biomass production sector, being responsible for the global growth of the sector in the last two decades (Figure 5.3) and accounting for 97% of the total production in 2015. The algae production in the other continents has been maintained at stable levels since 2000. America (north and south) is the second global producer followed by Europe.

Figure 5.3. Annual production of algae biomass at the continental scale dominated by Asia



The top 5 algae biomass producers at the global level are Asian countries. Between 2006 and 2015, China supplied 54% of the total worldwide production followed by Indonesia, Philippines, Republic of Korea and Japan (Figure 5.4a).

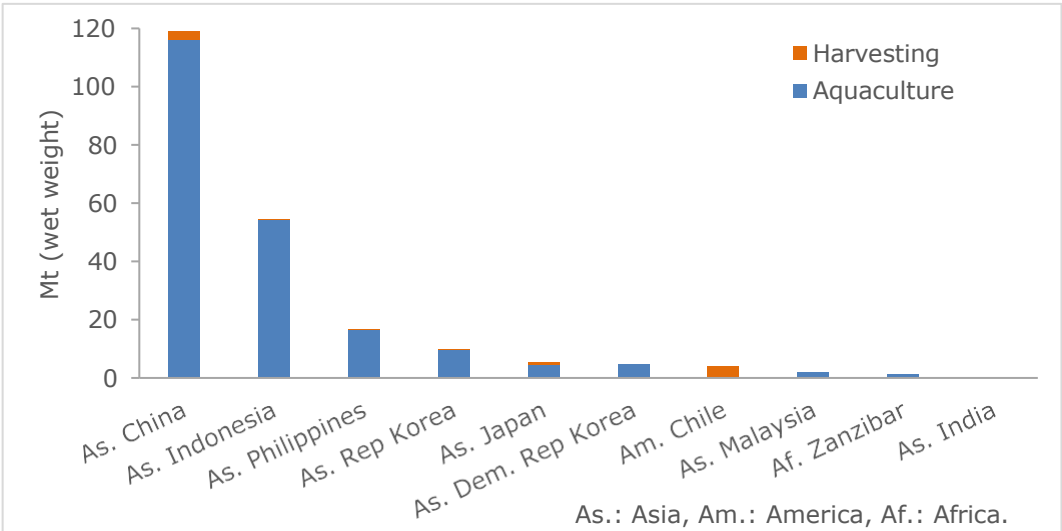
The most produced groups of macroalgae species worldwide are Nori seaweeds (including the seaweed species belonging to the genera *Porphyra* and *Pyropia*) mainly consumed as food, eucheumoid algae (including the species *Kappaphycus alvarezii*, *K. striatum* and *Eucheuma denticulatum*) that are the main worldwide source of raw material for carrageenan extraction and other not specified seaweeds (FAO 2016).

At a global scale, the main microalgae species produced photosynthetically belong to the genera *Spirulina* (*Arthrospira*: *A. platensis* and *A. maxima*) (the most significant microalgae production, both considering value and tonnage), followed by *Chlorella* (*C. vulgaris* and *C. pyrenoidosa*), *Dunaliella* (*D. salina*) and *Haematococcus* (*H. pluvialis*). *Chlorella* can also be produced by fermentation as well as *Crypthecodinium cohnii* that is produced in several countries.

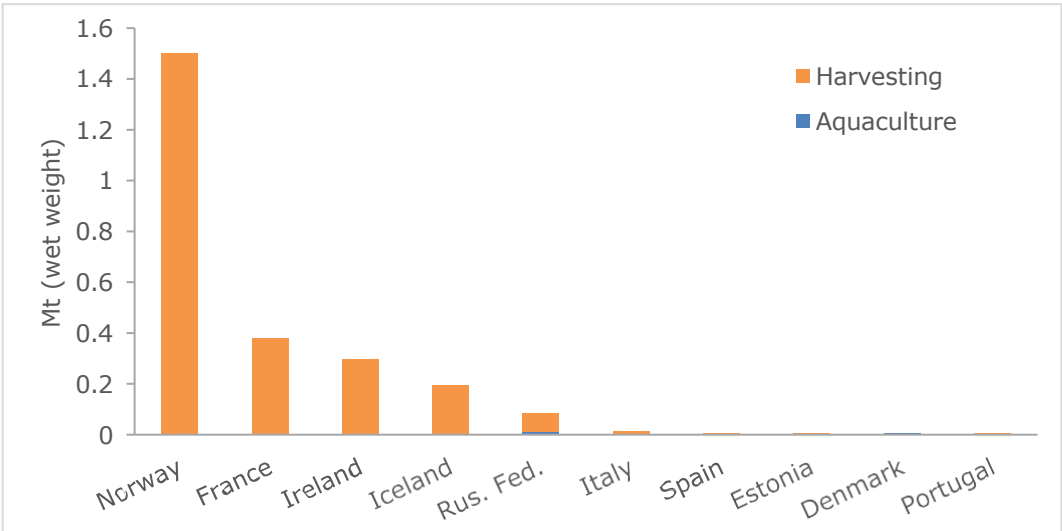
Algae biomass is supplied dominantly by aquaculture production for most of the top 10 producers with exception of Chile where production is based almost exclusively on harvesting the wild stocks (Figure 5.4a).

Figure 5.4: Total algae production (sum over the period 2006-2015 of the top 10 producers at the global (a) and at the European level (b) by production method

a)



b)

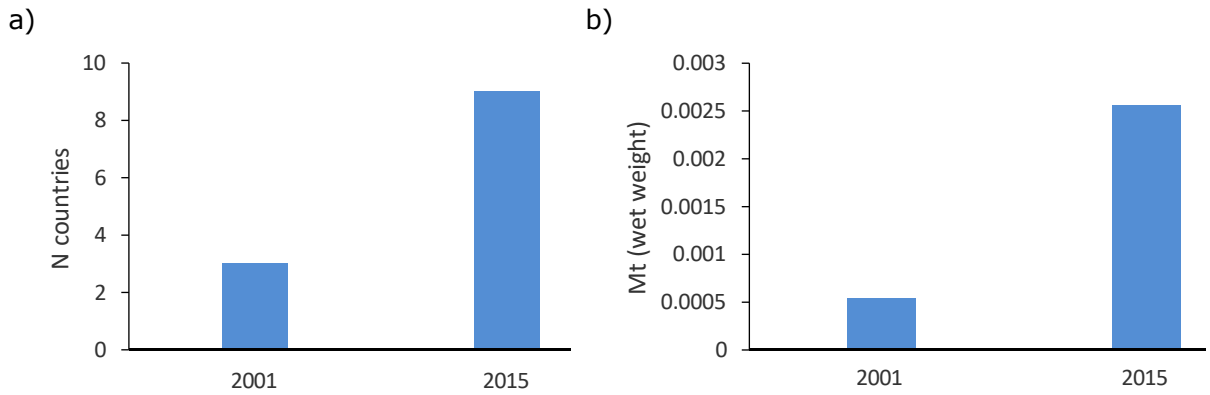


The European algae production accounted for 1.14% of the worldwide biomass supply between 2006 and 2015 (FAO 2016). Contrasting with the global increasing trend in the sector, European production of seaweed biomass showed some fluctuations over this period. The European supply of biomass decreased from a production of 0.38 Mt in 2000, to a minimum value of 0.24 Mt in 2006. Then, it increased slowly to a value of 0.28 Mt in 2013, dropping to 0.23 Mt in 2015. The European algae production sector is mainly based in Norway, France, Ireland, Iceland and the Russian Federation, accounting together for around 98% of the total European biomass supply between 2006 and 2015 (Figure 5.4b). The production is dominated by Norway, supplying more than half (65%) of the total European macroalgal biomass production in 2015.

The dominant biomass production method in Europe remains the harvesting of wild stocks with Denmark being the only country with the algae production sector exclusively based on aquaculture (Figure 5.4b). However, the aquaculture sector has been developing in the last few years, with an increase in the number of countries implementing aquaculture production facilities, reflected by an increased total amount of biomass supplied by aquaculture over the last decade (Figure 5.5).

The most important species contributing to the macroalgae production sector in Europe are *Ascophyllum nodosum*, *Chondrus crispus*, *Fucus* sp., *Himanthalia elongata*, *Laminaria hyperborea*, *L. digitata*, *Palmaria palmata*, *Porphyra umbilicalis*, *Sachharina latissima* and *Ulva* sp. (Walsh &, Meland & Rebours 2012, Mesnildrey et al 2012).

Figure 5.5. Temporal evolution of the aquaculture macroalgae production in Europe considering the number of countries with algae aquaculture facilities (a) and the total amount of biomass supplied by this production method (b)



The microalgae production in Europe includes the production of *Arthrospira platensis, Chlorella vulgaris, Isochrysis galbana, Nannochloropsis gaditana, Phaeodactylum tricornutum, Tetraselmis suecica* and *Porphyridium* sp.. Cultivation facilities are located in several countries among which France, Italy, Netherlands, Portugal and Spain.

5.2.2 Gaps, uncertainties and future developments

Several important knowledge gaps and uncertainties were identified during this study regarding the quality and availability of data on macro and microalgae production.

Databases on global biomass production are based on the FAO statistics. In general, these statistics contain very few references to the microalgae species production and in the case of Europe, the production reported is almost null. This results from the application of the Regulation 762/2018, establishing the rules for submission by Member States of statistics on aquaculture production that does not include microalgae in the groups of organisms to be reported. For macroalgae, FAO statistics include both harvested and cultivated species, organized by country and production year, over a representative temporal period. The

database is regularly updated with a delay of 2 years for public availability. However, in most cases, especially for harvested species (contributing for most of the macroalgae biomass production in Europe), the data are aggregated by major groups (red, brown, green algae) which greatly limits the extent of the analysis conducted. Additionally, a database on algae biomass production is available from Eurostat for EU-28, Norway and Iceland. For harvesting production, the data are shared between FAO and Eurostat databases but this is not the case for aquaculture production due to confidentiality issues. This poses a problem of standardization between analyses conducted at the global (based on FAO data) and European (based on more precise data at the European level available from Eurostat) scales. Due to confidentiality issues, there is also a lack of throughout information regarding the aquaculture production sector. Additionally, for some countries and years, due to deficient reporting by Member States, the Eurostat database lacks references to macroalgae production.

Another important knowledge gap identified in this study was the lack of a standardized conversion metrics to transform produced biomass based on wet weight to processed dry weight biomass. This conversion is not very relevant when considering commercial uses where the resource is used as fresh biomass, like for food consumption, but it is important to other uses where the biomass is commercialized dried. Relationship between wet and dry biomass is variable depending on species, season, age of the individual and drying method. These aspects should be considered in futures studies.

Although an effort has been made in the current study to complement the available information from the databases with additional sources of information, intense work is still required to organize the information in a reliable, complete and user-friendly way.

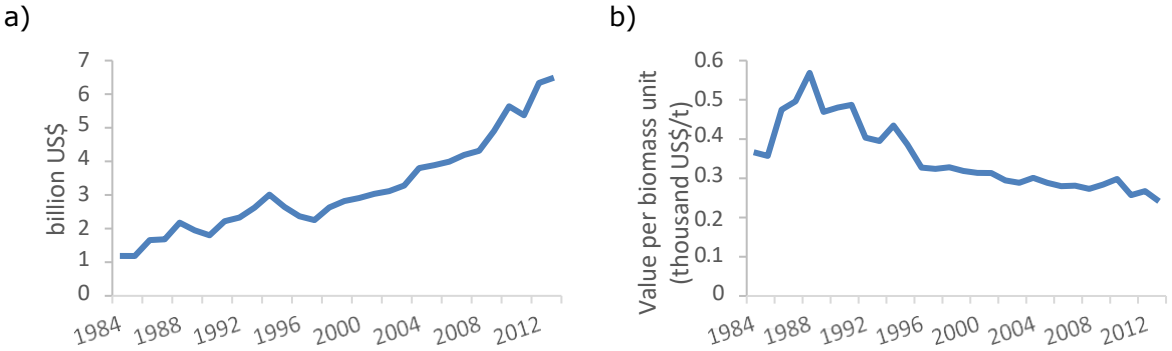
In October 2017, JRC organized a workshop in collaboration with FAO and the COST Actions Phycomorph (macroalgae development) and Eualgae (microalgae bio-products) to discuss the issues related to the availability and quality of data on algae biomass production in Europe. The workshop participants included researchers, industry, regulatory entities, statistical data providers and EU political bodies with relation to the algae biomass topic in Europe. The outcomes of this workshop as well as the network established between relevant sectors will be the starting point to organize different initiatives and actions led by JRC to improve the availability and quality of the data on algae biomass production in Europe.

5.3 Supply, uses and flows

5.3.1 Results

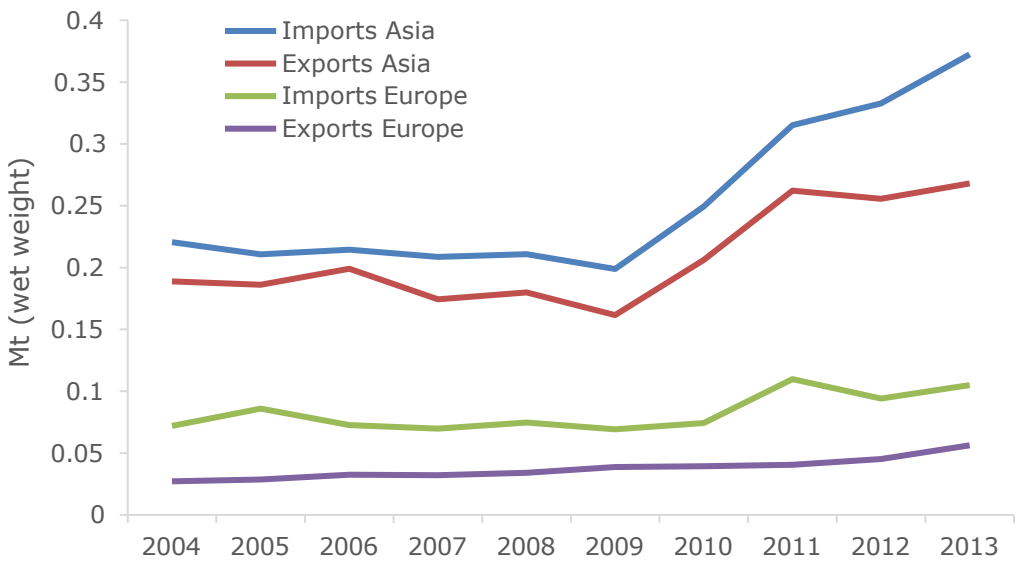
The FAO data on the economic value of the algae biomass trade refers only to the aquaculture production of macroalgae. These data show a progressive increase in the global economic value of biomass since 1984 (Figure 5.6a) mirroring the worldwide increase in biomass production. However, the economic value per tonne of biomass reached a maximum in 1987. Since then, it has decreased (Figure 5.6b).

Figure 5.6. Worldwide variation of the annual seaweed biomass value in billion US$ (a) and economic value per unit of biomass (thousand US$/tonnes) (b)



Dominated by the Asian market, the worldwide trade of macroalgae and derived products has generally increased from 2004 to 2013 (Figure 5.7). Data on internal consumption of algae biomass are not available in the official statistics. Both in Europe and Asia, the import flow dominates the overall trade of these products (Figure 5.7). More than half of the macroalgae and derived products in European markets are supplied by imports, which have increased by 46% since 2004, reaching a total imported biomass of 0.1Mt in 2013.

Figure 5.7. Annual variation in the global trade of algae and derived products[30]



The main exporting country was Indonesia, considering the period 2004 – 2013, with an exportation of 0.18 Mt in 2013, followed by China (0.019 Mt in 2013) and Chile, the second most important global exporter of macroalgae and derived products worldwide since 2007 (0.083 Mt in 2013).

The world leading importing country is China that has progressively increased the importation volume since 2004, reaching values of 0.28 Mt in 2013 followed by Japan,

[30] In general, in this database, bilateral trade are rather weak or inexistent. Therefore, the regional statistics presented in the following paragraphs correspond to the sum of the exports (or imports) of the countries located in a specific region rather than the actual exports (or imports) of the region to the rest of the world. In other words, trade within the region is included.

USA, Republic of Korea and Philippines, all maintaining a stable importation trade between 2004 and 2013.

The exporting trade at the European level is dominated by Ireland with an exportation volume of 54% of the total European exports of the sector between 2004 and 2013, reaching a quantity of 0.038Mt in 2013. The other top-5 European exporting countries maintained stable values between 2004 and 2013, with France, being the second most important European exporting country accounting for only 8% of the exports.

The importing flow in Europe is dominated by France, accounting for 23% of the imports between 2004 and 2013. However, since 2011 Ireland became the main importing country in Europe with 0.035Mt of biomass imported in 2013 (34% of the total imports).

According to the bibliographic references consulted in this study, about 472 tonnes dry weight of macroalgae were commercialized in Europe in 2013 from which a quarter were supplied by European producers (Organic monitor 2015). Nori (*Porphyra* sp. and *Pyropia* sp.) is the most important seaweed species imported to the European market with 99% imports from Japan, China and South Korea to UK, France, Germany and Spain. European wakame (*Alaria esculenta* and *Undaria pinnatifida*) supply is also mainly imported (56% from Asian countries to France, Germany and the UK). Spain, France and the Netherlands are leading the wakame European producing countries, while the biggest consuming markets are Spain, the UK and France. Kombu (*Laminaria* sp. and *Sacharina latissima*) supplies also rely mainly (58%) on importation from Asian countries mainly to the UK. The largest producers of Kombu in Europe are France and Spain. Dulse (*Palmaria palmata*) is mostly produced and sold in Europe (10% imported, mainly from North America and Iceland), with 70 tonnes dry weight supplied in 2013. France is the most important dulse producer and consumer (90% of the European consumption) in Europe and Ireland is the second largest producer (Organic monitor 2015).

The French processing industry relies on local raw macroalgae biomass but also on imports of dry and fresh biomass from Chile and the Philippines to fulfil seasonal needs (15 936 tonnes corresponding to €21.716 million in 2010), fresh agar-agar (373 tonnes corresponding to €5.685 million in 2010) and fresh alginate (1 624 tonnes corresponding to €9.961 million in 2010) (Mesnildrey et al 2012). A significant part of the Irish macroalgae biomass production is sold as raw material or for further industrial processing while the national industry imports large quantities of *Lithothamnion corallioides* from Iceland for agriculture and nutricional purposes (Netalgae report 2012). The Norwegian macroalgae industry relies almost exclusively in the harvesting of *A. nodosum* and *L. hyperborea* with aproximately 0.2 Mt harvested annualy over the last decades, corresponding to an estimated value close to three million euros (Rebours & Stevan personal communication). *A. nodosum* biomass is dryed for agriculture use and follows an industrial extraction process for cosmetics and nutraceutical applications. *L. hyperborea* biomass is used industrially to extract components for the nutraceuticals, pharmaceuticals and alginates industries (Rebours & Stevan personal communication). The macroalgae industry in Spain is mainly based on harvesting of *Gelidium sesquipedale* and cultivation of *L. ochroleuca* and *U. pinnatifida* used for phycocolloid extraction and human consumption as raw or processed material.

Microalgae biomass production in Europe includes several species that are commercialized as raw biomass to be used for research or cultivation purposes or processed to several applications such as food (human nutrition), aquaculture feed, cosmetics and pharmaceuticals. The amount of biomass produced is low but the commercial value of some species and applications are high with for example extracts of some species (e.g. *Haematococcus pluvialis*) being sold at a value of €125/ml.

5.3.2 Gaps, uncertainties and future developments

The FAO and Eurostat databases include very fragmented information regarding the uses, economic value and market flows of algae biomass at the European level. This results from

the incomplete reporting by member states and the confidentiality issues imposed by the business sector. Additionally, no information is available on the commercial use of algae biomass at national level. This limits the realistic assessment of the trade flows, for some species and countries with high internal market consumption of the biomass production. Regarding the value of commercialization of macroalgae and derived products in Europe, the FAO database includes data on aquaculture production only. Given the very recent development of the sector in the region, these data are very fragmented and not representative of the European production. For the microalgae sector no information is available on any of these topics.

The outcomes of the discussions conducted in the workshop on European algae production will be applied to address some of the knowledge gaps on the uses, application paths and market flows of algae biomass in Europe.

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).

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.

Developing the sustainable algae biomass production and use can take place as an application of the EU environmental and maritime policies related to the Bioeconomy, Blue Growth and Circular Economy.

At the European level, macroalgae production methods include harvesting from wild stocks and cultivation in land-based systems or offshore facilities. Microalgae are mainly produced in photo bioreactors or open ponds facilities.

Resulting from market demands, global seaweed biomass production has increased exponentially in the last decade. Globally, the production is mainly based on aquaculture cultivation, while in Europe harvesting supplies most of the macroalgae biomass (more than 90% between 2004-2015).

The European aquaculture sector has developed fast over the last decade. It is currently seen as an alternative to meet the increase in the market demand for high quality sustainably produced algae biomass.

There are still many knowledge gaps regarding the algae sector in Europe mainly related with the low quality and availability of production data, flows and uses data availability that prevent an overarching approach to assess the potential use and value of this biomass source in the bio-based European economy.

Several initiatives are being currently organized 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.

6 Integrated assessment

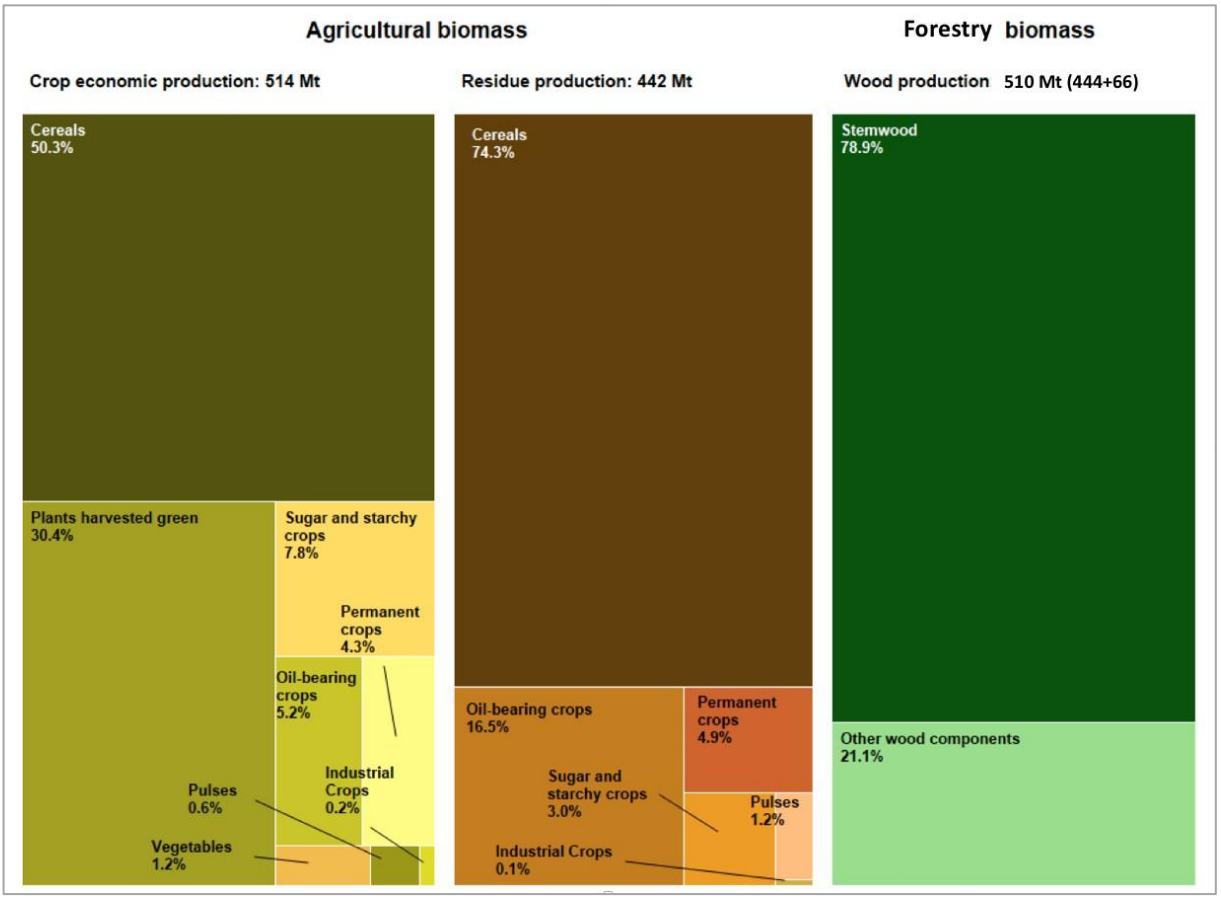
The sectors detailed in chapter 2 to 5 (agriculture, forestry, fisheries and aquaculture, and algae) are the main primary suppliers of biomass. Part of this biomass is processed by industries that may require specific types of biomass (e.g. wood for solid wood products) or not (e.g. cellulose for cellulosic ethanol production). Therefore, an integrated assessment including all sectors supplying biomass is required. This chapter presents a first cross-sectorial insight into the biomass production and the biomass flows in the European economies.

6.1 Biomass production in the European Union

To integrate figures across sectors, we express all biomass quantities in tonnes of dry matter. This common unit makes it possible to compare the relative contribution of each sector to the total biomass supply and use. If the agriculture and forestry sectors are quite used to report biomass at different levels of moisture content up to dry weight, dry matter content is less relevant for fisheries and aquaculture as well as for the algae sector, that usually report live or wet weights. Thus, for the marine-based sectors, we need to rely on conversion factors to dry matter which are not established and rather approximate also due to the wide range of possible water content.

The average EU-28 annual domestic biomass production from the land-based sectors (forestry and agriculture, excluding pastures) is 1466 Mt of (above ground) dry matter Estimates are 10-year averages based on the most recent period of available data. The break down by commodities and sectors is shown in Figure 6.1.

Figure 6.1. EU-28 annual biomass production from land-based sectors, excluding pastures (10-year averages, Mt dry matter)



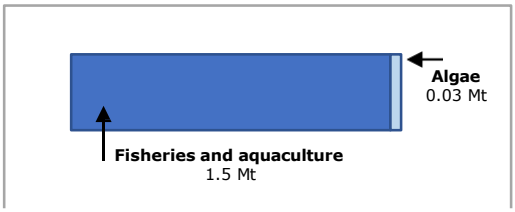
Removal rates in the land-based sectors are different depending on the resource. In agriculture, the crop economic production is almost entirely harvested and marketed, while 23% of the agricultural residues are harvested and used (see paragraph 2.2.2.1). Part of the residues can be removed to produce bio-based materials and energy, while a significant part must be left in the field to preserve soil structure and fertility and maintain ecosystem services. The potential for additional removals or residues subject to sustainability criteria remain difficult to estimate.

In the forestry sector, of the net annual increment of the forest considered available for wood supply (444 Mt), 63% is harvested. Of the harvested woody biomass amount, about 80% is removed from the forest, while part of the biomass from the felled trees (about 20%) is left in the forest as logging residue, together with the deadwood lost due to natural mortality which is not entirely removed, thus contributing to maintain the carbon sink and the provision of other ecosystem services (see paragraph 3.1.2.4). The annual increment in the forest not available for wood supply amounts to 66 Mt.

In 2013, the total biomass harvested in the EU and used from the EU agricultural and forestry sectors was estimated as 805 Mt dry matter (578 Mt from agriculture, 227 Mt from forestry). In addition, 119 Mt were grazed in pastures (see paragraph 2.2.2.1).

The biomass production from the water-based sectors adds up to 6.05 Mt live weight for fisheries and aquaculture and 0.30 Mt fresh weight for algae. Expressing these amounts in dry matter would permit a comparison of total amounts from agriculture and forestry however water content is highly variable and dry weight is never used in the scientific literature and official statistics. As an indicative order of magnitude, for fisheries and aquaculture considering an average value of 75% water content in fish for all species, the estimate in dry weight would be 1.5 Mt. With a similar crude approximation for algae, applying an average conversion factor available for few species, the total EU annual production of macro- and microalgae in dry weight would be 27,000 t (0.027 Mt), see Figure 6.2. The biomass provided by fisheries and aquaculture as well as algae measured in dry weight is limited. However, this does not reflect the economic importance of these two sectors. Moreover, all results correspond to the current production which hides the effective potential of production systems such as aquaculture of fishes or algae. These two sectors may play an important role in developing new bio-based products.

Figure 6.2. EU-28 annual biomass production from marine-based sectors (approx. Mt dry weight)



Further developments of the cross-sector analysis could rely on the values of the different types of biomass as well as the connection with the economy.

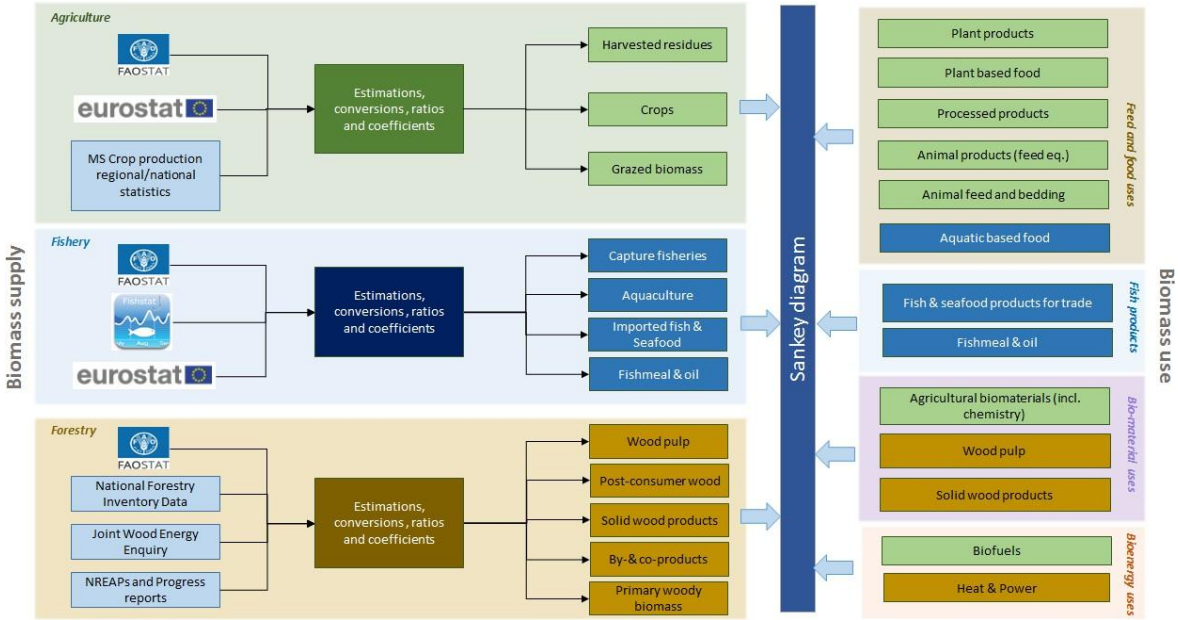
6.2 Cross-sectoral biomass-flows

The biomass supply sectors provide primary material to several economic sectors (food, bio-based material, chemicals, energy…). Reversely, these economic sectors can use materials from several of the supply sectors. For example, the food industries use inputs not only from agriculture but also from fisheries and aquaculture as well as from the algae sector. Among emerging uses of biomass, bioenergy and biochemical value chains can also make use of several sources of biomass. The flows between the biomass supply and the uses are therefore not internal to one sector, but rather interconnected with other sectors. Relying on official statistics, modelling and results illustrated in previous chapters, these biomass flows across sectors have been analysed. For the moment, the three main biomass suppliers in quantities (agriculture, forestry, fisheries and aquaculture) are considered and

the outcomes have been integrated into a Sankey biomass diagram. This diagram is a representation of harmonised data, representing the flows of biomass for each sector of the bioeconomy, from supplies to uses including trade. The diagram enables deeper analysis and comparison of the different countries and sectors across a defined time series.

Multiple data sources have been used to quantify biomass for each category of supplies and uses represented in the flow diagram (Figure 6.3), for each Member State and the EU-28. In order to represent the biomass flows, the Sankey biomass diagram connects biomass supplies to biomass uses. Each of these areas shows different categories: agriculture, forestry and fishery (supplies), as well as feed and food, biomaterials, bioenergy, and direct exports for each sector (uses). From the input side, the algae sector is not included in the current representation because of the lack of comparable information at the time of compilation.

Figure 6.3. Sources and categories of the Sankey biomass flow diagram



To analyse cross-sector flows, data on the production and trade in every sector had to be compiled and harmonised. This implied crosschecking the definitions used by the various sources and the use of conversion factors (for more details, see Gurría *et al*. 2017). In a first stage, all results are presented in weight of dry matter.

All relevant data from the different sources have been integrated into a single database hosted in the JRC DataM[31] Portal (Figure 6.4). In its published online version[32], the diagram accommodates users' choices dynamically thus enabling specific analyses and the comparison between different countries and between sectors across a defined time series.

[31] https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml
[32] https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS

Figure 6.4. Publication process of the Sankey biomass flow diagram

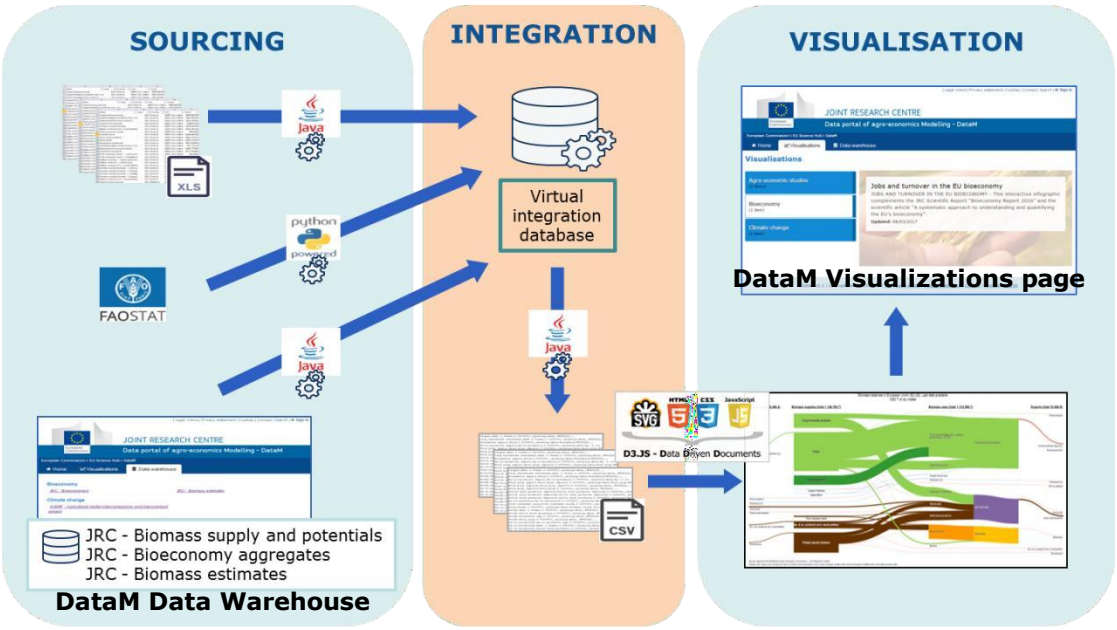


Figure 6.5. Biomass flow diagram for the EU-28

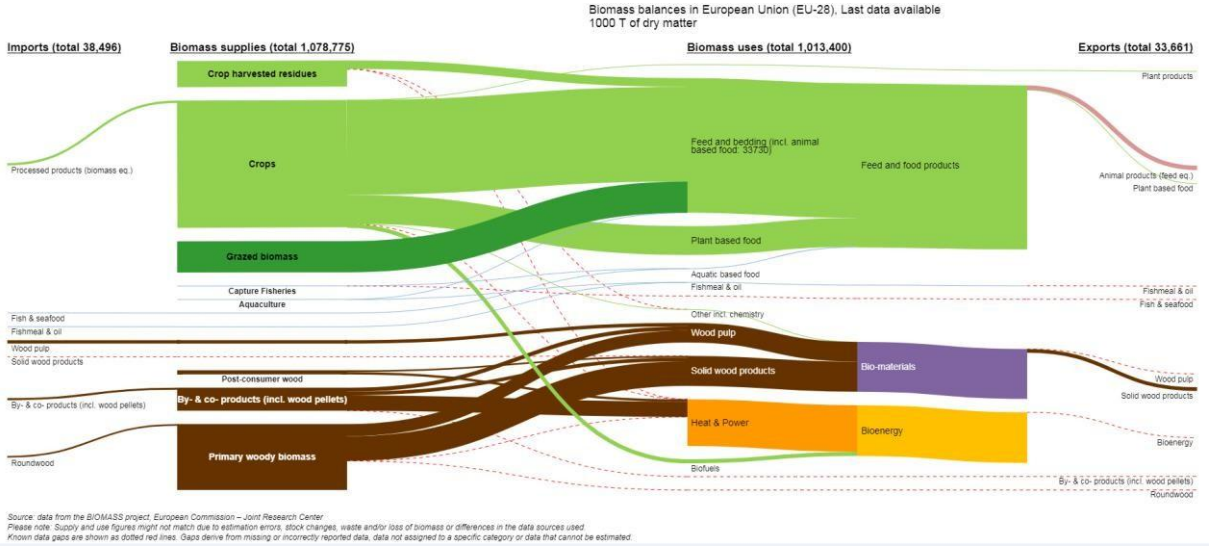


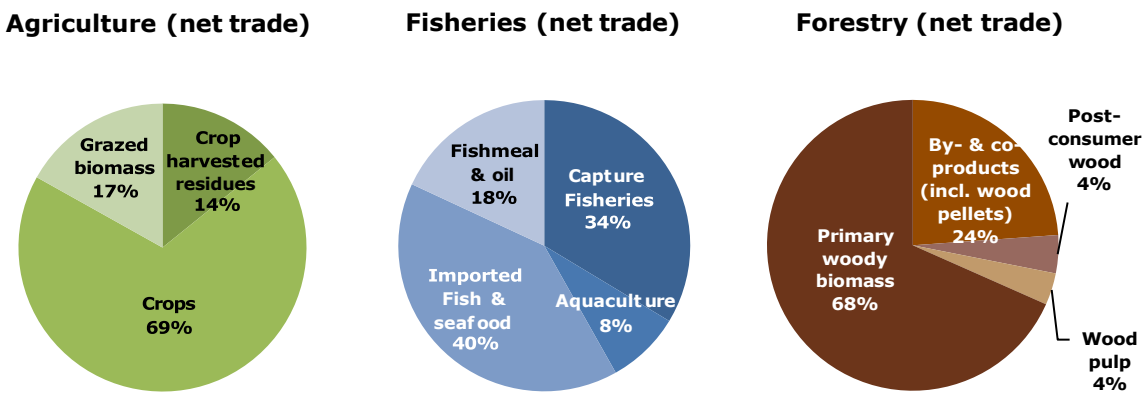
Figure 6.5 represents the flows of biomass between supply and uses in the EU-28 in the form of a Sankey diagram. This representation highlights the relative weight of the different sectors in the bioeconomy. While supply has been split in the traditional sectors (agriculture, forestry and fisheries and aquaculture), the uses have been distributed in different categories because their sources are diverse (e.g. biomaterials are sourced from both forestry and agriculture).

Considering production and net trade estimated in dry matter equivalent in the EU-28, agriculture is the biggest supply sector providing approximately 65% of the biomass (from 13% in Finland to 90% in Greece, Malta, Hungary and Cyprus), followed by forestry with 34% (from 8% in Malta to 87% in Finland). While the relative share of biomass from the fishery sector is quite small (less than 1%), we believe it will become increase once we consider economic or nutritional values.

In agriculture, crops represent 69% of the biomass supply (Figure 6.6) followed by grazed biomass (17%) and collected crop residues (14%). The dominant source of forestry

biomass is primary woody biomass production accounting for almost 70% of the total. As for the fishery sector, the biggest source of biomass is imported fish and seafood, followed closely by captured fish.[33]

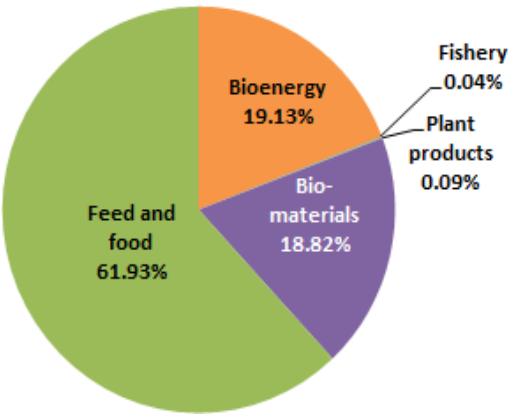
Figure 6.6. Composition of the EU-28 agricultural, fisheries and forestry biomass supplies



In regards to the uses, feed and food is the most important category adding up to over 60% of the biomass (Figure 6.7). 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.

The bioenergy and bio-materials categories are quite balanced. Bioenergy accounts for circa 19% of the total biomass in the EU-28. However, it is important to note that biogas and bioelectricity have not been considered at this stage. Bio-materials are the third biggest group.

Figure 6.7. Distribution of the EU-28 biomass uses



The added value of the overarching perspective provided by the biomass flows integrating different sectors of the bioeconomy has a trade-off in the level of detail and accuracy achievable with such integrated charts. This will have to be taken into account when comparing the results obtained with the two approaches (cross-sectorial and sectorial).

[33] Imported fish and seafood is a separate category because we currently have no data of whether its origin is capture fisheries or aquaculture.

6.3 Gaps and future challenges

The Sankey biomass diagram as presented above can be considered pioneer work. It is the first time that an agricultural biomass balance sheet is presented at EU-28 and Member State level in dry quantity of vegetal biomass equivalent that integrates food and non-food uses of agricultural biomass. As far as we are aware of, it is also the first time that dry quantities of biomass from the agriculture, forestry, fisheries and bioenergy sectors are integrated into a single study. As a pioneer diagram, there are multiple areas where it can be significantly improved. It also suffers from existing data gaps that hampered the complete estimation of biomass uses. Similarly, data quality checks are difficult in the absence of other data of reference with which to compare our numbers.

Possible areas of improvement are:

- The break-down of biomass uses at commodity level, and the consolidation of estimates related to bioenergy and biomaterial uses.
- Improvement of source data. Some data require further specification (e.g. absence of differentiation in origin of commodity flows in the trade and consumption statistics for aquaculture and capture fisheries) and some estimates are only approximate figures (e.g. grazed biomass). In some cases, official statistics omit data for specific countries. The diagram can be continuously improved by integrating additional data as they become available.
- Improvement of trade data, as only net trade is available in some cases. Accounting independently for import and export would provide a better understanding the flows and their connection to the economy.
- The extension of the time series to include additional historical data, as well as integration of modelled data to represent estimates for future periods.
- The estimation of resale data.
- Representation of circular flows for some commodities.
- Estimation of biomass in other units of measure, such as monetary values or fresh matter quantities. The current version only analyses the dry matter content of biomass, not the economic, nutritional or other values of the bioeconomy. Further research will be done in the future to include these aspects in the diagram so a broader view of the bioeconomy can be presented.
- Increase the granularity of the categories (e.g. groups of crops such as cereals, oil crops, etc.), down to a representation of the nutrient components of the biomass.
- Additional representations: geographical, disaggregation, shares of total, shares of total environmental potential.
- Include biomass not considered in this study: biogas, bioelectricity, algae, etc.

Key messages

The average annual biomass produced in the land-based sectors (agriculture and forestry) of the EU is 1466 Mt in dry matter (956 Mt agriculture, 510 Mt forestry). Not all the biomass produced is harvested and used; part of it has to remain in the field to maintain the carbon sink and the other ecosystem services.

In 2013 the biomass harvested in the EU and used was 806.03 Mt in dry matter (578 Mt agriculture, 227 Mt forestry, 1.5 Mt fisheries and aquaculture, 0.03 Mt algae). Conversion to dry matter content for the marine-based sectors is purely indicative. The dry matter quantities in the different sectors do not reflect their exact contribution to the economy.

All available data for the biomass flow assessment have been integrated into a Sankey diagram. It represents biomass flows (supply and uses, including trade) across sectors for each EU-28 Member State and the EU-28.

Considering both domestic supply and trade, agriculture (65.5%) is the largest biomass supply sector (in dry matter equivalent) in the EU-28, followed by forestry (34.2%) and fishery (0.4%).

The EU-28 uses more than 1 billion tonnes of dry matter of biomass. More than 60% are used in the feed and food sector, followed by bioenergy (19.1%) and biomaterials (18.8%). However, due to the lack of data, we assume these two last categories are underrepresented and their share will increase once more data is collected.

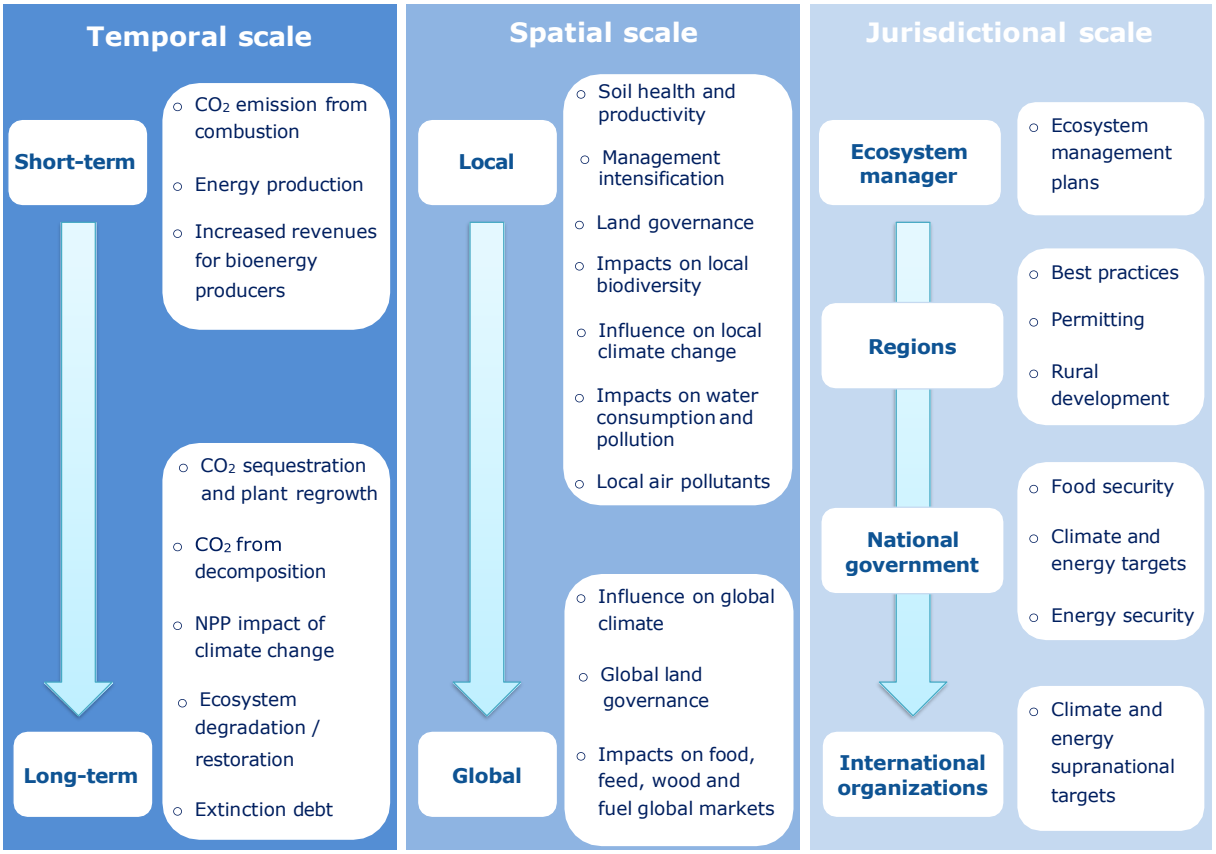
7 Environmental impact assessment of the bioeconomy: Methodological framework and guidance

The bioeconomy sectors are important for creating jobs and growth (Ronzon et al., 2016), but they are also expected to contribute to the EU targets for sustainable production and consumption by enhancing food security, improving the sustainable management of natural resources, reducing the dependence on non-renewable resources, and mitigating and adapting to climate change (EC, 2012).

Activities in the bioeconomy sectors rely strongly on healthy ecosystems and on maintaining the flow of ecosystem services (MEA, 2005). However, bioeconomy activities have the capacity to affect natural and human capital across different temporal, spatial and jurisdictional scales and along multiple levels (Cash et al. 2006). For instance, bioenergy systems can affect the local and global climate, can have a different impact depending on the time horizon considered and are regulated across multiple jurisdictional levels (Figure 7.1). In order to guarantee the necessary and timely protection of the ecosystems exploited for bioeconomy activities, it is crucial to evaluate and monitor accurately the potential environmental impacts of the expansion of bioeconomy sectors as well as of the use of bio-based commodities.

This chapter presents a methodological framework and guidance to using the proper tools to assess the environmental impacts of bioeconomy via a life cycle assessment approach.

Figure 7.1. Different scales and levels involved in the assessment of impacts of bioenergy systems on the environment



Examples linked to bioenergy are also mentioned at the appropriate scale and level.

7.1 Methods

The underlying methodology used to assess the environmental impact assessment of bioeconomy sectors and commodities in the JRC biomass study is Life Cycle Assessment (LCA).

LCA is a structured, comprehensive and internationally standardized method (ISO, 2006; CEN, 2015). It aims to assess all relevant flows of consumed resources and pollutants emissions associated with any goods or services ("products") in order to quantify the related environmental and health impacts as well as resource depletion issues.

LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to final use and end-of-life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or among individual processes can be identified and possibly avoided (ISO, 2006).

7.1.1 Life Cycle Assessment: modelling principles

Two main modelling principles are in use in LCA practice: Attributional (A-LCA) and Consequential (C-LCA) modelling, with the former being more widely used for historical and practical reasons. They represent with their logic two fundamentally different approaches of modelling a system (Figure 7.2).

The attributional life cycle inventory modelling principle depicts the potential environmental impacts that can be attributed to a system (e.g. a product) over its life cycle, i.e. upstream along the supply-chain and downstream following the product's use and end-of-life value chain. Attributional modelling makes use of historical, fact-based, average, measureable data of known (or at least know-able) uncertainty, and includes all the processes that are identified to relevantly contribute to the system being studied. In attributional modelling, the system is hence modelled "as it is" or "as it was" (or as it is forecasted to be) (EC, 2010). Attributional modelling is also referred to as "accounting", "book-keeping", "retrospective", or "descriptive".

The consequential life cycle inventory modelling principle aims at identifying the consequences that a decision in the foreground system has for other processes and systems of the economy, both in the product's background system and on other systems outside the boundaries. It models the studied system around these consequences. This is the case, for example, for the evaluation of the environmental impact of a policy that affects several sectors of the economy. The consequential life cycle model is hence not reflecting the actual (or forecasted) specific or average supply-chain. Rather, it models a hypothetical, generic supply-chain according to market-mechanisms, and potentially includes political interactions and consumer behaviour changes (EC 2010, Plevin et al. 2014). Secondary consequences may counteract the primary consequences ("rebound effects") or further enhance the preceding consequence.

Figure 7.2. Characteristics and objectives of the two main LCA modelling principles

	ATTRIBUTIONAL LCA	CONSEQUENTIAL LCA
Objective	• To depict **potential environmental impacts** of a system over its life cycle.	• To identify the **consequences** that a decision has on other systems, in the background and outside the boundaries.
Modelling	• It uses **historical, average, measureable data** of known/know-able uncertainty. • It includes all processes identified as relevant contributors to the system being studied. • The analysed system **is modelled as it is** (or forecasted to be)	• The modelling is driven by market-mechanisms, and potentially includes political interactions and consumer behaviour changes. • It models the studied system around these consequences, **as a hypothetical, generic supply-chain.**
Applications in EU legislation	❖ Renewable Energy Directive (RED) → attributional LCA approach to calculate GHG emissions for liquid biofuels. ❖ Product Environmental Footprint* (PEF) methodology → attributional LCA approach.	

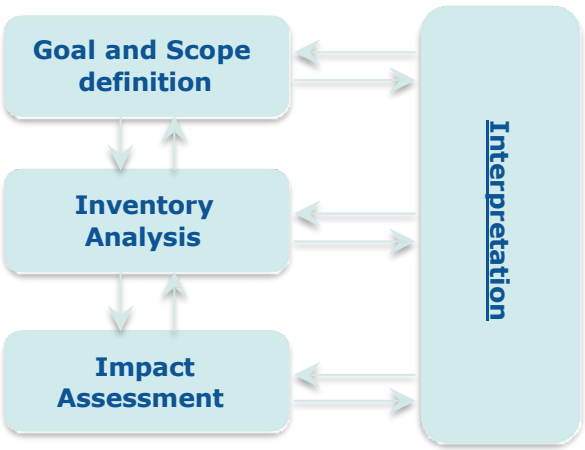
Source: Adapted from EC (2010)

Various applications of LCA, especially with attributional aspects, have already been included in European legislation. The "Better Regulation for Better Results" (COM(2015)215[34]) toolbox explicitly mentioned life cycle analysis as a tool for supporting impact assessment of policies. The Waste Framework Directive recommends that measures are taken to deliver the best overall environmental outcome, even departing from the waste hierarchy, as long as this is justified by life cycle thinking (EP 2008). The Renewable Energy Directive (RED), as well as the Fuel Quality Directive (FQD) and the proposal for a RED-Recast (EP 2009, EP 2009b and EC 2016) apply a simplified attributional LCA methodology to assess GHG emissions savings for a series of liquid biofuels pathways used in the transport sector. A similar methodology is also extended to biomass used for power, heat and cooling generation (EC 2016). The RED evaluates the supply-chains GHG emissions of various bioenergy pathways and compares them to each other on a common basis (GHG emission savings with respect to a fossil fuel comparator) to promote the pathways that perform best on this relative scale and to exclude the pathways with the worst technologies and GHG performances.

7.1.2 Avoiding mistakes and misinterpretation of LCA results

Life Cycle Assessment is a standardized method; however, the ISO standards for LCA (ISO 2006) leave much freedom to practitioners to use any modelling framework, as long as the modelling approach is capable of answering the question set in the goal of the study. The interpretation phase (Figure 7.3), thus, is a key part of any LCA study: it should make sure that the results are consistent with the defined goal and scope and that the conclusions are robust. The limitations of the assessment as well as recommendations should also be clearly mentioned.

Figure 7.3. Life Cycle Assessment framework (ISO 2006)



However, too often practitioners have overlooked this fundamental phase of the LCA framework and have either drawn conclusions which are not supported by the study performed, or have not properly identified the limitations of the study (e.g. the conclusions drawn are usually too broad compared to the study design and to the initial goal).

Examples of this can also be found in legislative documents. Since the 90's, the principle of Life Cycle Thinking has been increasingly integrated into the policymaking process, either at the stage of policy design and impact assessment, or directly into legislative documents (Sala et al. 2016). The case of bioenergy is one of the main examples where LCA has been used for the implementation of legislative requirement. In the Renewable Energy Directive (EP 2009) and the Fuel Quality Directive (EP 2009) the results from purely attributional studies are used to assess the GHG performances of biofuels compared to those of fossil fuels.

[34] COM(2015)215. Communication on Better regulation for better results - An EU agenda. http://ec.europa.eu/smart-regulation/better_regulation/documents/com_2015_215_en.pdf

However, these results must be interpreted with care. Specifically, they should not be used to evaluate whether a large-scale deployment of biofuels could mitigate GHG emissions compared to the fossil fuel alternatives. This is because purely attributional LCA studies of bioenergy systems are unable to capture properly all of the complexities linking bioenergy, climate, bioenergy and ecosystem services (e.g. market-mediated effects, biogeophysical, time-dependent effects). Ignoring these aspects could result in the improper interpretation of LCA results, with the risk to take strategic decisions, which will then require amendments with broad-ranging consequences on the stakeholders involved (EC, 2015).

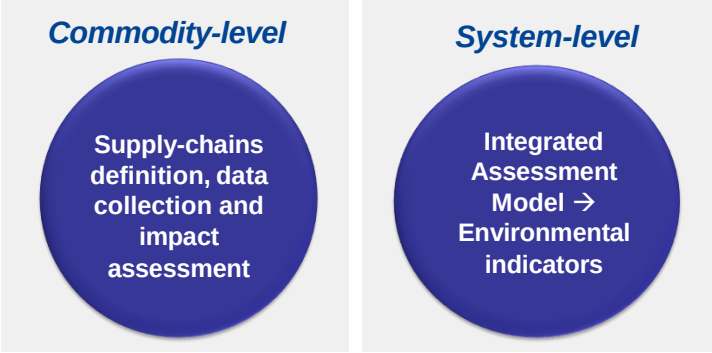
In the last decade, though, the LCA community working on bioenergy has made significant progresses in better understanding the broad-ranging ramifications of bioenergy systems, and improving the LCA modelling principles as well as the way in which LCA results are interpreted.

This improved approach and understanding is applied in this study to analyse the potential impacts of several bio-based commodities and supply chains.

7.1.3 Commodity-level and system-level analyses

The results of the environmental impact assessment can be elaborated using two different levels of analysis (Figure 7.4): the life cycle impact assessment of bio-based supply chains (*commodity-level analysis)* and the evaluation of environmental indicators for multiple future policy scenarios (*system-level analysis)*.

Figure 7.4. Two main levels of environmental impact assessment



Qualitatively, the modelling approaches described in this chapter can be classified based on the appropriate context and scale, and on the modelling complexity and level of uncertainty (Figure 7.5). LCA methodologies implemented in legislation (e.g. in the RED) respond to specific requirements and are generally based on characteristics that differ from LCA studies aiming at providing strategic impact assessment. Models that respond to 'regulatory' needs should have the following criteria: i) easy to calculate; ii) well-defined in all their rules; iii) use a well-specified, easily accessible and stable inventory; iv) should often be of general validity across the temporal and spatial scales covered by the legislation (Plevin et al. 2014).

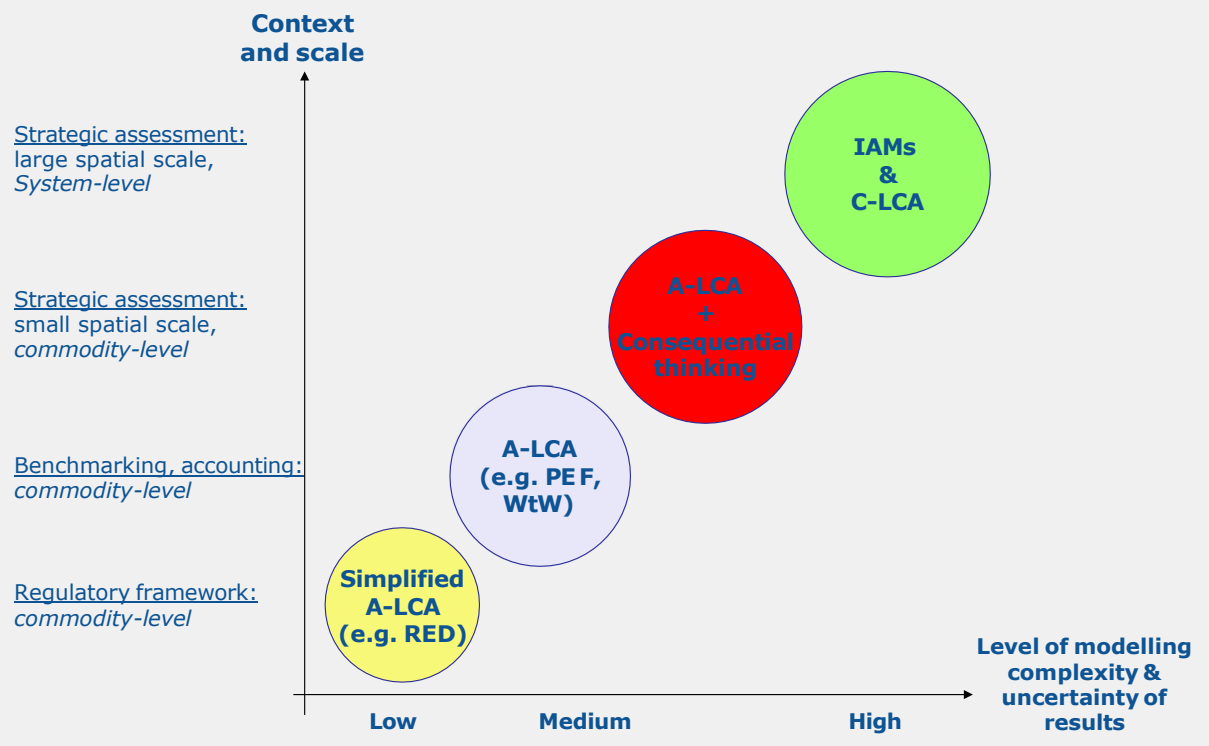
On the other hand, LCA studies carried out to assess the impacts of strategic decisions (e.g. impact assessment of policy choices) should focus on a broad range of potential environmental risks linked to such a strategy, technology shift or policy option. They should also present a comprehensive picture across scales and sectors that may be directly or indirectly affected by the policy. System-level studies usually rely on Integrated Assessment Models (IAMs) covering multiple market sectors and large geographic scales (JRC 2013; EC 2016b; Plevin 2016).

An intermediate approach is emerging in the literature. It is based on attributional modelling but incorporates elements of consequential thinking to produce impact assessments that are more comprehensive than A-LCA and that still works on a commodity-level. These assessments are easier to implement and evaluate than using

IAMs but can still highlight potential red-flags and mitigation strategies (Giuntoli et al. 2015, Giuntoli et al. 2016, EC 2016b).

The results presented in this report are limited to a *commodity-level* analysis and fall in the first three categories of approaches presented in Figure 7.5. *System-level* results obtained in the Biomass study fall into the last category and will be presented at a later stage.

Figure 7.5. Indicative distribution of the modelling approaches applied in this study, based on analytical context & scale, and on increasing level of modelling complexity & uncertainty of the results



The results presented in section 7.3 pertain to supply-chain impacts associated to several bio-based commodities. For instance, Figure 7.6 represents the processes involved to produce wood pellets from forest stemwood (Giuntoli et al., 2017). In practice, the energy and chemicals inputs as well as the pollutant emissions deriving from each process step are evaluated with a life cycle perspective, i.e. transport processes will account for the emissions associated to the combustion of the diesel but also for the emissions incurred in the whole life cycle of the diesel fuel (extraction, processing and transport). The results of these types of assessment are static in time and do not account for biogenic-C flows. It has become established practice in A-LCA to assume that any emission of biogenic CO_2 (release to the atmosphere of the carbon contained in biological resources) is compensated by photosynthesis during the re-growth of the biomass feedstock. This assumption originates from an interpretation of the rules for reporting national GHG inventories to the United Nations Framework Convention on Climate Change (UNFCCC). Biogenic-C flow are accounted for in the land use, land-use change, and forestry (LULUCF) chapter at the time the biomass commodity is harvested and are therefore not accounted for in the energy sector at the time the biomass is burnt (JRC, 2013). It remains valid for system-level analysis, when the changes in biomass carbon stocks are accounted in the land-use sector rather than in the energy sector (EC, 2016c). However, as illustrated in section 7.3.2, this accounting rule has important consequences on the interpretation of LCA results when applied to product-level analysis, and implications should be evaluated carefully when choosing the appropriate modelling approach (Figure 7.7).

Figure 7.6. Example of processes included in A-LCA studies for wood pellets

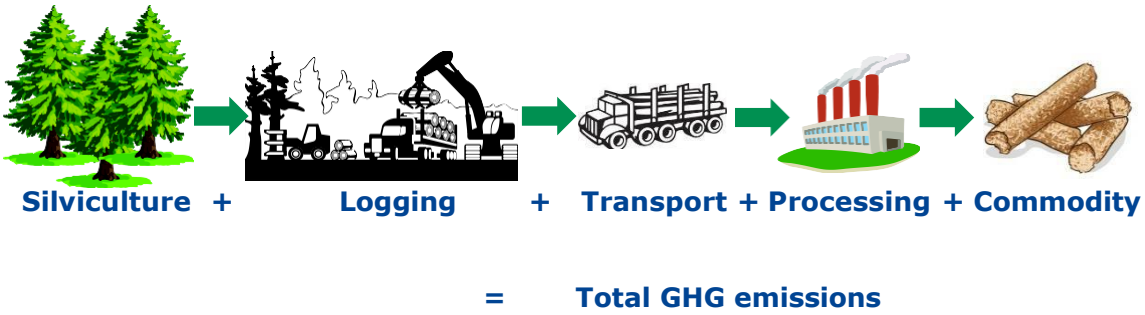
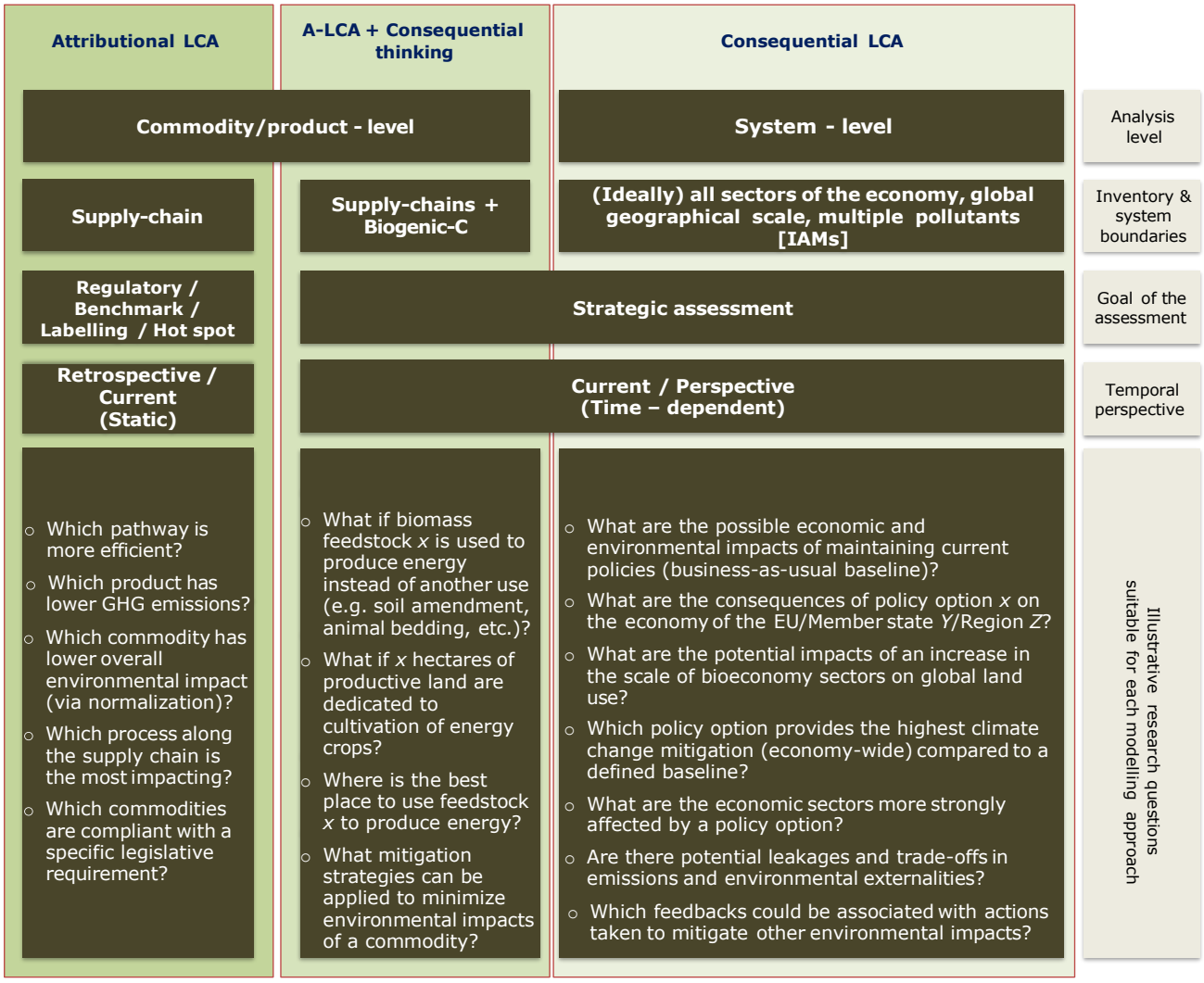


Figure 7.7: Characteristics and samples of research questions associated with the three modelling approaches mentioned in this report



7.1.4 A Decalogue for A-LCA integrated with consequential thinking applied to bio-based commodities

A-LCA studies can be combined with consequential thinking to provide precious information about the potential impacts of multiple strategic options for bio-based systems. Provided that a suitable system design as well as appropriate analytical tools are implemented, this approach can produce useful results avoiding the use of complex and time-consuming tools such as large integrated modelling suites. This approach corresponds to the red bubble in Figure 7.5.

For instance, assessing the potential impacts of a system in which cereal straw is displaced from animal bedding to energy requires the modelling and comparison of another series of systems analysing various possible straw replacements in the animal bedding market.

Such analysis can be considered to be still attributional: it will not give the answer whether the replacement is likely to happen and it will not define in which quantities such replacement may happen. It will only provide partial information; such as highlighting *red flags* that will need to be monitored and managed carefully in case a policy to increase the demand of straw for energy was designed. Examples of research questions that could be tackled with this approach can be found in Figure 7.7.

From the experience gathered within the LCA-bioenergy community in the last decade, ten critical points that need to be considered and applied when carrying out a commodity-level assessment of bio-based commodities can be distilled:

1) Clearly **define the goal and scope** of the assessment to choose the best methodological approach (see Figure 7.2 and Figure 7.7);
2) **Analyse multiple systems ("counterfactuals") and include all functions in each system.**

   Consider for example a case where three alternative uses for wheat straw are compared (see for instance Koponen et al. 2018):

   - System nr. 1) Reference system nr. 1: energy and animal bedding services are provided by a fossil source and an alternative material, respectively – wheat straw is considered a crop residue and incorporated in the soil assuming functions of soil amendment,
   - System nr. 2) Reference system nr. 2: energy is provided by a fossil source – wheat straw is used as animal bedding and the bedding is then applied back to the soil,
   - System nr. 3) Bioenergy system: wheat straw is used for power generation – Bedding is provided by a non-straw alternative and there is an avoided flow of straw to the soil;
3) Analyse results **relatively to each other** (System 1 vs. System N);
4) Account explicitly for all C-pools and all C-flows, including **biogenic-C**;
5) Treat time-dependent emission profiles explicitly in time, if the systems are characterized by transient phenomena;
6) Evaluate climate change impact both with normalized metrics (Global Temperature Potential, GTP(100), Levasseur et al. 2016) and with absolute metrics (Absolute Global Temperature Potential, AGTP). Furthermore, both cumulative (e.g. Absolute Global Warming Potential, AGWP) and end-point metrics (e.g. AGTP) are used to capture different impacts of climate change (Levasseur et al. 2016);
7) Use **advanced tools** where possible to build the Life Cycle Inventory, for instance:
   - Forest management and ecosystem models (e.g. CBM, EFISCEN, G4M),
   - Agricultural cropping system models (e.g. Cropsyst, Century, DNDC),
   - Energy system models (e.g. JRC EU-TIMES, PRIMES, POLES),
   - Etc.;
8) Impact on climate change accounts also for **Near Term Climate Forcers (NTCF)** (such as aerosols, ozone precursors etc.) emissions and for **biogeophysical forcers** (e.g. albedo);

9) Consider all potential environmental impacts (**avoid shifting of burdens**);

10) Carry out an **extensive sensitivity** analysis (scenario analysis) designing multiple storylines as well as varying the most critical and uncertain parameters.

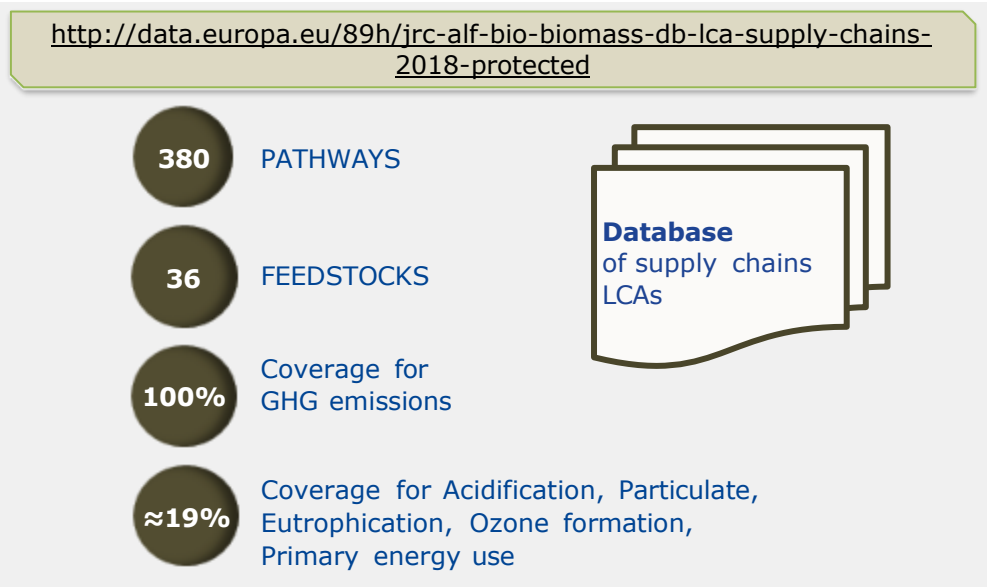
7.2 Supply chains description

In the framework of the JRC biomass study, a database was compiled to gather the LCA results calculated or assembled within JRC for multiple bio-based commodities. In this report, the term 'bio-based commodities' encompasses traditional agricultural products (such as food, feed and fibres), biofuels and bioenergy and bio-based materials. The latter term includes pulp and paper products, wood industry products and bio-based chemicals (Figure 7.9).

7.2.1 A large database of LCA results for bio-based commodities

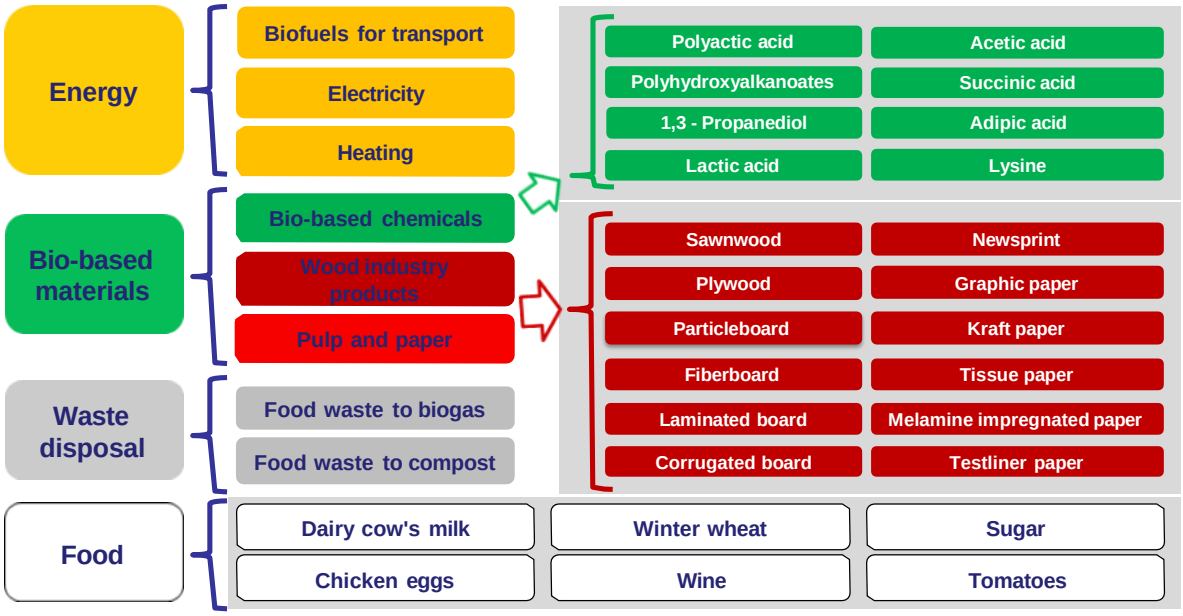
The database consists currently of ca. 380 pathways (Figure 7.8) and it is a live document, so that anytime additional commodities or pathways are analysed within JRC, the results can be added. Due to existing policy objectives, the bulk of the database consists of values referring to bioenergy commodities and focuses on Greenhouse Gas emissions (data for bioenergy are consistent with the datasets published in the JRC data catalogue (EC 2017)). However, the database contains also numerous datasets referring to bio-based products, waste disposal routes and food commodities (Figure 7.9).

Figure 7.8. Schematic of details of database of LCA results for bio-based commodities



The database is searchable and it is available in the JRC Data Catalogue (see http://data.europa.eu/89h/jrc-alf-bio-biomass-db-lca-supply-chains-2018-protected).

Figure 7.9. Visual synopsis of the commodities contained in the database



The following sections present some of the most interesting results from the datasets.

7.2.2 Sources of numerical variation in A-LCA results

When considering the environmental impacts associated to a product, results from A-LCAs can span a broad numerical range even when considering a single commodity. We identify three main sources of variation: i) *variability* in the values of parameters; ii) *decision variables* characterizing the supply chain; iii) *methodological* choices.

In this work, we define *variability* as the possible range of values that some key parameters can take within a specific pathway (Figure 7.9). During the data collection step, central base-case values for each item in the inventory are defined by averaging several sources. The base-cases presented in the database are usually representative of average conditions for the scope considered (EU-wide values in most of the pathways in the database, unless a different geographic scope is explicitly mentioned).

However, for each central value defined, a certain variability range can also be described. This can be tackled in a "continuous" way by defining a frequency distribution of values for each relevant parameter and then by running a Monte Carlo simulation to produce a probability distribution of results. Alternatively, a "discrete" approach can be applied by running a standard sensitivity analysis by means of varying the most important parameters by a certain quantity and calculating the range of results obtained.

The modeller assigns independent inputs to specific parameters, called here d*ecision variables,* thus producing a range of results deriving from different configurations of the same supply-chains associated to a single commodity. For instance, the distance at which biomass resources are transported influences significantly the overall impact of bio-based commodities. Conversion efficiencies can be both a source of variability (e.g. range of possible efficiencies for a single engine) and important decision variables (e.g. modelling different conversion technologies). Macro-aggregation into storylines can be used to facilitate the interpretation of the results. For instance, pre-defined transport schemes can be designed to represent biomass feedstock imported from certain world regions (see Giuntoli et al. 2017).

Another source of variation is linked to *methodological* choices in each assessment (e.g. allocation basis, background processes, etc.); for the benefit of the users, critical methodological choices are reported explicitly in the database.

7.3 Results and discussion

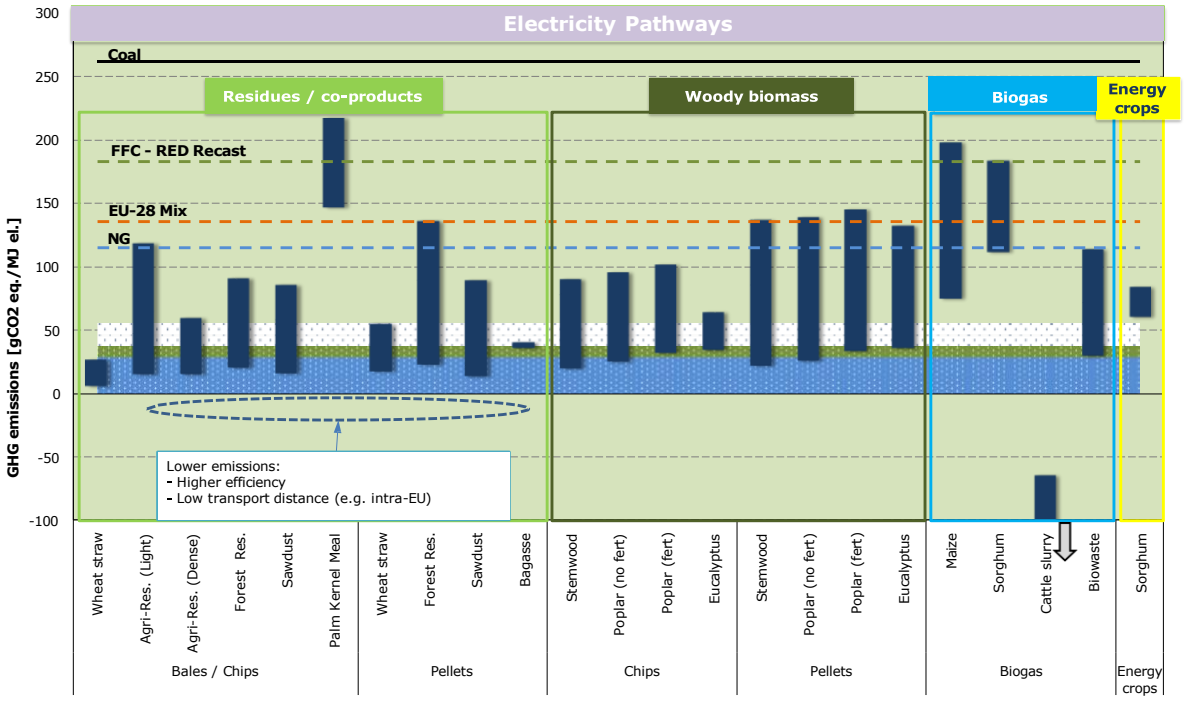
7.3.1 Attributional-LCA results for bio-based commodities

This section presents a sample of the life cycle impact assessments for several of the pathways contained in the database. The calculations follow an attributional approach as described in section 7.1.3.

Figure 7.10, Figure 7.11 and Figure 7.12 collect the GHG emissions results for several bioenergy commodities: electricity, heating and transportation biofuels. The floating bars represent the range of variability of results found in multiple studies and/or obtained for multiple supply chains configurations. These values can be compared with the GHG emissions associated to multiple alternative energy systems available in the EU (dashed lines). To provide an additional reading key, we also report the values of GHG savings[35] for bioenergy pathways as compared to the defined fossil fuel comparator (Giuntoli et al. 2017) (coloured areas).

The results presented here focus on GHG emissions because this is currently the most complete dataset available. However, additional impact categories are included in the database for several pathways.

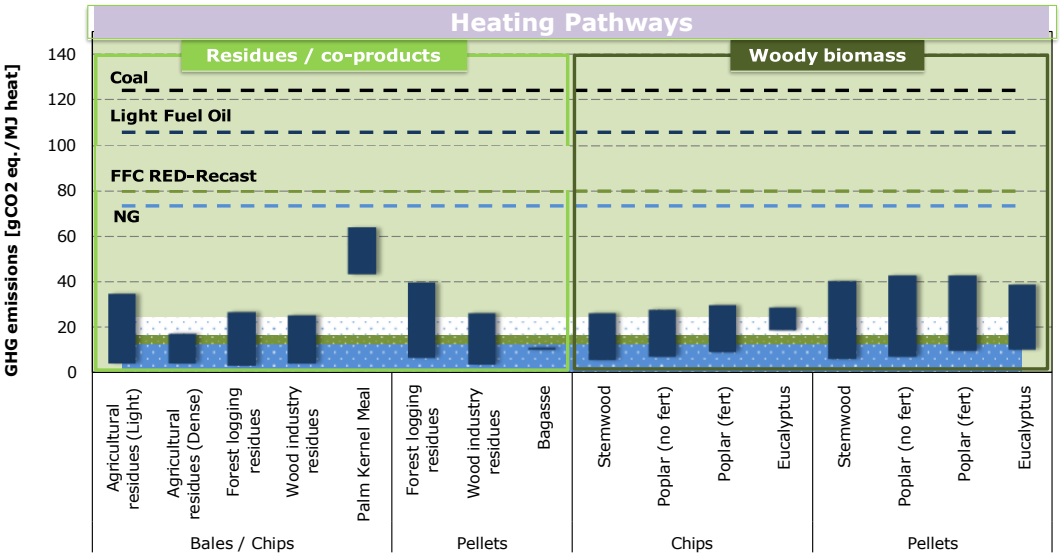
Figure 7.10. GHG emissions from pathways for the production of electricity from various biomass feedstocks



The floating bars represent the range of variability of results found in multiple studies and/or obtained for multiple supply chains configurations: the lowest bound represents the minimum value found, the highest the maximum. Dashed lines show, for illustrative purposes, the GHG emissions associated to multiple alternative energy systems available in the EU: Black line = EU-coal power plant (Source: Edwards et al. 2014); Blue line = EU-natural gas power plant (Source: Edwards et al. 2014); Orange line: EU-28 average electricity mix (Source: Edwards et al. 2014); Green line: Fossil Fuel Comparator as defined in (EC, 2016). The coloured areas represent levels of GHG emissions savings of the bioenergy commodity compared to the legally defined fossil fuel comparator (Giuntoli et al. 2017): the white area indicates GHG savings above 70%, the green area, above 80% and the blue area, above 85%. GHG emissions for biogas from cattle slurry are out of the negative scale (grey arrow).

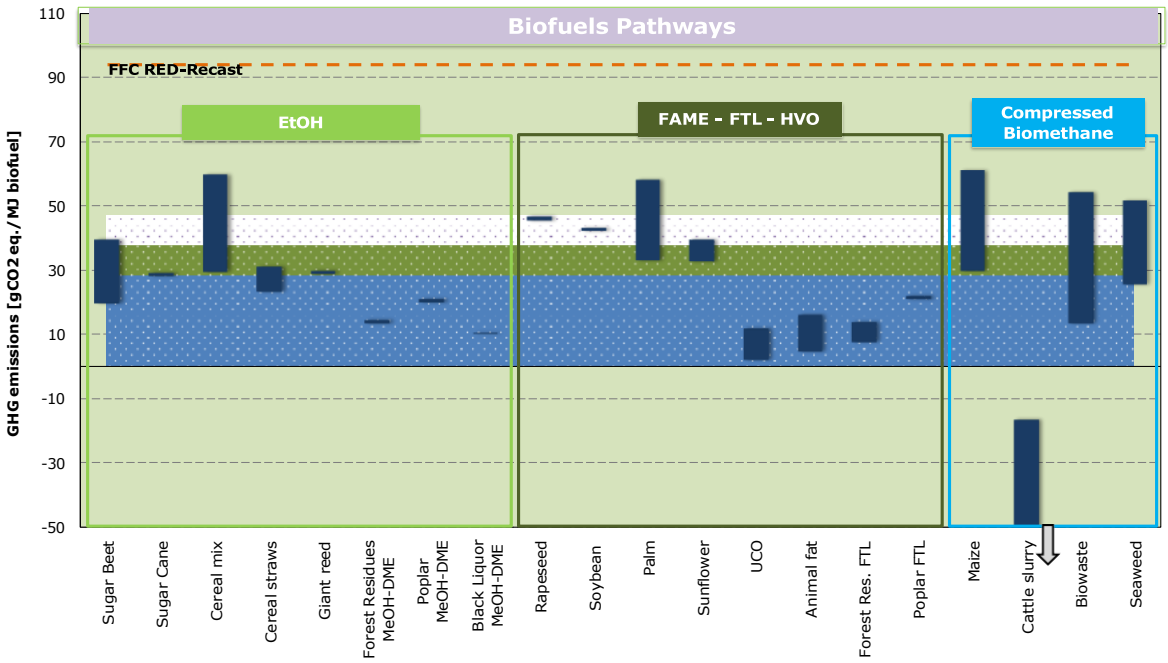
[35] The use of 'GHG savings' as a metric to assess climate change mitigation effects of bioenergy pathways compared to fossil fuels has been designed and defined by the EU in several legislative documents (EU 2009, Giuntoli et al. 2017). While this may have merits of simplicity and clarity for regulatory purposes, it should be remembered that this value does not reflect an intrinsic property of the commodity but it is the result of a series of value choices, the main one being the choice of the fossil reference. The definition of 'GHG savings' used in this document should be considered to refer solely to the methodology defined in EC 2016a – Annex V and Annex VI.

Figure 7.11. GHG emissions from pathways for the production of heating from various biomass feedstocks



The floating bars represent the range of variability results found in multiple studies and/or obtained for multiple supply chains definitions: the lowest bound represents the minimum value found, the highest the maximum. Supply chains for which only one value was available are represented as a single line. Dashed lines report, for illustrative purposes, the GHG emissions associated to multiple alternative energy systems available in the EU: Black line = EU-coal heat plant (Source: Edwards et al. 2014); Dark blue line: EU-Light fuel oil heat plant (Source: Edwards et al. 2014); Blue line = EU-natural gas heat plant (Source: Edwards et al. 2014); Green line: Fossil Fuel Comparator as defined in EC (2016). The coloured areas represent levels of GHG emissions savings of the bioenergy commodity compared to the legally defined fossil fuel comparator (Giuntoli et al. 2017): the white area indicates GHG savings above 70%, the green area, above 80% and the blue area, above 85%.

Figure 7.12. GHG emissions from pathways for the production of biofuels for transport from various biomass feedstocks



For indicative purposes, the emissions of the Fossil Fuel Comparator in EC (2016) (dashed line) are also reported. The floating bars represent the range of results found in multiple studies and/or obtained for multiple supply chains definitions: the lowest bound represents the minimum value found, the highest the maximum. Supply chains for which only one value was available are represented as a single line. The coloured areas represent levels of GHG emissions savings of the bioenergy commodity compared to the legally defined fossil fuel comparator (EC, 2016): the white area indicates GHG savings above 50%, the green area, above 60% and the blue area, above 70%. GHG emissions for biogas from cattle slurry are out of the negative scale (grey arrow).

In the present analysis for bioenergy commodities, the pathways have been aggregated by feedstock and by end-use. The range of results associated with each pathway is dependent on several factors of variability[36]:

1. Transport distances of the feedstock or of the final product,
2. End-use conversion efficiencies,
3. Utilities,
4. Process characteristics,
5. Background data,
6. LCA Methodology.

The GHG emissions reported in this work, therefore, should not be interpreted as a universal property associated to the product/commodity, since the changes in methodological choices and background data can largely influence the absolute value of GHG emission. However, the relative benchmarking among similar products and commodities can provide important information. The results in Figure 7.10, Figure 7.11 and Figure 7.12 show that, most bioenergy pathways emit less GHG along their supply chain than fossil fuel pathways. However, the various pathways can achieve very different GHG emission levels. For instance, using dairy cattle slurry to produce biogas or biomethane can guarantee the highest GHG emissions mitigation due to the emission credits assigned for the avoided methane emissions associated to the use of raw manure as organic fertilizer (Giuntoli et al., 2017).

In order for commodities to achieve the highest ambitions in terms of GHG emission savings (>85% savings), generally, high resource efficiency along the supply chain is required, and in particular:

1. Optimized logistics with short or efficient transport options (e.g. biomass feedstock is traded within EU neighbouring countries),
2. High efficiency of final conversion,
3. Use of renewable energy sources to supply process-heat and process-electricity,
4. Optimal process design (e.g. digestate residue from anaerobic digestion is stored in gas-tight tanks),
5. Use of wastes, residual or low-input feedstocks,
6. Assignment of credits to co-products (substitution method).

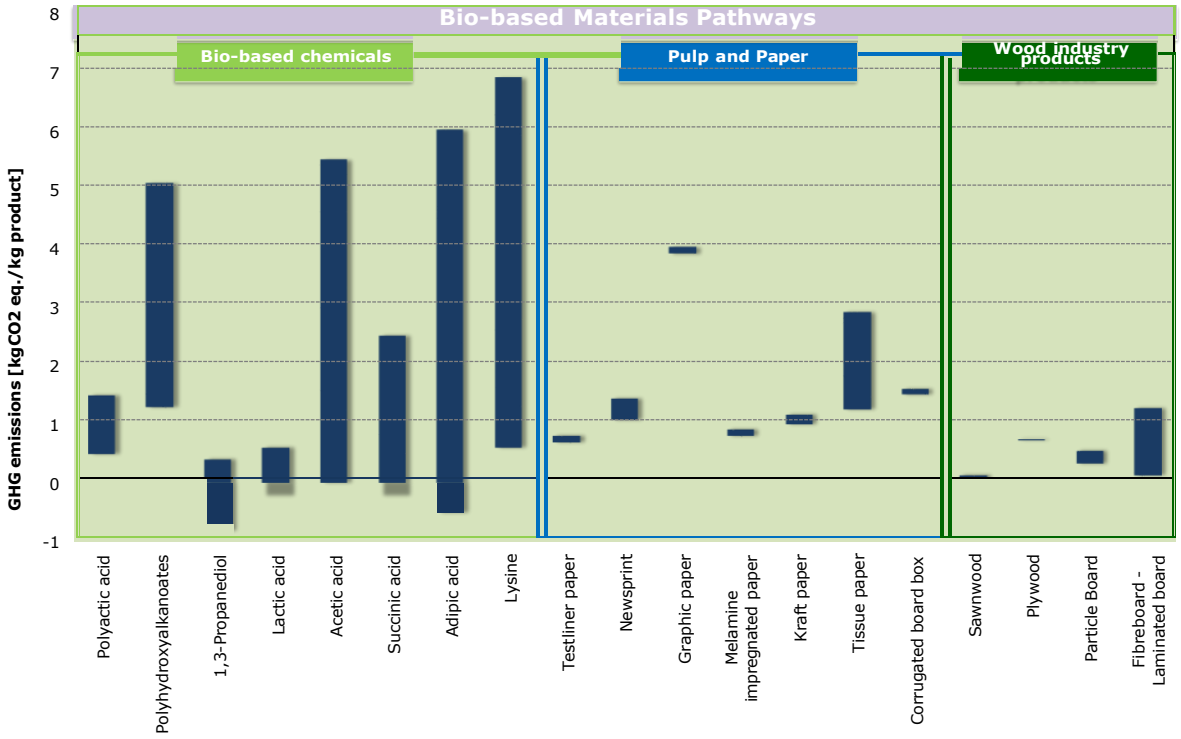
Nonetheless, the results show that even with current technologies, significant optimizations are available to reduce the impacts of each supply chain (lower boundary of floating columns).

Furthermore, results in Figure 7.12 show that biofuels produced from residual biomass have generally lower emissions along their supply chain and they are the only pathways that would achieve the highest ambition target of 70% GHG savings compared to EU Fossil Fuel comparator.

Figure 7.13 collects the GHG emissions associated to various bio-based materials, while Figure 7.14 shows the GHG emissions for a sample of supply chains for food commodities as reported by Torres de Matos et al. (2015).

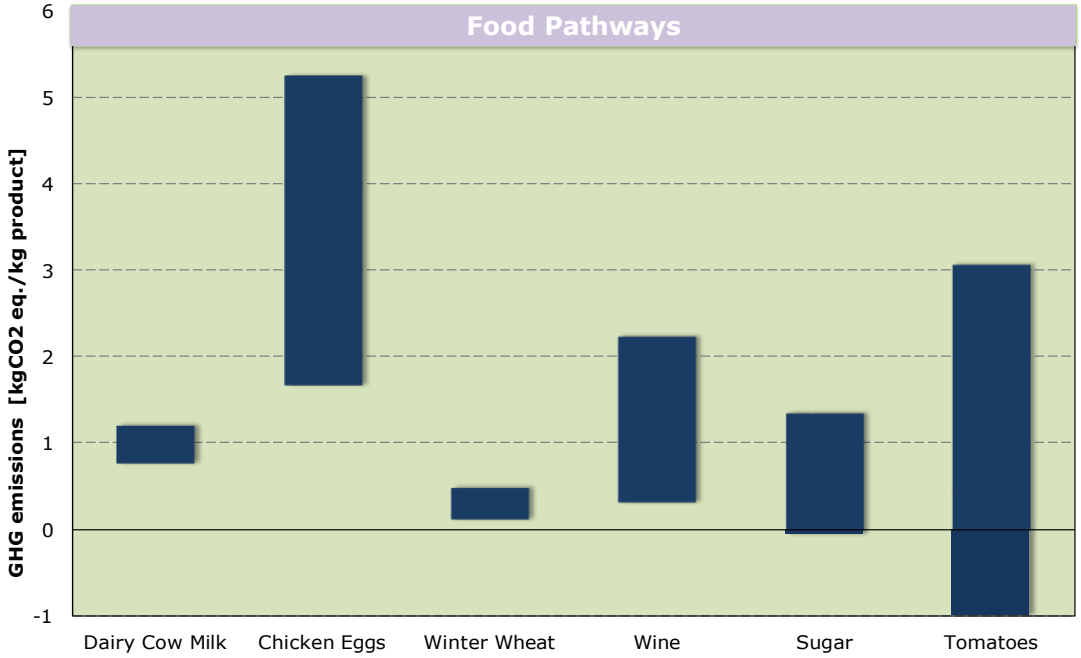
[36] Details on the results for each supply-chain, the design of each pathway, methodological choices and results for other environmental impacts can be found in the database.

Figure 7.13. GHG emissions from pathways for the production of bio-based chemicals, pulp and paper and wood industry products



The floating bars represent the range of results found in multiple studies and/or obtained for multiple supply chains definitions: the lowest bound represents the minimum value found, the highest the maximum. Supply chains for which only one value was available are represented as a single line.

Figure 7.14: GHG emissions from pathways for the production of various food commodities



The floating bars represent the range of results found in multiple studies (Torres de Matos et al., 2015): the lowest bound represents the minimum value found, the highest the maximum.

The assessment of GHG emissions from bio-based materials (Figure 7.13) shows larger values and significantly larger spread for novel bio-based products compared to pulp and

paper, and products from the wood industry. The large spread in values is to be expected when assessing novel products for which production processes are not yet established and data availability is still scarce (Torres de Matos et al., 2015). Similarly, the food commodities assessed (Figure 7.14) show broad-ranging results linked mainly to agricultural management, geographical origin and processing characteristics.

7.3.2 Case studies applying A-LCA with consequential thinking

This section introduces briefly the case study detailed in Giuntoli et al. (2016) and it highlights how the Decalogue described in section 7.1.4 was applied (Table 7.1).

The main goal of the study was to produce a strategic assessment of the climate change mitigation potential of using several biomass residual feedstocks to provide electricity as compared to the existing EU electricity grid mix.

Three systems were designed to represent three different power production scales (see Figure 7.15): i) large-scale power plant of 80 $MW_{el.}$ fuelled with wood pellets from forest logging residues (FRel); ii) medium-scale power plant of 15 $MW_{el.}$ fuelled with cereal straw bales (STel); iii) small-scale internal combustion engine of 300 $kW_{el.}$ fuelled with biogas produced from anaerobic digestion of cattle slurry, employing an open or gas-tight tank for digestate storage (Biogas OD/CD).

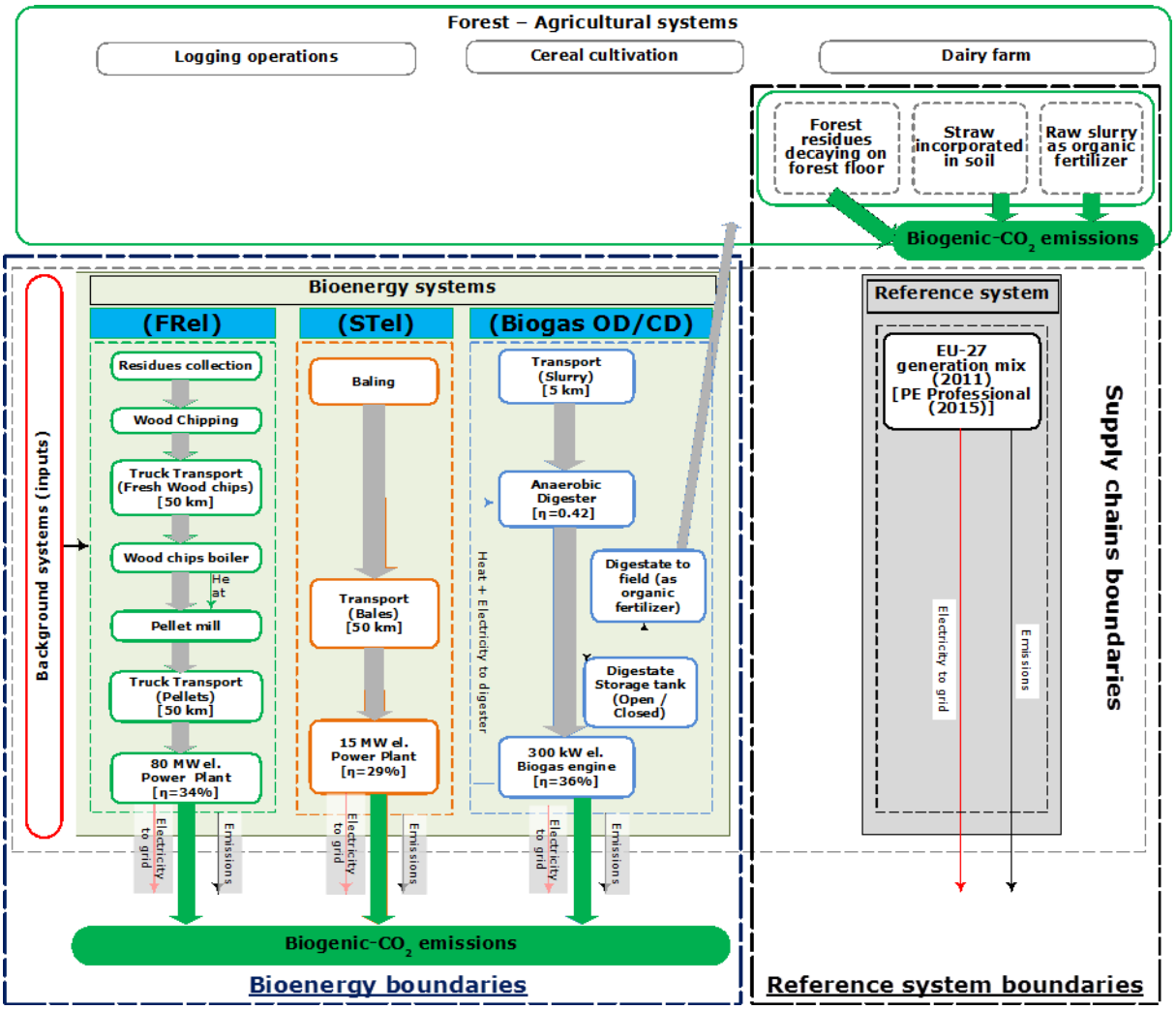
The functional unit considered was 1 MJ of electrical energy per year[37]. The geographical scope of the paper referred to the EU-27 countries.

The counterfactual uses of biomass materials were defined in the reference system (point 2 of the Decalogue): forest residues are considered to be left on the forest floor, the cereal straw to be incorporated in the soil, and raw manure to be used as organic fertilizer. It is important to notice that the definition of the reference system (both the energy system and the counterfactual biomass use) is as important as the definition of the bioenergy systems since the stated goal of the study is to assess the mitigation potential of the new systems as compared to the reference one. The results of the study must be interpreted as a relative comparison (point 3).

The system boundaries for the supply chains (highlighted in Figure 7.15) are consistent with the boundaries considered for the analysis presented in section 7.3.1, but an additional inventory is created to account for the biogenic-C flows (point 4). Therefore, the results depicted in Figure 7.16, are calculated in line with what is presented in section 7.3.1: only supply-chains processes are considered, the analysis is static in time and only Well-mixed GHG (CO_2, CH_4, N_2O) are accounted for.

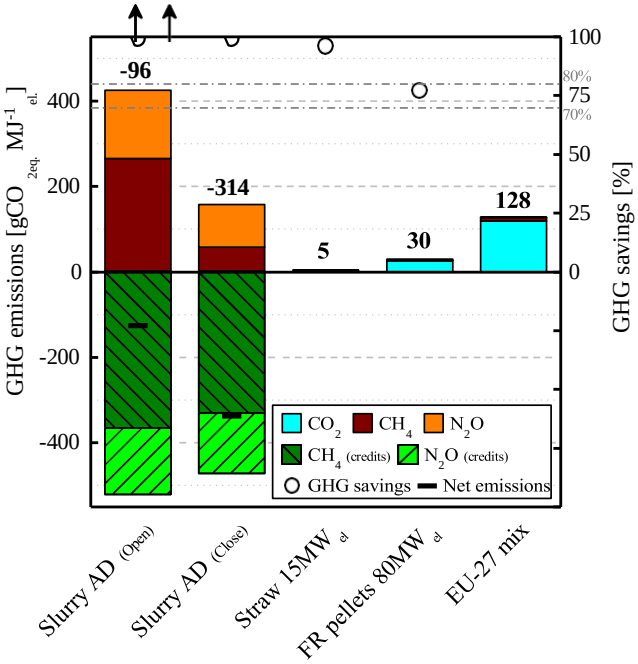
[37] Considered at the power plant outlet, thus including own consumption but excluding transmission and distribution losses.

Figure 7.15. System boundaries for the three systems considered



Left: bioenergy systems; Right: reference system(s) considered. Both bioenergy and reference systems include the energy production supply chain ("Supply chains boundaries") as well as biogenic-CO_2 flows (green arrows). Details of the systems are given in Giuntoli et al. (2016). FRel = Forest logging residues pellets used in an 80 MWel. power plant; STel = Wheat straw bales used in a 15 MWel. power plant; Biogas OD/CD = Biogas from cattle manure used in a 300 kWel. internal combustion engine; with open storage tank for digestate (OD) and with gas-tight tank (CD).

Figure 7.16. Supply chain GHG emissions for bioenergy and EU-27 mix



Only WMGHG and no biogenic-C emissions from changes in forest and soil carbon stocks are considered. Evaluation is based on GWP(100) with climate feedback. GHG emissions for the bioenergy pathways and reference system are on the basis of 1 MJ of electricity. The bars are stacked based on the contributing GHG. The total value is written on top of the bars. The circles represent GHG savings of bioenergy compared to the EU-27 mix (right y-axis); values outside the scale are above 100%.

The four systems analysed provide GHG emissions savings above 75%, but the pellets system ($FR_{el.}$) would fail to comply with higher GHG savings thresholds.

However, as explained in the sections above, results that focus only on supply-chain emissions cannot provide meaningful results for strategic decisions on the use of biomass for bioenergy. Figure 7.17 thus presents the results obtained for the A-LCA+ Consequential thinking analysis. The results are explicit in time, Near-Term Climate Forcers (i.e. ozone precursors and aerosols) are included, an instantaneous, absolute climate metric is used and biogenic-C flows are explicitly accounted for (see Table 7.1 for all methodological details).

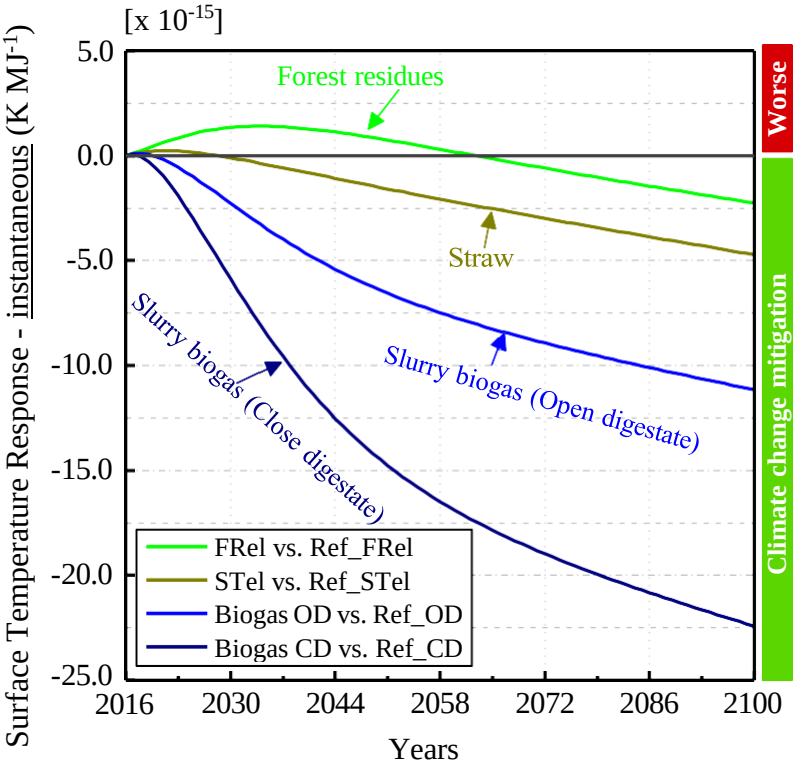
These results reveal additional details compared to the analysis in section 7.3.1. For instance, they indicate with clarity that power generation from cereal straws and cattle slurry can provide, by 2100, global warming mitigation compared to the current European electricity mix in all of the systems and scenarios considered. Power generation from forest logging residues is an effective mitigation solution only in situations in which the decay rates of the residues on the forest floor were above 5.2%/yr. Even with faster-decomposing feedstocks, bioenergy temporarily causes a climate change worsening compared to the fossil system. Strategies for bioenergy deployment should thus take into account the potential increase in global warming rate and temporary increase in temperature anomaly.

Further details on the methodology and on the results of the case studies can be found in Giuntoli et al. (2016).

Table 7.1. The Decalogue applied to the case study

	Decalogue	Implementation in the case study
1	Define the goal and scope	The goal of the study was to assess the climate mitigation potential of using various biomass residues to produce electricity compared to the current average EU electricity mix. The geographical scope covered the EU-27 conditions.
2	Consider multiple systems and counterfactuals	As shown in Figure 7.15, the study analysed four different bioenergy systems, and one counterfactual use for each feedstock. The functions covered in the systems are always consistent: 1 MJ of energy is produced in all the systems and biomass management is considered (either as bioenergy or as the reference use)
3	Results are relative to specific reference systems	The climate mitigation potential of each bioenergy system is evaluated relative to its reference system (Figure 7.17). Conclusions can be drawn only concerning the relative difference and caution should be applied when extrapolating results to other situations.
4	Consider all C-flows and C-pools	A biogenic-C inventory is created to account explicitly for biogenic CO_2 emissions and pools.
5	Time-dependent inventory	Because the natural decay of forest residues and of cereal straw in the soils is a dynamic process, a time-dependent inventory is created.
6	Use multiple climate metrics	Absolute and normalized climate metrics are used. Furthermore, the analysis is carried out using both cumulative (AGWP) and instantaneous (AGTP) metrics. These different metrics capture different aspects of the impacts associated to the pressure (GHG emissions). AGTP can better represent the climate change impacts associated with increasing surface temperatures, such as heat waves and extreme weather events. A cumulative metric is more suitable to capture the potential risks associated to sea level rise.
7	Use advanced tools to build the life cycle inventory	The impact of straw removal on soil organic carbon content was evaluated with the use of the agricultural model Century (Lugato et al., 2014).
8	Consider all climate forcers	The study considered not only Well-Mixed GHG (CO_2, CH_4, N_2O), but also Near Term Climate Forcers (CO, NO, SO, PM) and surface albedo change.
9	Avoid burden shift	The goal of the study was focused solely on climate change. However, additional studies looked into the overall environmental performance of the pathways considered (Giuntoli et al., 2015; Marelli et al., 2015)
10	Scenario analysis	Multiple scenarios were created and several parameters were changed, both for the bioenergy systems and for the reference systems, to perform an extensive sensitivity analysis. Two kinds of dependencies can be identified: variables that influence the final result because of multiple permutations possible in the reference system (*Indirect sensitivity*); variables which are direct attributes of the bioenergy system (*Direct sensitivity*). The latter can be influenced when setting up legislation, while the Indirect variables are not an attribute of the bioenergy system, but can define situations where the promotion of bioenergy may be more or less beneficial in terms of climate change mitigation.

Figure 7.17. Global warming mitigation potentials for all the bioenergy systems studied in their base cases



Mitigation potential is defined as the net result of Surface Temperature Response (STR) for the bioenergy system subtracted of the STR caused by the reference system; negative values indicate potential climate change mitigation by bioenergy; positive values indicate a climate change worsening.

7.4 Gaps and future challenges

The following knowledge gaps and recommendations for future actions can be recognized:

Frequent misinterpretation and inappropriate use of LCA results

The LCA community, especially the one involved in bioenergy studies, should communicate better and to a wider audience of stakeholders the importance of applying the appropriate LCA modelling approach to meet the goal and scope of the assessment. The bioenergy LCA community should share the lessons learned in the last decade so that practitioners and academics working in other sectors (especially in bio-based sectors) could have a jump-start in solving eventual similar issues in their specific research areas. At the same time, it is crucial to provide decision-makers with a framework to interpret LCA results in the context of policy design and implementation.

Data availability to expand the list of bio-based commodities analysed

Several commodities are still suffering from a lack of available inventory data (e.g. bio-based polymers) due to the lack of commercial technology. As technology progresses, it will be possible to expand the list of commodities evaluated.

Quantification and modelling of some non-climate impacts (e.g. biodiversity)

The evaluation of impacts on biodiversity and ecosystem services in LCA is at present done mainly in indirect ways (e.g. while the midpoint impact on eutrophication is quantifiable, the quantification of the end-point effects of eutrophication on natural capital is still highly uncertain). New methods are being developed to link land-use changes to biodiversity loss (Milà i Canals et al. 2016).

Furthermore, availability of inventory data at the necessary spatial scales to assess impacts on local biodiversity, is still limited, if present at all.

Treatment of uncertainty and variability of results

More rigorous evaluation of the effects of uncertainty on inventory data and parameters variability is necessary to provide more complete impact assessments and to decrease the risk of misinterpretation of results.

Key messages

Key messages from LCA and environmental impact assessment of the bio-economy:

1. LCA modelling approach must be appropriate to meet the goal and scope of the assessment: benchmarking products or evaluating impacts of strategic decisions require different approaches.
2. 'Regulatory' LCAs must: be easy to calculate; have well-defined rules; use a well-specified inventory; be of general validity across temporal and spatial scales.
3. Strategic assessments must include elements of consequential thinking to support policy decisions.
4. Most bio-based commodities release less GHG than fossil products along their supply chain; but the magnitude of GHG emissions vary greatly with logistics, type of feedstocks, land and ecosystem management, resource efficiency, and technology.
5. The climate change mitigation potential of bio-based commodities can only be revealed if biogenic-C, counterfactual uses of biomass and land, and indirect effects are considered.
6. Too often, the focus of environmental impact assessment of bio-based systems has been solely on climate change and carbon emissions. However, bio-based systems have the potential to cause trade-offs between climate change mitigation and negative impacts on biodiversity or ecosystem services. This should be investigated more thoroughly.

8 Conclusions

We have presented here results from the first two years of work of the JRC biomass study. In the report we have focused on the assessments of the biomass produced in the EU, the quantities being used and their uses. Results for the sectors examined are presented individually but also with an integrated perspective, building cross-sectorial biomass flows diagrams. In addition, we have illustrated the methodological framework developed to assess the environmental impacts of bio-based value chains.

According to our estimates, 1466 Mt of dry matter of biomass are produced annually by the land-based sectors of the EU (agriculture 956 Mt and forestry 510 Mt). However not all the biomass produced can enter the supply chains, part of it remains in the field to maintain the carbon sink and the other ecosystem services. In agriculture, 46% of the production corresponds to residues out of which about one fourth is collected. In the forestry sector, about two thirds of the net annual increment of the forests are harvested as EU average, with marked differences among countries. Therefore, elaborating from current statistics, about one third of the wood produced annually remains in the forest increasing the carbon stock. However, according to our analysis, wood removals are under reported, thus the unharvested biomass is likely lower, although still in the positive range.

The marine-based sectors (fisheries and aquaculture, algae) supply slightly less than 2 Mt of dry matter annually. Although in this case the conversion to dry matter content is purely indicative, the amount of biomass supply is quite far from the land-based sectors productions. It is worth recalling however, that these biomass shares do not reflect their actual relative importance in the bioeconomy.

Overall, the EU is a net importer of biomass, but the balance varies highly depending on products. For example, the trade balances of animal and processed products as well as solid wood products and paper and paperboard are positive. On the contrary, the EU is a net importer of plant-based food, solid biofuels, fish and seafood as well as algae.

The EU uses annually more than 1 billion tonnes of dry matter of biomass. The biomass flows, represented using Sankey diagrams, show that more than 60% is used in the feed and food sector, followed by bioenergy (19.1%) and biomaterials (18.8%).

Environmental impact assessment of bio-based commodities and sectors is based on Life Cycle Analysis (LCA). As we highlighted, the LCA modelling approach must be chosen in accordance with the goal of the analysis. Benchmarking, labelling or regulatory assessments require an attributional-LCA, while strategic assessments require consequential thinking and system-level analysis.

We have compiled an extensive database of LCA results for several bio-based commodities: bioenergy, bio-based chemicals, pulp and paper, wood industry products, and food commodities. We present the GHG emissions of several supply-chains of bio-based commodities.

In the report we have provided the best quantitative estimates we had been able to attain from available data and current knowledge, yet highlighting remaining gaps and underlying uncertainties after the first two years of the study.

The biomass study, initiated after the biomass mandate to JRC, has a long-term perspective; the work is progressing and will continue in the coming years. Thus, this report can be considered as a first assessment, the numerous identified gaps will be further explored in the prosecution of the study. For example, improving the comparability across sectors, reducing the knowledge gaps between supply and uses of biomass, complementing the analysis with information on algae and waste flows, thus with a closer look at the circularity aspects of the bioeconomy, assessing bio-based supply chains against all dimensions of sustainability (environmental, economic and social).

As a final note, we recall that important components of the biomass study, which have not been reported here, such as the modelling framework to develop forward-looking scenarios of biomass supply and demand, are intended to be presented in dedicated reports.

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List of acronyms

Acronym	Definition
AGB	Above Ground Biomass
A-LCA	Attributional Life Cycle Assessment
CFP	Common Fisheries Policy
C-LCA	Consequential Life Cycle Assessment
dm	Dry Matter
EEZ	Exclusive Economic Zone
ETS	Emissions Trading System
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAWS	Forest Available for Wood Supply
GDP	Gross Domestic Product
GHG	Greenhouse Gases
ha	Hectares
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
JWEE	Joint Wood Energy Enquiry
LCA	Life Cycle Assessment
LULUCF	Land Use, Land-Use Change and Forestry
MRIO	Multi Region Input-Output model
MS	(EU) Member State
Mm^3	Million cubic meters
Mt	Million tonnes
NAI	Net Annual Increment
NFI	National Forest Inventory
NREAP	National Renewable Energy Action Plan
NUTS	Nomenclature of Territorial Units for Statistics
OWC	Other Wood Components
SWE	Solid Wood Equivalent
tdm	Tonnes of dry matter
TPB	Technical Potential Biomass
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
WRB	Wood Resource Balance

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Annex 1. Conversion to dry matter of non-processed vegetal product

Table A1.1. Dry matter (dm) content of agricultural commodities

Description	% dm	Description	% dm
Cereals		**Olives**	0.84
Wheat and meslin	0.88	Pulses	
Rye	0.88	Leguminous vegetables	0.90
Barley	0.88	Dried leguminous vegetables	0.90
Oats	0.88	Starchy roots	
Maize (corn)	0.88	Potatoes	0.21
Rice	0.88	Manioc, sweet potatoes and similar roots and tubers	0.21
Grain sorghum	0.88	**Vegetables**	
Other cereals	0.88	Tomatoes	0.06
Cereal straw and husks	0.88	Onions, shallots, garlic, leeks and other alliaceous vegetables	0.06
Fiber crops		Cabbages, cauliflowers, kohlrabi, kale and similar edible brassicas	0.06
Cotton linters	1	Lettuce and chicory	0.06
Fruits and nuts		Carrots, turnips and similar edible roots	0.06
Coconuts, Brazil nuts and cashew nuts	0.9	Cucumbers and gherkins	0.06
Other nuts	0.9	Vegetables	0.06
Bananas, including plantains	0.15	Dried vegetables	0.90
Dates, figs, pineapples, avocados, guavas, mangoes and mangosteens	0.15	**Sugar crops**	
Citrus fruit	0.15	Sugar beet	0.24
Grapes	0.15	Sugar cane	0.31
Melons, watermelons and papayas	0.06	**Fodder crops**	**0.50**
Apples, pears and quinces	0.15	**Other crops**	
Apricots, cherries, peaches, plums and sloes	0.15	Live trees and other plants	0.50
Other fruit, fresh	0.5	Coffee, tea, maté and spices	0.29
Fruit and nuts	0.15	Seeds	0.29
Peel of citrus fruit or melons	0.5	Hop cones, lupulin	0.29
Oilseeds		Plants used in perfumery, pharmacy or similar purposes	0.29
Soya beans	0.78	Seaweeds and other algae	0.29
Groundnuts	0.78	**Live animals**	**0.30**
Copra	0.78	**Products of animal origin n.e.s**	**0.4**
Linseed	0.78		
Rape or colza seeds	0.78		
Sunflower seeds	0.78		
Other oil seeds and oleaginous fruits	0.78		

Annex 2. Estimation of feed and Food uses

Feed and food uses are made of agricultural biomass and in a lesser extent of aquatic biomass. They are split into: (i) aquatic food, (ii) plant-based food, (iii) animal-based food) and (iv) animal feed and bedding. The estimation of aquatic food uses is presented in section 4. The quantification of the first three categories is derived from the "Total Food Supply" reported in the FAOSTAT Food Balance Sheets.

Calculation steps:

1. The total food supply (FS) expressed in kcal/capita/day is converted into kcal/year using population data from the same source (i.e. FAO Food Balance Sheets)

$$\text{i.e. } \mathrm{FS\ (kcal)}_{i,j} = \mathrm{FS}_{i,j} \times \mathrm{Population}_{i,j} \times 365$$

   where FS is the food supply in kcal/cap/d of the country *i* and for the year *j*.

2. The food supply (kcal) is split into its 3 main nutrients: proteins, fats and carbohydrates, using nutrient ratios corresponding to the average composition of food supply in the EU27 in 2013 (see Table A2.1)

Table A2.1. Proportion of Carbohydrates, fats and proteins in total food supply

Nutrient k (N_k)	**Share of nutrient** ($\%N_k$)
Carbohydrates	0.50
Fats	0.38
Proteins	0.12

Source: Piotrowski (2015b), calculated for the EU27 in 2013 from FAO Food Balance Sheets.

Thus, the nutrient supply is calculated as follows:

$$\mathrm{NS\ (kcal)}_{i,j,k} = \mathrm{FS\ (kcal)}_{i,j} \times \%\mathrm{N}_k$$

where %N is the share of nutrient *k* in the total food supply of the country *i* and for the year *j*.

Plant-based food uses and animal-based food uses are estimated by splitting Nutrient Supply: $\mathrm{NS\ (kcal)}_{i,j,k}$ into the three biomass sources of food supply: vegetal, animal (excl. aquatic) and aquatic (see factors in Table A2.2).

Table A2.2. Factors used in the conversion of nutrient supplies from kcal to kg (dry matter)

Nutrient k	**Conversion factor** (MJ/kg)(1)	**Share of biomass from plant origin**	**Share of biomass from aquatic origin**	**Share of biomass from animal origin (excl. aquatic)**
Carbohydrates	16.7	0.95	0.0005	0.0495
Fats	37.7	$\mathrm{Plant}_{i,j,k}/\mathrm{FS}_{i,j,k}$	$\mathrm{Aqua}_{i,j,k}/\mathrm{FS}_{i,j,k}$	$1-[(\mathrm{Plant}_{i,j,k}-\mathrm{Aqua}_{i,j,k})/\mathrm{FS}_{i,j,k}]$
Proteins	16.7	$\mathrm{Plant}_{i,j,k}/\mathrm{FS}_{i,j,k}$	$\mathrm{Aqua}_{i,j,k}/\mathrm{FS}_{i,j,k}$	$1-[(\mathrm{Plant}_{i,j,k}-\mathrm{Aqua}_{i,j,k})/\mathrm{FS}_{i,j,k}]$
Other	non-nutritional food components (minerals, dietary fibres) account for an additional 10% of total food supply			

(1) 1 kcal = 0.004187MJ.

Source: Piotrowski (2015b).

$\mathrm{Plant}_{i,j,k}$ is the supply in vegetal products in nutrient *k* of the country *i* and for the year *j* (source: FAO Food Balance Sheets)

$\mathrm{Aqua}_{i,j,k}$ is the supply in aquatic products in nutrient *k* of the country *i* and for the year *j* (source: FAO Food Balance Sheets)

$\mathrm{FS}_{i,j,k}$ is the total food supply in nutrient *k* of the country *i* and for the year *j* (source: FAO Food Balance Sheets)

i.e.

$$\textbf{Plant-based food supply (1000 tdm)}_{\textbf{i,j}} =$$

$$\text{FS (kcal)}_{i,j} \times 0.004187 \times 1.1 \times (16.7 \times 0.95 + 37.7 \times \frac{\text{Plant}_{i,j,k=fats}}{FS_{i,j,k=fats}} + 16.7 \times \frac{\text{Plant}_{i,j,k=proteins}}{FS_{i,j,k=\text{proteins}}})$$

and

$$\textbf{Animal-based food supply (1000 tdm)}_{\textbf{i,j}} =$$

$$\text{FS (kcal)}_{i,j} \times 0.004187 \times 1.1 \times (16.7 \times 0.0495 + 37.7 \times (1 - [\frac{\text{Plant}_{i,j,k=fats} - \text{Aqua}_{i,j,k=fats}}{FS_{i,j,k=fats}}]) + 16.7 \times (1 - [\frac{\text{Plant}_{i,j,k=proteins} - \text{Aqua}_{i,j,k=proteins}}{FS_{i,j,k=proteins}}]))$$

3. Feed and bedding supply

Animal-based food uses are converted in feed equivalents using the efficiency conversion coefficient of 6.8% from Piotrowski et al. (2015a).

i.e.

$$\textbf{Animal feed uses (1000 tdm)}_{\textbf{i,j}} = \frac{\text{Animal-based food uses (1000 tdm)}_{\text{i,j}}}{0.068}$$

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