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Biomass flows in the European Union

The Sankey biomass diagram – towards a cross-set integration of biomass

P. Gurría, T. Ronzon, S. Tamosiunas, R. López, S. García Condado, J. Guillén, N. E. Cazzaniga, R. Jonsson, M. Banja, G. Fiore, A. Camia, R. M'Barek

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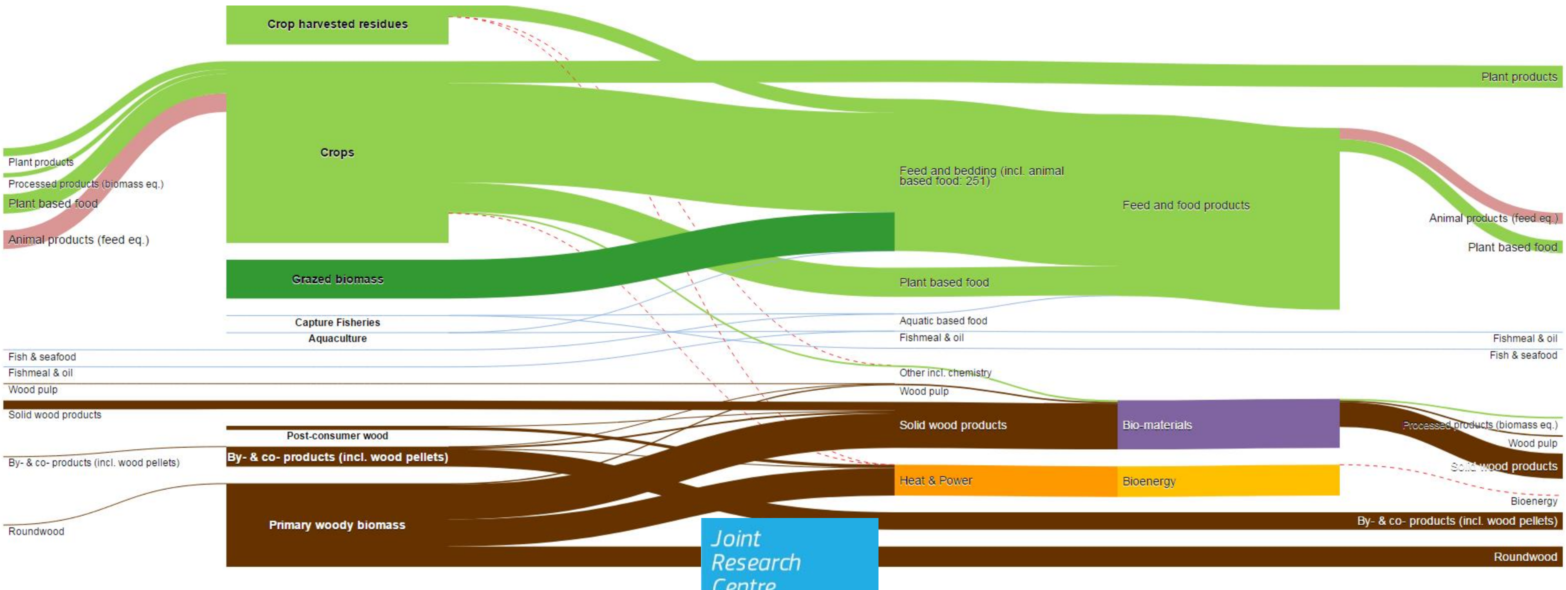

Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sourc
Known data gaps are shown as dotted red lines. Gaps derive from missing or incorrectly reported data, data not assigned to a specific category or data tha

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

Abstract

The Sankey biomass diagram is a representation of harmonised data from the various Joint Research Centre (JRC) units contributing to the BIOMASS Assessment study of the JRC[2]. It represents the flows of biomass for each sector of the bioeconomy, from supply to uses including trade. The diagram enables deeper analysis and comparison of the different countries and sectors across a defined time series. This report includes illustrations for the 28 EU Member States and the EU-28 aggregation.

Multiple data sources have been used to quantify biomass for each category and Member State. All relevant data from the different sources have been integrated into a single database. The Sankey biomass diagram represents the categories and flows of this database.

The diagram is hosted in the JRC DataM Portal, in the Bioeconomy visualization area[3]. It can be accessed directly in the following link:

https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html#

As a pioneer work, the diagram suffers from existing data gaps that hampered the complete estimation of the biomass. Due to the conversions and transformations performed on the original data to enable categorization and comparison across sectors, data quality checks are also difficult to perform in the absence of other data of reference with which to compare our numbers.

The current version of the diagram only represents 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.

In this document, we explain where the data used for the diagram was sourced, as well as the main data gaps and challenges encountered. We also briefly discuss the main features and functionalities of the Sankey biomass diagram. Finally, we present some insights based on the represented data and potential future research opportunities.

[2] https://biobs.jrc.ec.europa.eu/biomass-assessment-study-jrc; see also Ronzon et al 2017.

[3] https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml; see also initial work by Ronzon, Santini and M'barek (2015b)

1 Introduction

Sankey diagrams are used to illustrate flows of a specific commodity (e.g. money or, in this case, material). Because the amount of material in each portion of the diagram is represented by the width of the stream, Sankey diagrams visually emphasise the major transfers or flows within a system. They are helpful in locating dominant contributions to an overall flow by comparing the weight of the different flows.

Sankey diagrams are named after Captain Matthew H. P. R. Sankey, who used this type of diagram in a publication on energy efficiency of a steam engine in 1898[4].

The flow diagram offers some particular advantages to other types of representation:

— It represents the biomass flows in addition to values, enabling the analysis of the different uses for biomass of diverse origin as well as the different uses of a specific biomass supply.

— It allows integration of data from different sources.

— It showcases the evolution of biomass flows over time as well as the difference between the EU countries.

[4] http://ec.europa.eu/eurostat/statistics-explained/index.php/Sankey_diagrams_for_energy_balance

2 Architecture and integration

2.1.1 Integration

The base data of the diagram has been extracted from multiple sources using different methods. In order to be able to compare values, some actions have been taken to integrate the available data.

— Organic products have different water contents. Therefore, dry matter weight has been chosen as the unit of measure used for the diagram in order to compare biomass values of different origin (i.e. vegetal vs. animal). For this purpose, conversion coefficients have been applied to the fresh matter values. The different conversion coefficients used for each biomass component will be detailed later in this document.

— Total trade values are not available for some biomass categories. As a result, there are two separate views for the biomass flows: a total trade view and a net trade view. The missing values are currently shown as dotted red lines in the total trade view.

— In addition, some specific attributes have not been reported for some countries and/or years. They will also be shown as dotted red lines. Any missing values will be included in the representation as they become available.

— Some use categories will integrate biomass of several sectors. For example, biomaterials and bioenergy can be of either agricultural or forestry origin. Although we have used colours to differentiate the different sectors (green for agriculture, brown for forestry and blue for fishery), these hybrid categories will be shown in a different colour to demonstrate their mixed origin.

2.1.2 Structure

In order to represent the biomass flows, the Sankey biomass diagram is split into biomass supply (shown on the left of the diagram) and biomass uses (right portion of the diagram). Each of these areas shows different categories: agriculture, forestry and fishery (supply), as well as feed and food, biomaterials, bioenergy, and direct exports for each sector (uses).

Some of the components of the diagram will be missing for a certain country and/or year if the corresponding data has been reported as 0. Consequently, not all countries and years show all identified biomass categories.

The distribution and size of each component of the biomass flow diagram will change according to the filters selected by the user (geography and/or time).

As mentioned previously, Sankey diagrams are used to visualise the magnitude of flow between nodes in a network. In the case of the Sankey biomass diagram, the flows are visualised using a Sankey plugin of the D3 JavaScript library. Because of specific additional needs the plugin has been extended to support custom colours, labels, nesting of nodes, and other functions.

The category nodes and weighted links required to create the diagram are provided in a CSV file. From this base structure, separate diagrams are created to illustrate the biomass flows of a particular country and year.

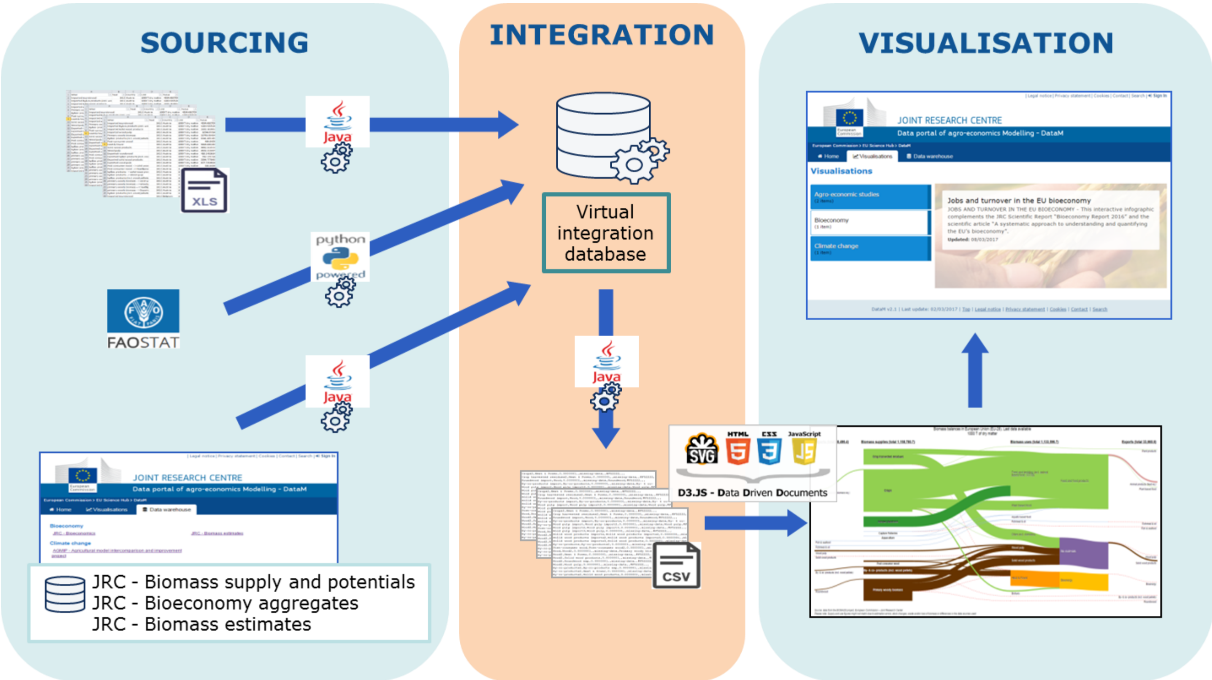
There are multiple sources for providing initial data. Fishery and forestry data comes in Excel files. Agricultural data is compiled from several JRC datasets in DataM and from

FAO using FAOData APIs. The specific data sources will be described in following chapters.

All source data is compiled in one single database, harmonized, transformed and aggregated by applying calculations. It is then exported in form of multiple CSV files (one per country and year) for the Sankey plugin.

The data processing process is illustrated in the following figure.

Figure 1. Schematic representation of the Sankey structure and interfaces



The Sankey diagram component and data files are published in the DataM portal as a visualisation for public access. The different functionalities of this public visualisation will be described in Chapter 4.

3 Data sourcing and transformation

3.1 Agriculture

3.1.1 Methodology and data sources

Agricultural biomass balance sheets build on economic crop production[5] and total crop residues data elaborated by the JRC D5 unit as well as trade and use data elaborated by the JRC D4 unit.

Statistics on agricultural biomass supply and uses are usually reported separately in different datasets. The different datasets are integrated to represent the biomass content of each component of the diagram. More details on the data sources can be found in Table 1 below.

- Agricultural biomass production has three components:
    - Economic crop production (biomass produced in form of grains, fruits, roots or tubers) is assessed using EUROSTAT official production statistics (table apro_acs[6]) within the period 1998-2015.
    - Crop residue production (biomass produced in form of straw, chaff, husks, etc.) is estimated from economic production for crops from the following groups: cereals, oil-bearing crops, sugar and starchy crops, pulses, industrial crops, and permanent crops. Estimations are based on crop-specific empirical models and transformation coefficients relating crop economic production with residues (see Section 3.1.2).

    All estimates for crop and residue production are compiled in the JRC - Biomass supply and potentials database[7].

    - Grazed biomass (biomass produced in grasslands that is not harvested, but used only for grazing) estimates are based on FAOSTAT data.
- FAOSTAT Food Balance Sheets are used to calculate the food use of agricultural biomass (feed and bedding as well as plant and animal based food).
- EUROSTAT Comext is used for the quantification of biomass trade data.

3.1.2 Estimations and transformations

- Conversion of crop economic yield and production into dry matter, following the expression:

$$Y_0 = Y_m * (1 - m)$$

[5] "Total economic crop production", mentioned as "crops" on the Sankey diagram, refers to the crop quantity harvested from the field. Therefore, it excludes post-harvest collected crop residue.
[6] http://ec.europa.eu/eurostat/cache/metadata/en/apro_acs_esms.htm
[7] The JRC Biomass supply and potentials is a database that compiles the data provided for the Biomass project by all participating JRC units (D1, D2, D4, D5 and C2). This database has different sources, including EUROSTAT and FAOSTAT.

where Y_0 is dry-matter economic yield (or production) and Y_m is economic yield (or production) statistics at moisture content m. The values used for m are shown in Annex 1, coming from the EUROSTAT reference values (Eurostat, 2017) and several scientific studies consulted. In the case of fodder crops and pulses, the moisture content at which Member States report production data to EUROSTAT differ substantially and, therefore, for those countries reporting m that value was used. If m is not reported, then the reference value is used as default.

— Estimation of crop residues production. Biomass from crop residues is estimated using crop-specific empirical models. Annex 2 lists the approaches used for each of the crops covered. For cereals, oilseeds, and sugar and starchy crops, new empirical models were developed in this project, assuming that a relationship exists between crop economic yield at 0% moisture content (Y_0) and the harvest index (HI), or directly with the dry matter residue yield (R). Once Y_o and HI are known, R (in tonnes/ha) is calculated as:

$$R = \frac{Y_0}{HI} - Y_0$$

A full explanation of the fundamentals of these new models is given in van der Velde (Ed.) (2016).

For the remaining crops, existing empirical models or fixed values for HI found in scientific literature were used (see Annex 2). For fodder crops, vegetables and energy crops, residue yields were not estimated, and thus all plant biomass is considered as economic production.

— Estimation of collected biomass from crop residues production. A coefficient has been applied to the crop residues production of each crop type to estimate the portion of said residues that is actually collected. The coefficients applied are presented in Annex 3.

— Estimation of grazed biomass. Grazed biomass is considered as proportional to pasture and meadows land area reported in FAOSTAT land (1.8 Tdm/Ha).

— Estimation of crop conversion into food and biomaterial uses. In the case of crop to food use, flows were estimated according to the FAOSTAT Food balance sheets. Factors from the scientific literature have been applied in the case of the flows from crop residues to feed and bedding and to bio-material uses (see Annex 4).

— Estimation of agricultural biomass trade and uses of agricultural biomass in dry matter of vegetal biomass equivalent. All data were converted into dry matter and coefficients were applied to take into account the production process of manufactured products (e.g. the manufacture of one tonne of bread makes use of 1.3 tonnes of cereals).

More details are given in Figure 2 and Figure 3 as well as in Table 1.

Figure 2. Data sourcing and transformation for agricultural biomass supply in the Sankey biomass diagram

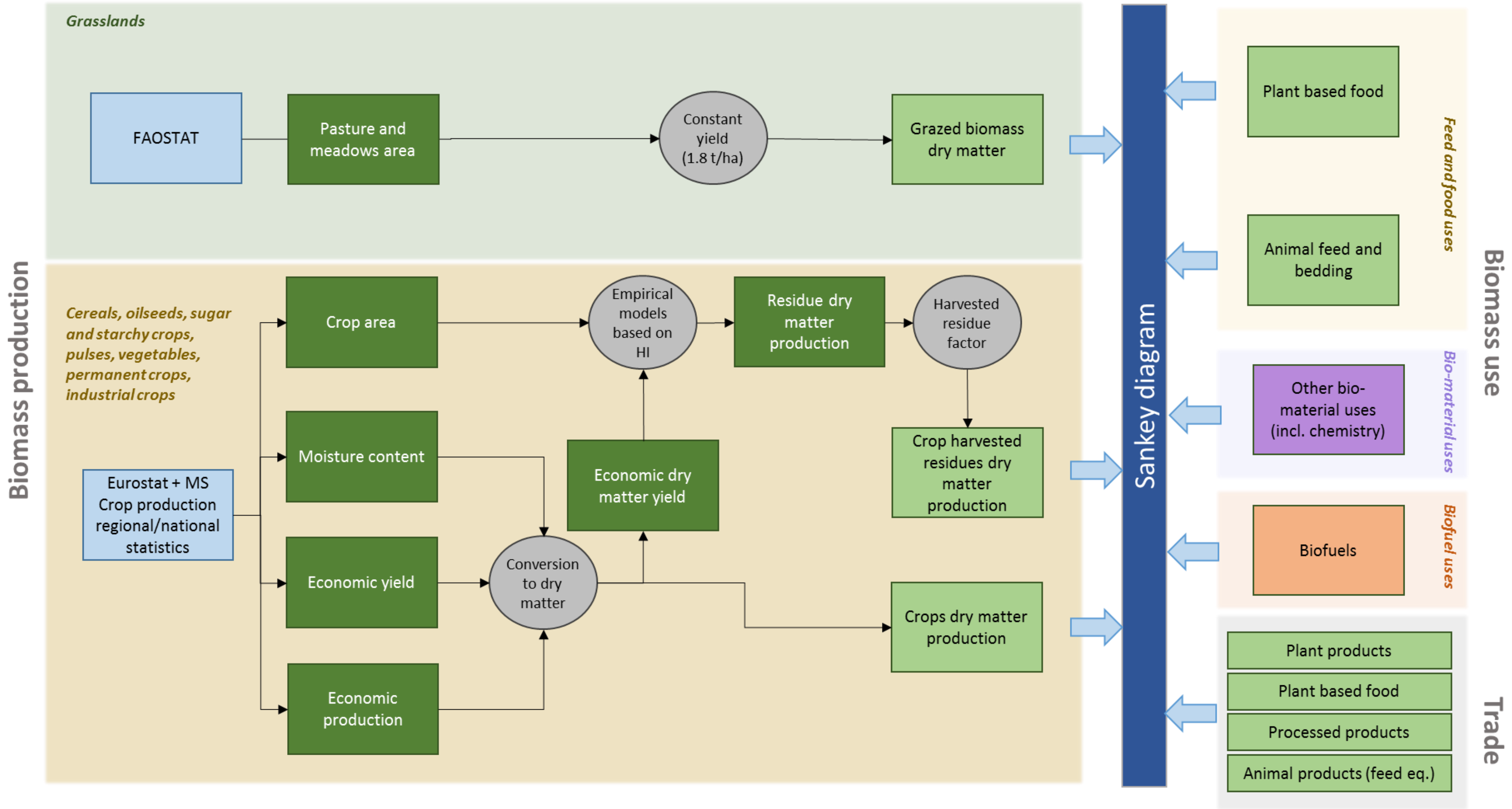


Figure 3. Data sourcing and transformation for agricultural biomass uses and trade in the Sankey biomass diagram

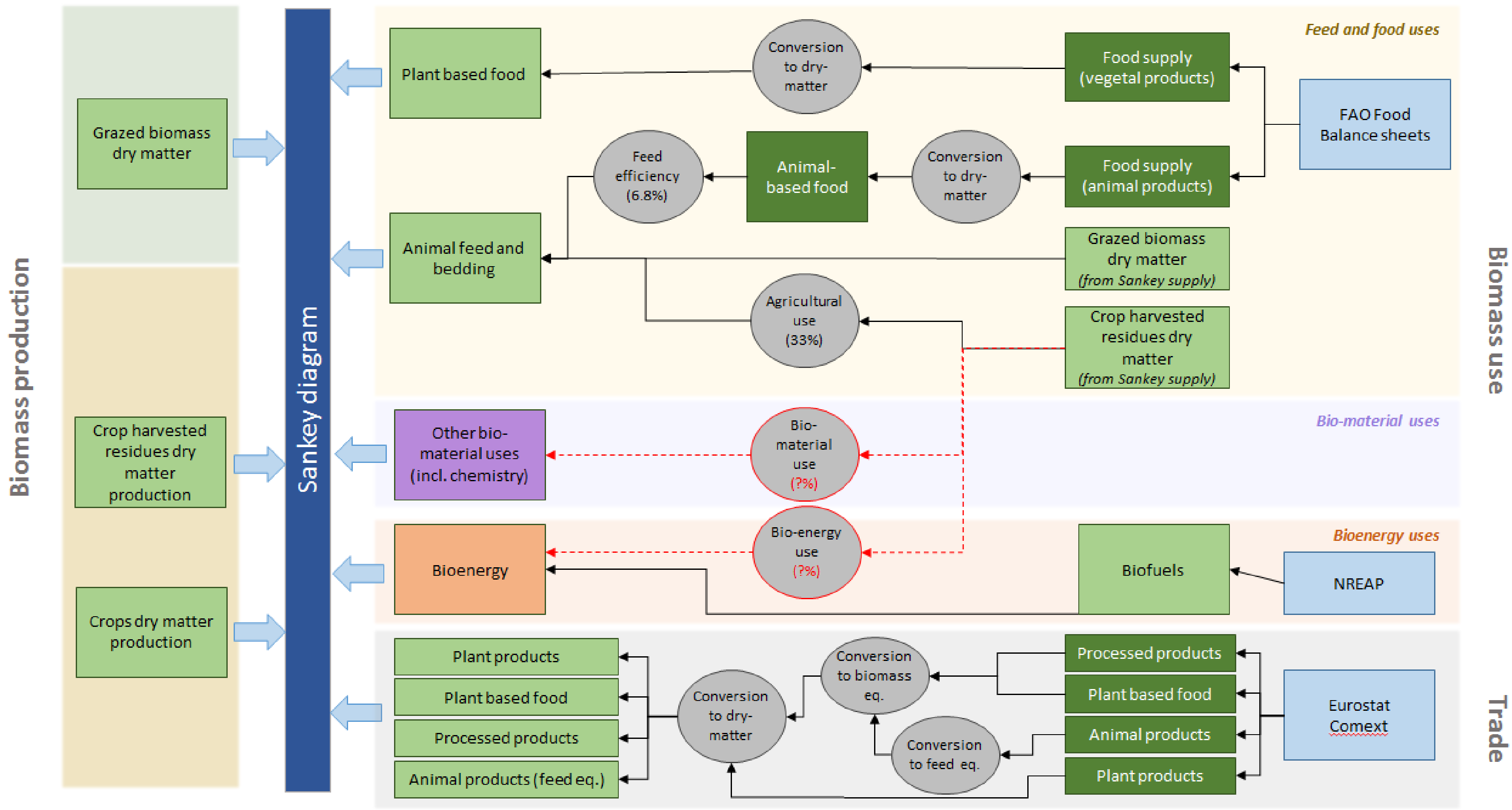


Table 1. Overview of data sources and data transformations integrated in the agricultural biomass balance sheet

Function	Sector	Domestic/ Trade	Measure	Data source	Data transformation
Supplies	Agriculture	Imports	Plant products	JRC - Biomass aggregates (DataM)(a)	Conversion to dry matter (See Annex 1)
			Plant based food		Conversion to biomass equivalent (Tdm)(e)
			Processed products		Conversion to biomass equivalent (Tdm)(f)
			Animal products (feed eq.)		Conversion to feed equivalent (Tdm): 3.69%(f)
		Domestic production	Crops	JRC - Biomass supply and potentials (DataM)(a)	Dataset Attribute: Agriculture Economic Production Dry Matter
			Crop harvested residues		Dataset Attribute: Agriculture Residue Production Dry Matter. Application of a share of used residues (See Annex 3)
			Grazed biomass	FAOSTAT Inputs (Land)(b)	Application of a grazed biomass yield: 1.8 Tdm/Ha of meadows and pastures(f)
Uses	Feed, food & plant products	Animal feed and bedding (incl. animal food in feed eq.) produced in agriculture	from harvested crops	FAOSTAT Food balance sheets(c)	Conversion animal food supply to feed equivalent (Tdm) (See Annex 4)
			from grazed biomass	Equal to grazed biomass supplies	-
			from crop residues	Collected crop residues (see supplies)	Application of a share for collected residues used in agriculture (feed and bedding): 33%(g)
		Plant based food	Plant based food	FAOSTAT Food balance sheets(c)	Conversion vegetal food supply to Tdm (See Annex 4)
		Exports	Plant products	JRC - Biomass aggregates (DataM)(a)	Conversion to dry matter (See Annex 1)
			Plant-based food		Conversion to biomass equivalent (Tdm)(e)
			Processed products		Conversion to biomass equivalent (Tdm)(f)
			Animal products (feed eq.)		Conversion to feed equivalent (Tdm): 8.34%(f)
	Bio-mat.	Exports	Processed products	JRC - Biomass aggregates (DataM)(a)	Conversion to biomass equivalent (Tdm)**Error! Bookmark not defined.**(f)
	Bioenergy	Biofuels consumption	Liquid biofuels 1st generation	NREAP database(d)	-

(a) Accessible with restricted access at: https://datam.jrc.ec.europa.eu/datam/public/pages/datasets.xhtml
(b) Accessible at: http://www.fao.org/faostat/en/#data/RL
(c) Accessible at: http://www.fao.org/faostat/en/#data/FBS

(d) Accessible at: http://iet.jrc.ec.europa.eu/remea/national-renewable-energy-action-plans-nreaps
(e) The conversion from tonnes of final products to vegetal biomass equivalents is based on the coefficients published by the EC DG Agriculture and Rural Development 2015, Agricultural Trade Statistics, Annex I, available at:
https://ec.europa.eu/agriculture/sites/agriculture/files/statistics/trade/2016/products-description.pdf
(f) Same methodology as the one presented in Piotrowski et al. 2015.
(g) Based on Scarlat, Martinov et al. (2010), Piotrowski et al. (2015), Bentsen et al. (2014) and Ericsson and Nilsson (2006).

3.1.3 Data availability and limitations

- The Sankey biomass diagram displays agriculture data for the time series 2000 – 2014.
- Estimates of crop biomass production rely on EUROSTAT crop production statistics (apro_acs), which sometimes presents some data gaps within the period considered for some minor crops.
- Agricultural production data is available for all EU-28 Member States and EU-28 total.
- Both total and net trade values are available for all EU-28 Member States and EU-28 total. Therefore both the net and total trade views are available for the agriculture categories.

3.2 Fishery

3.2.1 Methodology and data sources

Fisheries biomass balance sheets have been elaborated by the JRC D2 unit using a Multi Region Input-Output (MRIO) model based on seafood production[8], trade and use data.

The biomass flows within the seafood supply chain are estimated using a MRIO model (Leontief & Strout, 1963; Lenzen et al., 2004; Wiedmann, 2009). This model extends the Leontief's input-output analysis (I/O) used in macroeconomics and in national accounting to represent inter-industry relations by accounting for relations between different national economies as determined by international trade.

The data used to populate the model and calculate the technical coefficients were obtained from the FAO commodity balance sheets, aquaculture and capture fisheries statistics, seafood commodities production statistics, EUROSTAT - COMTRADE trade statistics and technical coefficients on the use of fishmeal in aquaculture and in the feed industry reported in the literature (see Table 2).

Table 2. Overview of data sources and data transformations integrated in the fishery biomass balance sheet

Data	Data source
Aquaculture production	FAO - FishstatJ
Catches from fisheries	FAO - FishstatJ
Production of fish meal	FAO - FishstatJ
Production of processed fish commodities	FAO - FishstatJ
Trade of fish commodities	EUROSTAT - COMTRADE
Apparent consumption of fish	FAO - Food balance sheets
Coefficient for the conversion of fish commodities into live weight	EUMOFA
Livestock (pigs and chicken)	FAOSTAT
Ratio of aquaculture production on aquafeed and economic feed conversion ratio and ratio of fishmeal and fish oil in aquafeed	Tacon & Metian, 2015; Shepherd & Jackson, 2013
Proportion of fish for reduction into fishmeal	Tacon & Metian, 2015; Alder et al., 2008

3.2.2 Estimations and transformations

— <u>Use of live weight</u>. At a first stage, the seafood balance sheets are expressed in live weight equivalents because most seafood statistics are reported in live weight equivalents. Moreover, the use of live weight equivalents allows full comparability with production and seafood availability (i.e. stock assessments) estimates used in

[8] By seafood, in this study, we refer to fish, molluscs and crustaceans from capture fisheries and aquaculture, both from marine (including brackish water) and freshwater environments. So, no aquatic plants, mammals, amphibians, reptiles and aquatic invertebrates have been considered.

fisheries science. In order to do so, trade statistics have been converted from tonnes of processed products to live weight equivalents using the EUMOFA conversion factors, and the fishmeal statistics in fishmeal equivalents have also been converted to live weight equivalents.

- Conversion to dry matter. Once all fishery data has been aggregated and classified, live weight equivalents are converted into dry matter weight. This is necessary to allow comparability with agricultural and forestry biomass. For this conversion, we have considered an average 25% content of dry matter[9].
- Estimation of the final fish demand. The final demand for fish was taken directly from the FAO food balance sheets.
- Estimation of fishmeal production. The total amount of fishmeal produced is obtained by converting the catches of the industrial species (e.g. fish species such as sandeels and Norway pout) into fishmeal. The live weight equivalents are converted into fishmeal equivalents using the coefficient of 4.8[10].
- Estimation of fishmeal used by the aquaculture sector. The amount of fishmeal used by the aquaculture sector is estimated, following Tacon & Metian (2015) and Shepherd & Jackson (2013), by multiplying the aquaculture production, by the feed conversion ratio, by the percentage of production using feed and by the level of inclusion of fishmeal in this feed.
- Estimation of fishmeal used by the livestock sector. The demand for fishmeal by the livestock sector and pet industry was calculated in proportion to the number of livestock in each country using a fixed allocation of 25% of fishmeal supply to pigs, 5% to chicken and 2% to other uses (Shepherd & Jackson, 2013).

3.2.3 Data availability and limitations

The database contains fisheries and aquaculture production data for the time period 2000-2014. Trade data, intra- and extra-EU imports and exports, are only available for 2011, the year for which the MRIO model was calibrated.

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 and Peridy 2000; 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 EU's demand for fish.
- 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.

[9] We have considered an average value of 75% content of water in fish flesh for all species as, for the time being, calculations are not done on a species level. This average has been estimated from Table 1 in *J. Murray and J. R. Burt, The composition of fish*, 2001. http://www.fao.org/wairdocs/tan/x5916e/x5916e01.htm#Fish

[10] The conversion factor estimate of 4.8 comes from the calibration of the MRIO model. A conversion of 4.4 is often used for the conversion of whole fish to fishmeal. However, our estimate apart from the conversion of whole fish to fishmeal, it also incorporates the direct use of fish in aquaculture and the use of trimmings from the processing sector.

- 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.
- Data omissions from official statistics, issues related to the technical coefficients used as parameters in the MRIO model which are not able to capture country specificities or to inconsistencies between demand, trade and primary production across the different statistical data sources.
- Finally, it should be noted that while measures in dry matter were used for the sake of harmonisation with agriculture and forestry biomass, they are hardly used for fisheries and aquaculture, where the main interest is related to food production. Moreover, the use of a general conversion applicable to all fisheries and aquaculture is a significant limitation, considering that depending on the fish species and stock the composition in terms of fat, protein and water can be substantially different. These differences are much more relevant when we consider shellfish, which accounts for an important share of all fisheries and aquaculture production.

3.3 Forestry

3.3.1 Methodology and data sources

The forest-based biomass balance sheets—Wood Resource Balances (WRBs)—and flow charts elaborated by the JRC D1 unit build on the integration of a number of different data sets: production and trade of wood-based products and roundwood, conversion factors, and input/output coefficients for material and energy uses of wood (see Table 3).

Table 3. Data sources used for the biomass flow diagrams

Data source	Organization	Data
FAOSTAT[11]	FAO	Production, imports and exports of forest products and removals
National Forest Inventory data	NFI (JRC database)	Net Annual Increment
Resource shares	Infro (Mantau 2016)	input/output coefficients for wood products industry
Forest product conversion factors for the UNECE region[12]	UNECE, FAO	Bark correction factor
Joint Wood Energy Enquiry (JWEE)[13]	UNECE/FAO Forestry and Timber Section, IEA, EUROSTAT	Energy use of wood, conversion factors
NREAPs and Progress Reports Data Portal[14]	JRC	Energy use of wood

3.3.2 Estimations and transformations

WRBs and flow diagrams are based on production and trade statistics, supplemented by sector-specific analysis. The WRBs and flow charts consider all the most important sources and uses for the year 2013. For material uses—coniferous and non-coniferous sawnwood; veneer sheets and plywood; chemical wood pulp; semi-chemical wood pulp; mechanical wood pulp; dissolving wood pulp; fibreboard; particle board; wood pellets—FAOSTAT is the source (FAO, 2014), while, for energy production, the main source is the JWEE (UNECE/FAO, 2014). For some Member States—Belgium, Greece, Spain, Italy, Lithuania, Malta, Poland, Portugal, Romania and Slovakia—the NREAPs and Progress Reports Data Portal is used (Banja et al. 2015), as data in the JWEE are missing. However, it is important to underline that in many cases information on woody biomass for energy is still incomplete (Hetsch et al. 2007). For two Member States, Bulgaria and Latvia, there is no information about the heat and power production from woody biomass.

Sources of woody biomass comprise (i) primary woody biomass (PWB)—coniferous wood in the rough under bark, non-coniferous wood in the rough under bark, forest residues,

[11] http://www.fao.org/3/a-i5542m.pdf
[12] http://www.unece.org/fileadmin/DAM/timber/publications/DP-49.pdf
[13] http://www.unece.org/forests/jwee.html
[14] https://ec.europa.eu/jrc/en/scientific-tool/nreap-data-portal

bark; (ii) by- and co- products (BCP)—bark as by-product from industry processes, sawmill by-products, other industrial residues, black liquor, wood pellets; and (iii) post-consumer wood (PCW).

The values of BCP, exempting wood pellets, are obtained by multiplying production data (from FAOSTAT) for the different wood-based commodities with corresponding output coefficients (from Infro). As for PCW, the amount used for particle board (Pb) production, obtained by multiplying Pb production with the corresponding input coefficient, is, where available, complemented with the amount used for energy generation (JWEE).

FAOSTAT values do not consider bark (values are reported under bark, u.b.). The source amount of bark has been estimated by multiplying country-specific output coefficients by quantities of primary woody biomass used. In most instances this approach results in an underestimation of the (potential) supply of bark. In future work, starting in 2017, as an alternative approach we will estimate the (potential) supply of bark by applying a coefficient to the gross domestic supply of roundwood u.b.

Roundwood equivalents under bark are calculated for every item, based on product-related and country-specific conversion factors (from Infro), so that all quantities are expressed in the same unit; cubic meter solid wood equivalents. These values are subsequently converted to tons of dry matter, using conversion factors from the JWEE.

3.3.3 Data availability and limitations

There are unfortunately numerous data gaps and inconsistencies. These result from, e.g., informal trade (e.g., private uses of fuelwood) as well as underestimated or unreported fellings, wood residues and co-product flows, waste recovery streams (e.g., post-consumer recovered wood), and heat and power production uses of wood and incorrectly reported trade data (e.g., including re-exports). Adjustments are thus needed to compensate for the significant gaps and unbalances found in the underlying data. Many values were adjusted, sometimes significantly, to obtain the final values.

Made adjustments include:

- when the recorded (direct) export quantity of a commodity was larger than the corresponding production quantity, the quantity of exports was reduced,
- when there is no information as to heat and power use of woody biomass, or the information is incomplete, an amount of woody biomass is assigned by considering "excess" woody biomass, i.e., biomass sources that could not be attributed to material production.

All the applied adjustments are summarized in Table 4.

Table 4. Applied adjustments to the evaluated values

Member State	PWB [1]	PWB to HP [1]	BCP to SWP [1]	BCP to HP [1]	HP [1]	BCP exp [1]	SWP [1]	SWP exp [1]	PCW [1]	WPu exp [1]
Austria	+	+		-						
Belgium	+	+		-		-				-
Bulgaria		+		+	+		+		N/A	
Croatia	+	+		-			-			
Cyprus	+	+		-					N/A	
Czech Republic	+	+		-			-			
Denmark	+	+		-		-	+			-
Estonia	+	+		-		-	+			
Finland	+	-		+						
France	+	+		+			-			
Germany	+	+		-			-			
Greece	+	+		+			-			-
Hungary	-	-		+		-	-	-	N/A	-
Ireland	+	+		-						-
Italy	+	+		-						
Latvia	+	+		N/A	+		-		N/A	-
Lithuania	-	+		+		-	-		N/A	-
Luxembourg	+	+	-	+			+			
Malta	+	+						-	N/A	
Netherlands	+	+		+				-		-
Poland	-			+	+		-			
Portugal		+		+	+		-			
Romania	+	+			+		-			-
Slovakia	+	+		-			-			
Slovenia	+	+		-			-	-		
Spain	+	+		-			-			
Sweden	+	+		-			-			
United Kingdom	+	-		+						

(1) PWB: primary woody biomass, HP: heat & power, BCP: By- and co-products, exp: exports, SWP: solid wood products (sawnwood, plywood & veneer, particle board, fibreboard), PCW: post-consumer wood, WPu: wood pulp (chemical wood pulp, dissolving wood pulp, mechanical wood pulp, semi-chemical wood pulp)

+ represents value increase, - represents value decrease, N/A stands for not available and not assessable information

3.4 Biofuels

3.4.1 Methodology and data sources

Data from the EU Member States biennial reporting under Renewable Energy Directive[15] have been used in this part of Sankey diagram. The Sankey diagram makes use of data on biomass supply for transport for the years 2011 and 2013. Data are sourced from Table 4 of the EU Member States progress reports template[16], in which data on sustainable biofuels[17] for transport are available as: (i) common arable crops for biofuels; (ii) Energy crops (grasses etc.) and short rotation trees for biofuels; (iii) other (liquid waste and by-products). The data reported by Member States on biomass supply for transport include both domestic and imported raw material (from the EU and outside the EU). Reporting of the EU Member States on biomass supply for transport is done with respect to the Article 17 of the Directive 2009/28/EC on 'sustainability criteria for biofuels and bioliquids' and also with respect to Article 18 'Verification of compliance with the sustainability criteria for biofuels and bioliquids'.

3.4.2 Estimations and transformations

The progress reports template requires Member States to report on forestry in m^3 while Agriculture and Waste are reported in tonnes. Despite this, the EU Member States reporting on biomass supply for transport is not uniform. It is sometimes difficult to define the measurement units because there are not even reported by MS. When the data are reported in tonnes we assume it is dry matter. Some Member States reports on biomass supplied for transport in litres (e.g. rapeseed oil). In this case the conversion from litres to tonnes is performed using the density of oil that can be found in the literature[18].

3.4.3 Data availability and limitations

Data are recent but not complete[19] or easily comparable across countries due to the difficulty of defining the reported units (tonnes, litres etc.). Some Member States report data using the above mentioned table in the progress reports template, whereas some other Member States use only the description on biomass supply.

The EU Member States reporting under the Renewable Energy Directive do not provide data on crop mix used for biofuels.

[15] Directive 2009//EC http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=en
[16] https://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports
[17] MS are requested to report only on biofuels that fulfil the criteria of sustainability as specified in Article 17 (2) to (6) of the Renewable Energy Directive
[18] Physical properties of fats and oils http://www.dgfett.de/material/physikalische_eigenschaften.pdf
[19] Only half of EU MS has reported on biomass supply in transport sector in their biennial progress reports.

Table 5. Availability of common arable crops data for transport, 2011 and 2013

Member State	2011	2013
Austria	+	+
Belgium	+	+
Bulgaria	+	N/A
Croatia	+	+
Cyprus	+	+
Czech Republic	+	+
Denmark	N/A	N/A
Estonia	N/A	N/A
Finland	N/A	N/A
France	N/A	N/A
Germany	+	+
Greece	N/A	N/A
Hungary	N/A	N/A
Ireland	N/A	+
Italy	+	+
Latvia	N/A	N/A
Lithuania	N/A	+
Luxembourg	N/A	N/A
Malta	N/A	N/A
Netherlands	N/A	N/A
Poland	N/A	N/A
Portugal	+	N/A
Romania	+	+
Slovakia	+	+
Slovenia	N/A	N/A
Spain	+	+
Sweden	N/A	N/A
United Kingdom	N/A	+

4 Visualization and reporting

The Sankey diagram offers several choices to make visualization and reporting more appropriate for each user.

- Net vs. total trade. The diagram is available in two separate views, total trade and net trade. Net trade is calculated as the difference between imports and exports. The net trade view was developed because total trade values were not available or sufficiently accurate for some categories. This is both due to missing data and the difficulty in estimating re-imports and/or re-exports.
- The user can select a single country among the EU-28 Member States, or the aggregation at EU-28 level.
- The user can select a single year from 2000 to 2013. Additionally, the selection "Last data available" will show the latest year for which data is available from each sector (e.g. 2013 for agriculture and 2011 for fishery).
- Currently, the diagram displays data in million tonnes of dry matter only. However, the objective is to include economic and nutrient or energetic values in the future. Therefore, the unit selection menu includes these additional units of measure.
- The user has the possibility to show the values for each category using the "Values" button.
- For reporting purposes, the Sankey biomass diagram has different download capabilities. An authorised user can download all data, data for a specific country (for a single year or full time series) and data for a specific year (for a single Member State or all individual Member States and EU-28 aggregation). Data will be downloaded in CSV format.
- Finally, the download button also enables screenshot download (PNG format).
- As mentioned previously in this document, the diagram is hosted in the JRC DataM Portal, in the Bioeconomy visualization area[20]. It can be accessed directly in the following link:

  https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html#

[20] https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml

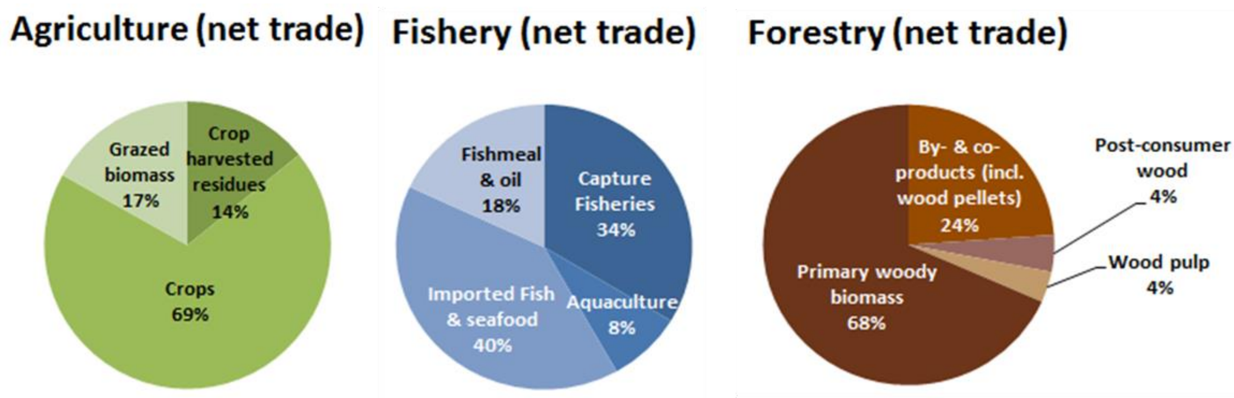
5 Insights in supply and uses

A first analysis of the represented total data of the European Union shows the relative weight of the different sectors in the bioeconomy. While supply has been split in the traditional sectors (agriculture, forestry and fishery), the uses have been distributed in different categories because their sources are diverse (e.g. biomaterials is sourced from both forestry and agriculture). We have considered the **net trade** figures for this analysis as using the full trade values would not allow for comparison across sectors.

5.1 Biomass supply

In the EU-28, agriculture is the biggest supply sector with a relative weight of approximately 65% (from 13% in Finland to 90% in Greece, Malta, Hungary and Cyprus), followed by forestry with 34% of the dry matter content (from 8% in Malta to 87% in Finland). While the relative weight of the fishery sector is quite small (less than 1%), we believe it will become more important once we consider economic or nutritional values. In agriculture, crops represent almost 62% of the biomass supply with collected crop residues (23%) and grazed biomass (15%) being closer in weight but representing much smaller portions. The dominant source of forestry biomass is primary woody biomass 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.[21]

Figure 4. Composition of the EU-28 agricultural, fishery and forestry biomass supply



Agriculture

The European agricultural biomass total supply (in full trade figures) amounts to approximately 765 million tonnes of dry vegetal biomass equivalents. It is composed of crop harvested production, collected crop residues, grazed biomass and imports of bio-based products.

— The crop harvested production is estimated at 478 million tonnes of dry biomass in the EU-28 for the year 2013 (i.e. approximately 2 billion tonnes of fresh biomass).

— Collected crop residues provide additional 100 million Tdm of biomass.

— 119 million tonnes of biomass are grazed in pastures and meadows.

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

— Around 10 million additional tonnes of dry matter of crop residues could be collected without hampering the production of ecosystem services such as soil carbon conservation, fertility maintenance, water retention, etc.

— Around 67 million Tdm of vegetal biomass equivalents are imported, 53% in the form of crop products (non-manufactured), 25% in the form of food products and the rest in the form of biomaterial products (ca. 22%).

Fishery

EU production of seafood by capture fisheries and aquaculture was 6.4 million live weight tonnes in 2011 (i.e. approx. 1.6 Mio tonnes dry matter), with 5.2 million tonnes originating from capture fisheries (i.e. approx. 1.3 Mio tonnes dry matter) and 1.3 million tonnes from aquaculture (i.e. approx. 0.3 Mio tonnes dry matter) (FAO, 2016). EU net imports of seafood products in 2011 amounted to 6.1 million tonnes expressed in live weight equivalents.

Note that:

— Increases of seafood production, and consequently of seafood biomass production, could be obtained if fish stocks were managed to produce the Maximum Sustainable Yield. The status of fish stocks has been improving in the Northeast Atlantic and Baltic waters over the period 2003-2014, where most fish in the EU is caught (STECF, 2016). Nevertheless, in 2014, the number of overfished stocks (i.e., fishing pressure levels above Maximum Sustainable Yield) in these waters is about 50% of the total number of stocks which were assessed (STECF, 2016). In the Mediterranean and Black Sea, the trend of overfishing is opposite to that in the northern seas of Europe since it has been rising since 2003-2005 for those stocks that were assessed (STECF, 2016). The current situation of Mediterranean and Black Sea's stocks is considered critical with more than 90% of the assessed stocks being overexploited (STECF, 2016).

— Nellemann *et al.* (2009) reported worldwide discards to be about 30 million tonnes, accounting for 23% of the world-wide catches. The establishment of landing obligation (discard ban) is one of the main aspects in the new EU Common Fisheries Policy (CFP), which aims for a gradual elimination of discards of commercially exploited stocks on a case-by-case basis (EU, 2013). In fact, the extended practice of discarding has been identified as one of the reasons for the failure of the past CFP. Discarding has prevented several fish stock from recovering, despite of the low quotas (EC, 2009). Moreover, the obligation to land all catches and a better use of marine resources are in line with the EU's Europe 2020 Strategy objective of a more resource efficient economy (EC, 2010).

— In the Multiannual National Strategic Plans (European Commission, 2016a) for the promotion of sustainable aquaculture, EU Member States quantify objectives (e.g. production growth) for their domestic aquaculture sector based on addressing the strategic priorities and the EMFF funds received. According to the figures presented in MS' Strategic Plans, the estimated projection for aquaculture production in 2020 is an increase of over 300,000 tonnes (25%) to a total of more than 1.5 million tonnes (European Commission, 2016b).

Forestry

Following the adjustments described earlier, EU-28 woody sources are estimated in total at almost 370 million tonnes of dry matter. Based on the approach followed, the total estimated removals from the forest of primary wood in EU-28 add up to 252 million Tdm, while the net-import of roundwood is estimated to be about 6.8 million Tdm. It is worth recalling that these figures are the result of adjustments made on the original data sources to account for the numerous inconsistencies and data gaps found (see section 3.3.3 for details). The ratio of annual removals to net annual increment (NAI) of stemwood of forest available for wood supply is 64% for 2013[22]. In addition to stemwood, there is a sizeable NAI of other woody tree components, increasing the total primary supply potential by more than one fourth.

Removals from forests were composed for 78.6% of industrial roundwood, and 21.4% of fuelwood. Based on the country-level decomposition of biomass, we estimate this amount of fuelwood as being composed of 33% stemwood and 67% other wood components (branches, tree tops, sub-merchantable stems). It is useful to recall that, in addition to the removals classified as fuelwood, the total amount of woody biomass used for energy in the wood resource balance also includes secondary residues from wood processing, black liquor, removals from outside forest, imported secondary residues and wood pellets, post-consumer wood and actually also part of pulpwood classified as industrial roundwood.

Net-import of by- and co- products (incl. wood pellets) is about 8 million tonnes dry matter, while net-import of wood pulp is 13 million tonnes.

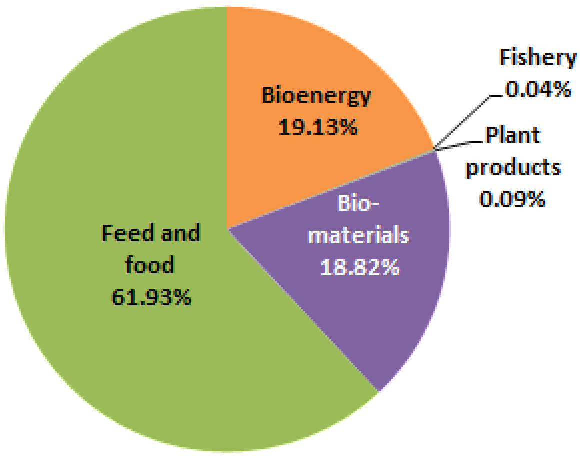
[22]The ratio of annual fellings to annual net annual increment on FAWS is a commonly used indicator of the intensity of forestry. As a rule of thumb, values lower than 100% indicate harvest levels that can be sustained in the long term, as they entail an increasing growing stock. The opposite holds if the ratio is higher than 100%.

5.2 Biomass uses

Feed and food is the most important category in terms of biomass use, adding up to over 60% of the biomass. 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 in this document.

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 for this study. Bio-materials are the third biggest group.

Figure 5. Composition of the EU-28 biomass uses



Feed and Food

The biomass used for feed and food products is almost entirely of agricultural origin.

— One third of the crop used residues is used for feed and bedding and horticulture purposes, while the other two thirds of which are used in downstream sectors. How these two thirds are split into bio-materials and bioenergy uses cannot be quantified at this point.

— 71% of the total agricultural biomass supply (expressed in dry matter) is used as food and feed: 69% is used as animal feed & bedding for the production of animal-based food while the rest is directly consumed as plant-based food.

0.5% of the biomass that is used for feed and food is of aquatic origin. As explained in the previous section, aquaculture and capture fisheries growth may not be able to meet the increasing demand so that imports will need to increase, further increasing the dependency of Europe on the rest of the world for its seafood products (Failler, 2007).

Bioenergy

First generation biofuels still play a very minor role in the total European Union bioenergy sector, although in some countries they have a bigger weight.

Most of the biomass used in bioenergy is sourced from forestry products. In 2013, 178.7 Tdm of wood were estimated to have been used for energy, either directly or indirectly[23] gathered from forest.

Only 2% of the EU agricultural supply is processed into sustainable biofuels for transportation. The rest is either used as biomaterial or waste[24].

Biofuels use in the EU transport sector in 2013 totalled 11970 ktoe in energy terms. Common arable crops had the main contribution to the total biomass supplied to the transport sector, at more than 90% in 2013.

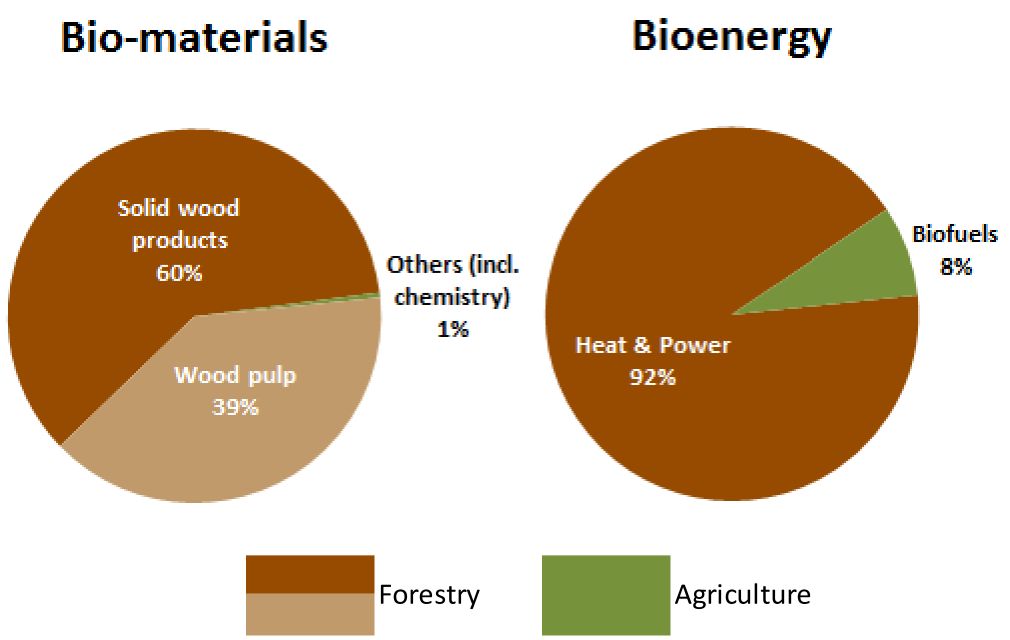
Based on the available data[25], the volume of domestic common arable crops supplied to the transport sector is estimated at 15 million Tdm in year 2013.

Germany was the main supplier with 12 million Tdm followed by Slovakia (668 thousand Tdm) and Romania (475 thousand Tdm).

Biomaterials

Almost all of the bio-materials also have an origin in forestry activities with the biggest component being solid wood products. In 2013, 189.9 million tonnes of dry matter of wood were used for bio-materials. EU-28 is also a net exporter (14.3 million tonnes of dry matter) of solid wood products.

Figure 6. Origin of biomass used for bioenergy and bio-materials



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

[24] According to the FAO Balance sheets around 23 million of tonnes of biomass (in fresh matter) were wasted in the EU in 2013.

[25] Since not all EU Member States reported on biomass supply for transport this amount does not represent the total amount of biomass that has been supplied in the EU transport sector in this year (see ***Table 5***). The contribution of this volume of common arable crops in energy terms in year 2013 is equal to 4878 ktoe. To calculate the overall contribution of common arable crops in energy terms in the EU transport sector the conversion ratio between crops and biofuels use in transport sector is assumed equal to 1. Taking into account this assumption the overall contribution of common arable crops in energy terms in year 2013 was estimated 10991 ktoe.

6 Further research opportunities

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 MS 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, fishery and bioenergy sectors are integrated into a single study.

Nevertheless, as a pioneer work, 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.

— 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.

— 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.

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List of acronyms

Acronym	Definition
dm	Dry matter
EMFF	European Maritime and Fisheries Fund
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
IEA	International Energy Agency
JRC	Joint Research Centre
JRC C2	Joint Research Centre Unit C.2. Energy Efficiency & Renewables
JRC D1	Joint Research Centre Unit D.1. Bio-Economy
JRC D2	Joint Research Centre Unit D.2. Water & Marine Resources
JRC D4	Joint Research Centre Unit D.4. Economics of Agriculture
JRC D5	Joint Research Centre Unit D.5. Food Security
JWEE	Joint Wood Energy Enquiry
ktoe	kilo tonnes of oil equivalent
m^3	Cubic metres
MS	(EU) Member State
NFI	National Forest Inventory
NREAP	National Renewable Energy Action Plan
SWE	Solid wood equivalents
Tdm	Tonnes of dry matter
UNECE	United Nations Economic Commission for Europe
WRB	Wood Resource Balance

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Annexes

Annex 1. Reference moisture content (m) values to calculate dry-matter economic yield and production.

Description	m	Source
Cereals		
Barley	0.14	EUROSTAT Handbook
Cereal straw and husks	0.12	Ronzon et al., (2015)
Maize (corn)	0.14	EUROSTAT Handbook
Oats	0.14	EUROSTAT Handbook
Rice	0.13	EUROSTAT Handbook
Rye	0.14	EUROSTAT Handbook
Grain sorghum	0.14	EUROSTAT Handbook
Wheat and meslin	0.14	EUROSTAT Handbook
Other cereals	0.14	EUROSTAT Handbook
Energy crops	0.0945	Duong et al., (2013)
Fiber crops	0.05	EUROSTAT Handbook
Fodder crops	0.65*	EUROSTAT Handbook
Fruits and nuts		
Apples, pears and quinces	0.8	EUROSTAT Handbook
Apricots, cherries, peaches, plums and sloes	0.8	EUROSTAT Handbook
Bananas, including plantains	0.8	EUROSTAT Handbook
Citrus fruit	0.8	EUROSTAT Handbook
Dates, figs, pineapples, avocados, guavas, mangoes and mangosteens	0.8	EUROSTAT Handbook
Coconuts, Brazil nuts and cashew nuts	0.1	Ronzon et al., (2015)
Fruit and nuts	0.8	EUROSTAT Handbook
Grapes	0.85	Ronzon et al., (2015)
Groundnuts	0.22	Ronzon et al., (2015)
Melons, watermelons and papayas	0.94	Ronzon et al., (2015)
Other fruit, fresh	0.5	Ronzon et al., (2015)
Other nuts	0.1	Ronzon et al., (2015)
Peel of citrus fruit or melons	0.5	Ronzon et al., (2015)
Starchy roots		
Potatoes	0.783	Deblonde et al., (1999)
Manioc, sweet potatoes and similar roots and tubers	0.79	Ronzon et al., (2015)
Live animals	0.7	Ronzon et al., (2015)
Products of animal origin n.e.s	0.6	Ronzon et al., (2015)
Oilseeds		
Copra	0.22	Ronzon et al., (2015)
Cotton seeds	0.09	EUROSTAT Handbook
Linseed	0.22	Ronzon et al., (2015)

Description	m	Source
Rape or colza seeds	0.09	EUROSTAT Handbook
Soya beans	0.14	EUROSTAT Handbook
Sunflower seeds	0.09	EUROSTAT Handbook
Other oil seeds and oleaginous fruits	0.22	Ronzon et al., (2015)
Other crops		
Coffee, tea, maté and spices	0.71	Ronzon et al., (2015)
Hop cones, lupulin	0.71	Ronzon et al., (2015)
Live trees and other plants	0.5	Ronzon et al., (2015)
Olives	0.16	Ronzon et al., (2015)
Plants used in perfumery, pharmacy or similar purposes	0.71	Ronzon et al., (2015)
Seaweeds and other algae	0.71	Ronzon et al., (2015)
Seeds	0.71	Ronzon et al., (2015)
Tobacco	0.1	Ronzon et al., (2015)
Pulses		
Leguminous vegetables	0.14*	EUROSTAT Handbook
Dried vegetables	0.14*	EUROSTAT Handbook
Dried leguminous vegetables	0.14*	EUROSTAT Handbook
Sugar crops		
Sugar cane	0.69	Ronzon et al., (2015)
Sugar beet	0.756	Draycott (2006)
Vegetables		
Cabbages, cauliflowers, kohlrabi, kale and similar edible brassicas	0.94	Ronzon et al., (2015)
Carrots, turnips and similar edible roots	0.94	Ronzon et al., (2015)
Cucumbers and gherkins	0.94	Ronzon et al., (2015)
Lettuce and chicory	0.94	Ronzon et al., (2015)
Tomatoes	0.94	Ronzon et al., (2015)
Onions, shallots, garlic, leeks and other alliaceous vegetables	0.94	Ronzon et al., (2015)

**for those Member States reporting m*

Annex 2. Summary of methods followed to compute crop residues yield $\boldsymbol{R}$ from dry-matter economic yield $\boldsymbol{Y_0}$ and the harvest index $\boldsymbol{HI}$.

Crop	Method of assessment	Source	Model assumptions	Coefficients/ HI modelling
Cereals				
Barley	Empirical model for barley	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y) ●HI predicted from average $\bar{Y}_0$ over the period 1998-2015 ●HI varies from region to region (climate) ● HI is stable from year to year	$HI = f(\bar{Y}_0) \pm CI$
Grain maize	Empirical model for grain maize	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from Y ●HI varies from region to region (climate) ● HI varies from year to year	$HI = f(Y_0) \pm CI$
Oats	Empirical model for wheat	Same as wheat		
Other cereals	Empirical model for wheat	Same as wheat		
Rice	Empirical model for rice	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from Y_0 ●HI varies from region to region (climate) ● HI varies from year to year	$HI = f(Y_0) \pm CI$
Rye	Empirical model for wheat	Same as wheat		
Sorghum	Empirical model for sorghum	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y) ●HI predicted from Y ●HI varies from region to region (climate) ● HI varies from year to year	$HI = f(Y_0) \pm CI$
Soybean	Empirical model for soybean	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from Y_0 ●HI varies from region to region (climate) ● HI varies from year to year	$HI = f(Y_0) \pm CI$
Triticale	Empirical model for wheat	Same as wheat		
Wheat	Empirical model for wheat	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from average $\bar{Y}_0$over the period 1998-2015	$HI = f(\bar{Y}_0) \pm CI$

Crop	Method of assessment	Source	Model assumptions	Coefficients/ HI modelling
			●HI varies from region to region (climate) ● HI is stable from year to year	
Energy crops n.e.c.	–		Not estimated	
Fibre crops	Constant HI	Ronzon et al., 2015	●R derived from constant HI	HI =0.83
Fodder crops	–		Not estimated	
Oilseeds				
Cotton seed	Constant HI	Gemtos and Tsiricoglou (1999)	●Residues production includes stalks+ branches biomass ●$HI = 0{,}173$	$R = \frac{Y_0}{HI_{pruning}} - Y_0$
Rapeseed	Empirical model for rapeseed	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from average $\bar{Y}_0$ over the period 1998-2015 ●HI varies from region to region (climate) ● HI is stable from year to year	$HI_m = f(\bar{Y}_0) \pm CI$
Sunflower	Empirical model for sunflower	van der Velde (Ed.) (2016)	●R derived from predicted HI (heteroscedasticity between R and Y_0) ●HI predicted from Y_0 ●HI varies from region to region (climate) ● HI varies from year to year	$HI = f(Y_0) \pm CI$
Other crops				
Fruit trees	Constant HI	Di Blasi, Tanzi, and Lanzetta (1997)	●HI calculated from a fixed RPR accounting for pruning residues) for wet biomass ●$RPR_{pruning} = 0{,}91$	$HI_{pruning} = \frac{1}{1 + RPR_{pruning}}$
Tobacco	Constant HI	Ronzon et al., 2015	●R derived from constant HI	HI =0.5
Olives	Constant R	Spinelli and Picchi (2010)	●Constant pruning residues (stems+leaves)	$R = 3.44\ t/ha$
Potato	Empirical model for potato	van der Velde (Ed.) (2016)	●R predicted from Y_0	$R = f(Y_0) \pm CI$
Sugar beet	Empirical model for sugar beet	van der Velde (Ed.) (2016)	●R predicted from Y	$R = f(Y_0) \pm CI$
Tobacco	Constant HI	Ronzon et al., 2015	●R derived from constant HI	HI =0.5
Vineyards	Constant HI	Manzone et al. (2016)	●Residues production: pruning (sarmenta) ●$HI_{pruning} = 0{,}76\ and\ m = 0$	$R = \frac{Y_0}{HI_{pruning}} - Y_0$

Crop	Method of assessment	Source	Model assumptions	Coefficients/ HI modelling
Pulses	Empirical model for pulses	New model from experimental data	●R derived from predicted HI ●Field peas, a=3.644 ● Beans, lupins and other dry pulses, a =3.232	$HI = \frac{1}{a * e^{-0.3*Y_0} + 1}$
Vegetables	–		Not estimated	

Annex 3. Share of used residues of agricultural commodities

COMMODITIES:	Share of used 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%

Annex 4. Estimation of feed and food uses

Feed and food uses are split in the Sankey diagram into: (i) aquatic food, (ii) plant-based food, (iii) animal-based food) and (iv) animal feed and bedding. The present annex details the calculation steps for the estimation of the last 3 categories. The estimation of aquatic food uses is made separately (see section 3.2.2).

The quantification of plant-based, animal-based and feed and bedding uses 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)

   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 considering that the shares of nutrients $\%N_k$ given by Piotrowski et. al (2015b):

Table 6. Proportion of Carbohydrates, fats and proteins in total food supply

Nutrient *k*	Share of nutrient ($\%N_k$)[26]
Carbohydrates	0.50
Fats	0.38
Proteins	0.12

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*.

3. Plant-based food uses and animal-based food uses are estimated by splitting Nutrient Supply: $\mathrm{NS\ (kcal)_{i,j,k}}$ into the 3 biomass sources of food supply: vegetal, animal (excl. aquatic) and aquatic.

   Factors are given in Table 7. It is considered that 1 kcal = 0.004187MJ

[26] Note: calculated for the EU27 in 2011 by Piotrowski (2014) from FAO Food Balance Sheets.

Table 7. Factors used in the conversion of nutrient supplies from kcal to kg (dry matter)

Nutrient *k*	**Conversion factor (MJ/kg)**	**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	$Plant_{i,j,k}/FS_{i,j,k}$	$Aqua_{i,j,k}/ FS_{i,j,k}$	$(1- Plant_{i,j,k}- Aqua_{i,j,k})/ FS_{i,j,k}$
Proteins	16.7	$Plant_{i,j,k}/ FS_{i,j,k}$	$Aqua_{i,j,k}/ FS_{i,j,k}$	$1- Plant_{i,j,k}- Aqua_{i,j,k})/ FS_{i,j,k}$
Other	non-nutritional food components (minerals, dietary fibres) account for an additional 10% of total food supply			

Note: Fixed factors are taken from Piotrowski (2014)

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

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

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

i.e.

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

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

And

$$\textbf{Animal} - \textbf{based food uses } (\textbf{1000 Tdm})_{\textbf{I,j}} =$$

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

4. Feed and bedding uses

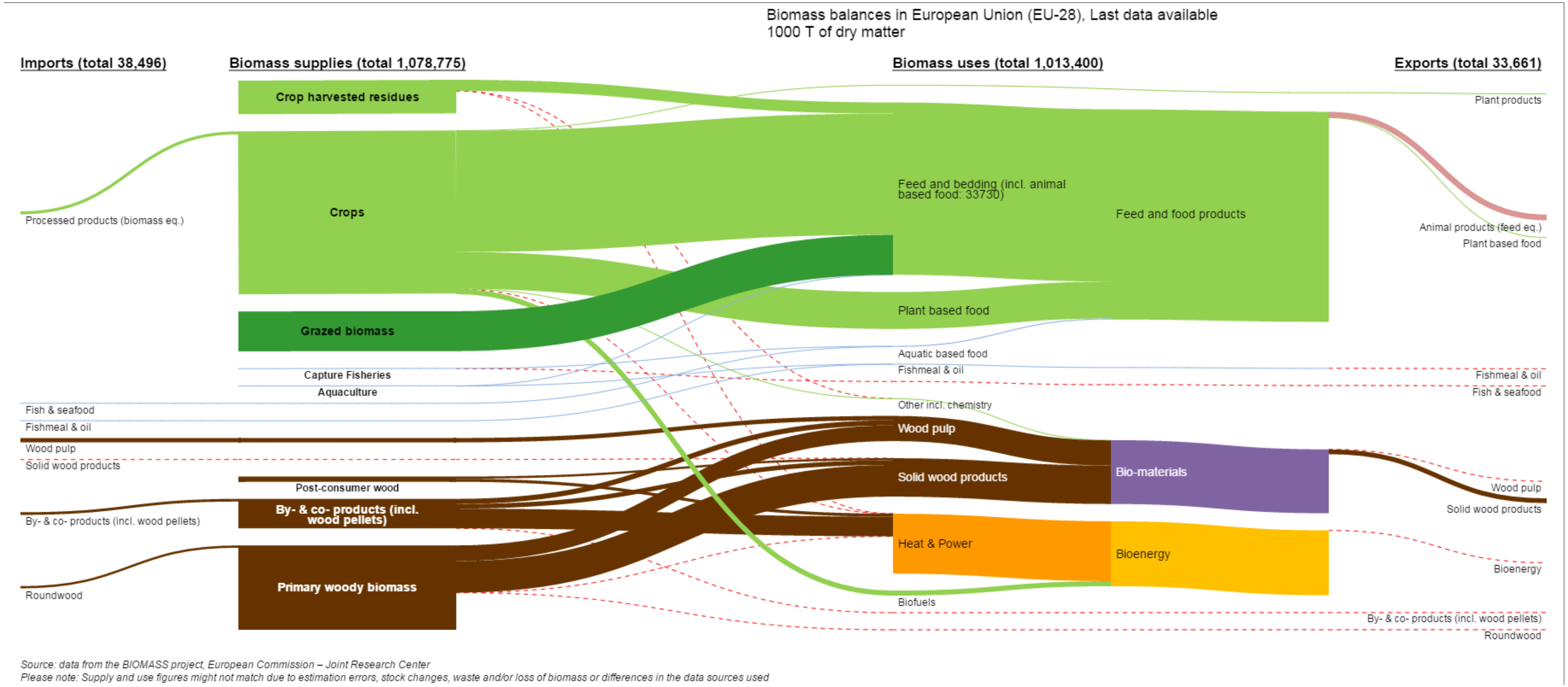
Animal-based food uses are converted in feed equivalents using the efficiency conversion coefficient of 6.8% from Piotrowski et al. (2015a).

i.e.

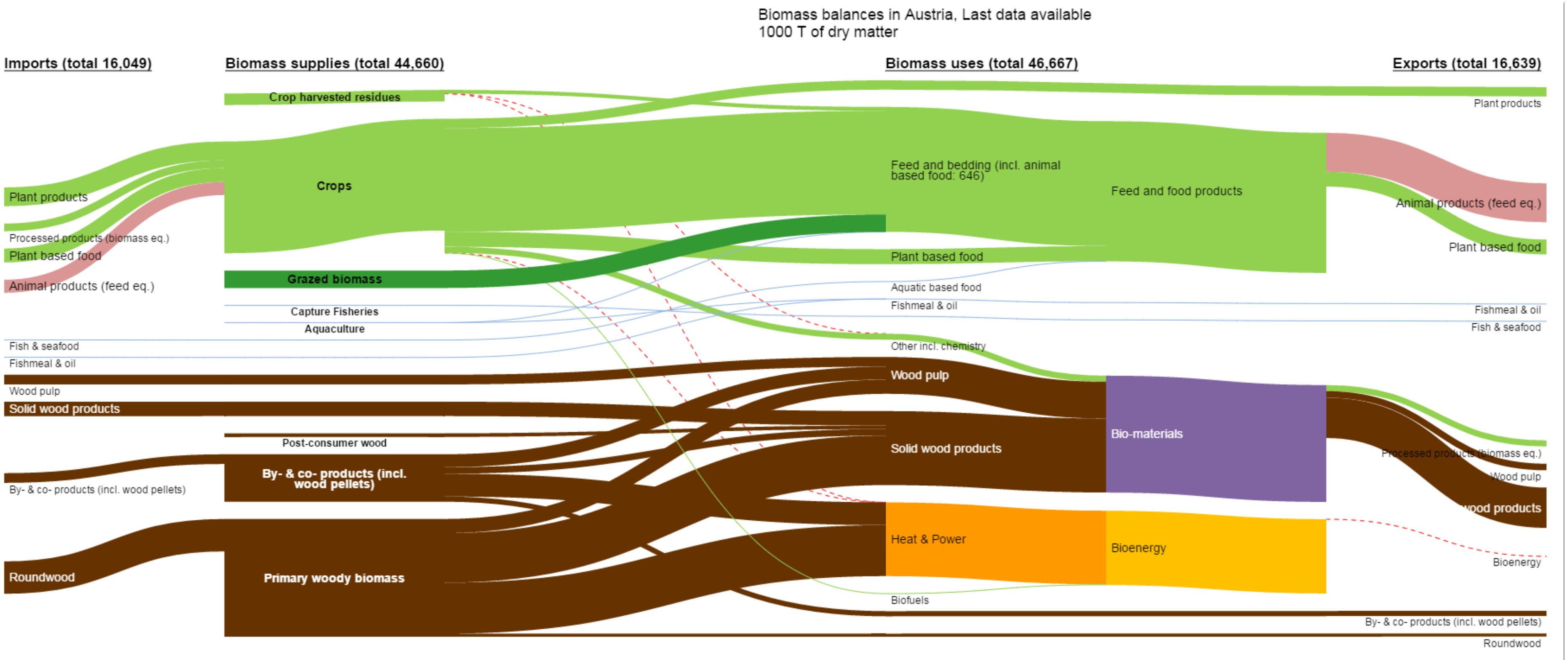
$$\textbf{Animal feed and bedding uses } (\textbf{1000 Tdm})_{\textbf{i,j}} = \frac{\text{Animal} - \text{based food uses (1000 Tdm)}_{\text{I,j}}}{0.068}$$

Annex 5. Screen shots of Sankey biomass diagram

EU-28, Net trade

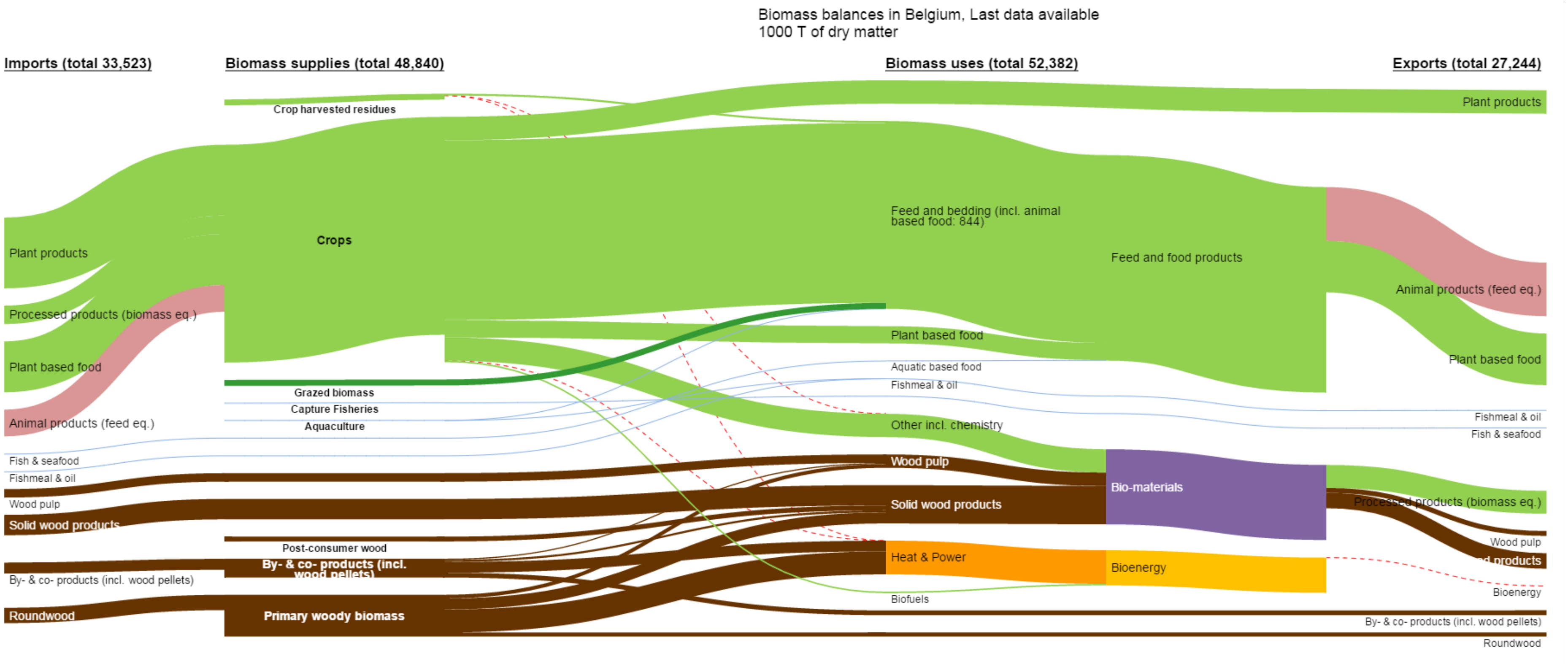


Austria, Full trade



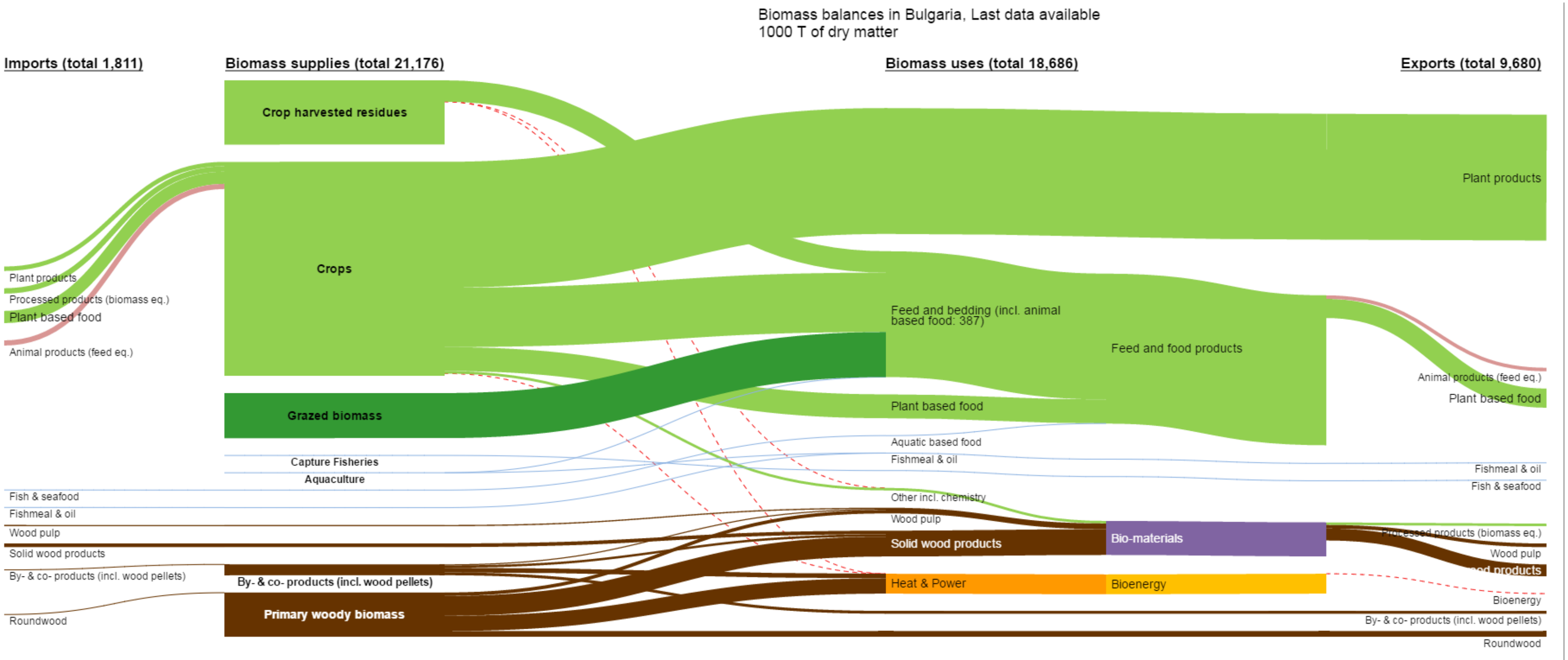
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Belgium, Full trade



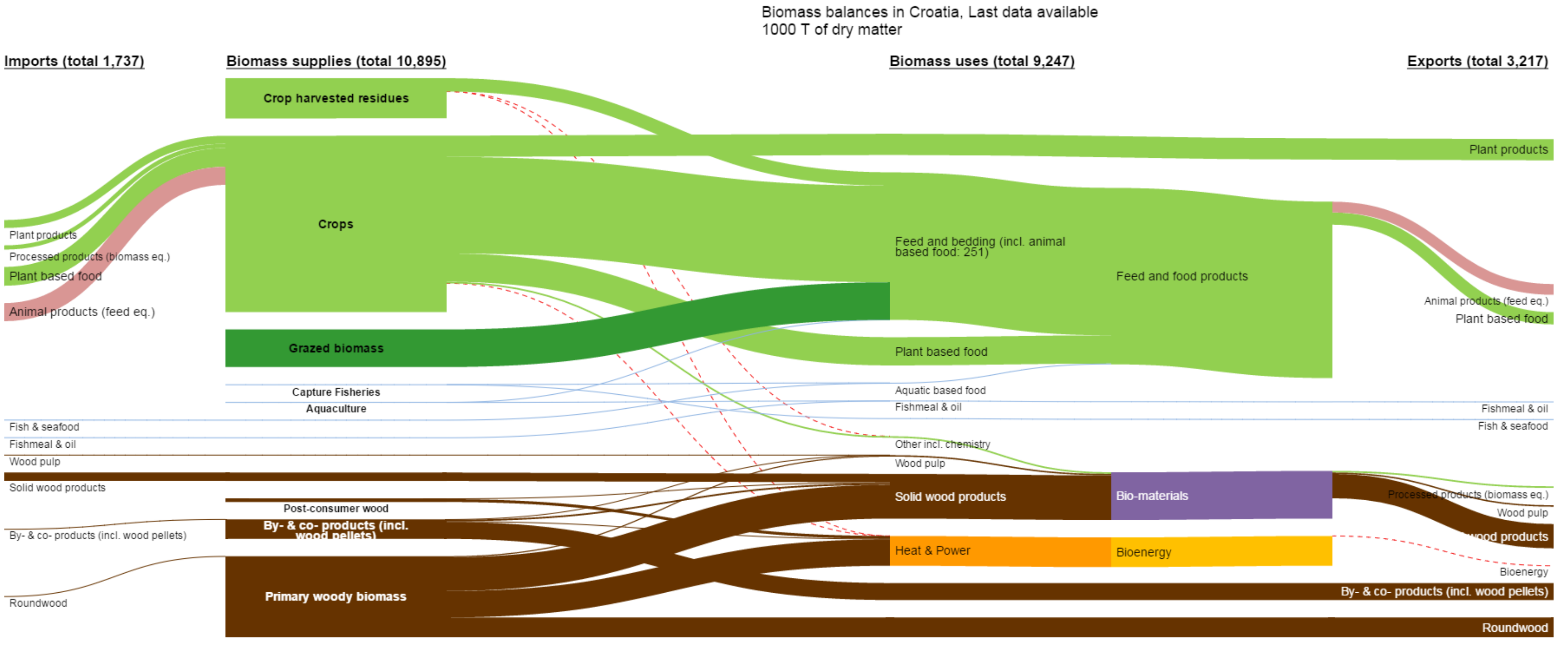
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Bulgaria, Full trade



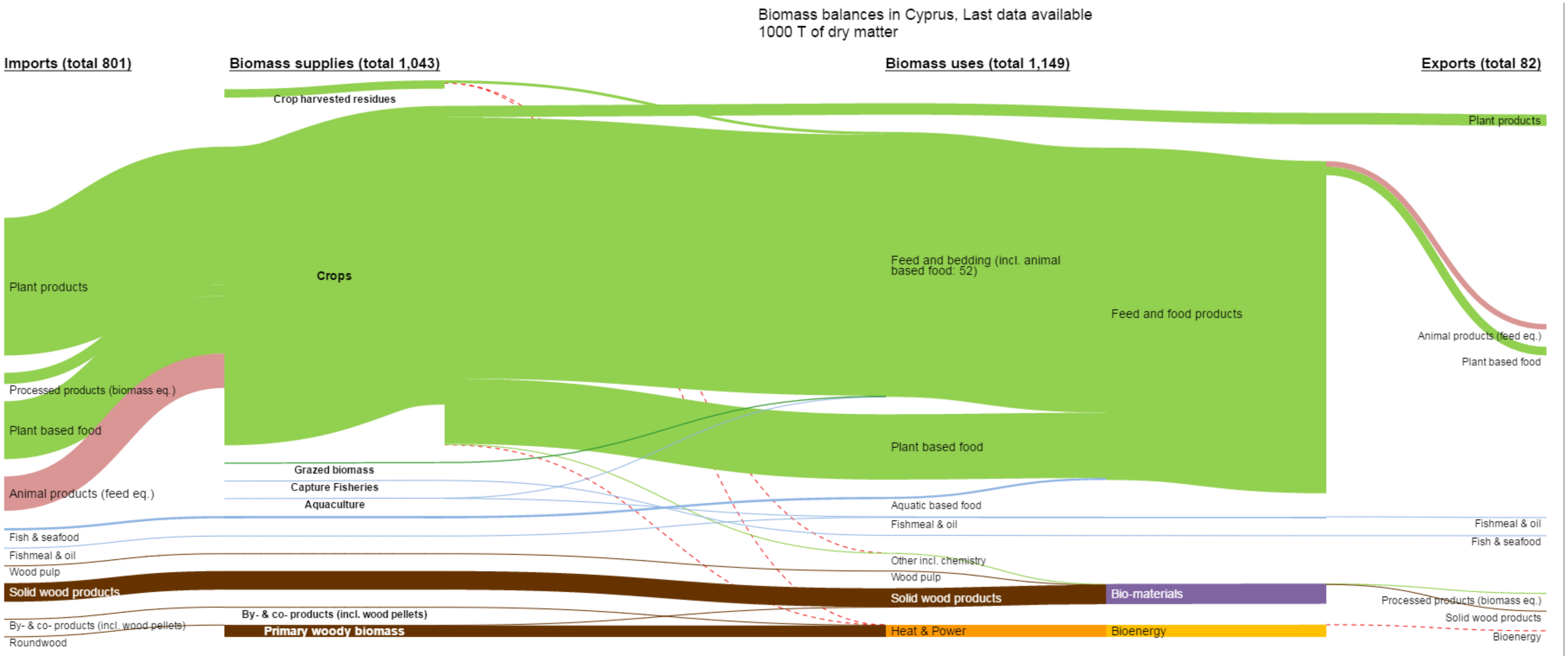
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Croatia, Full trade



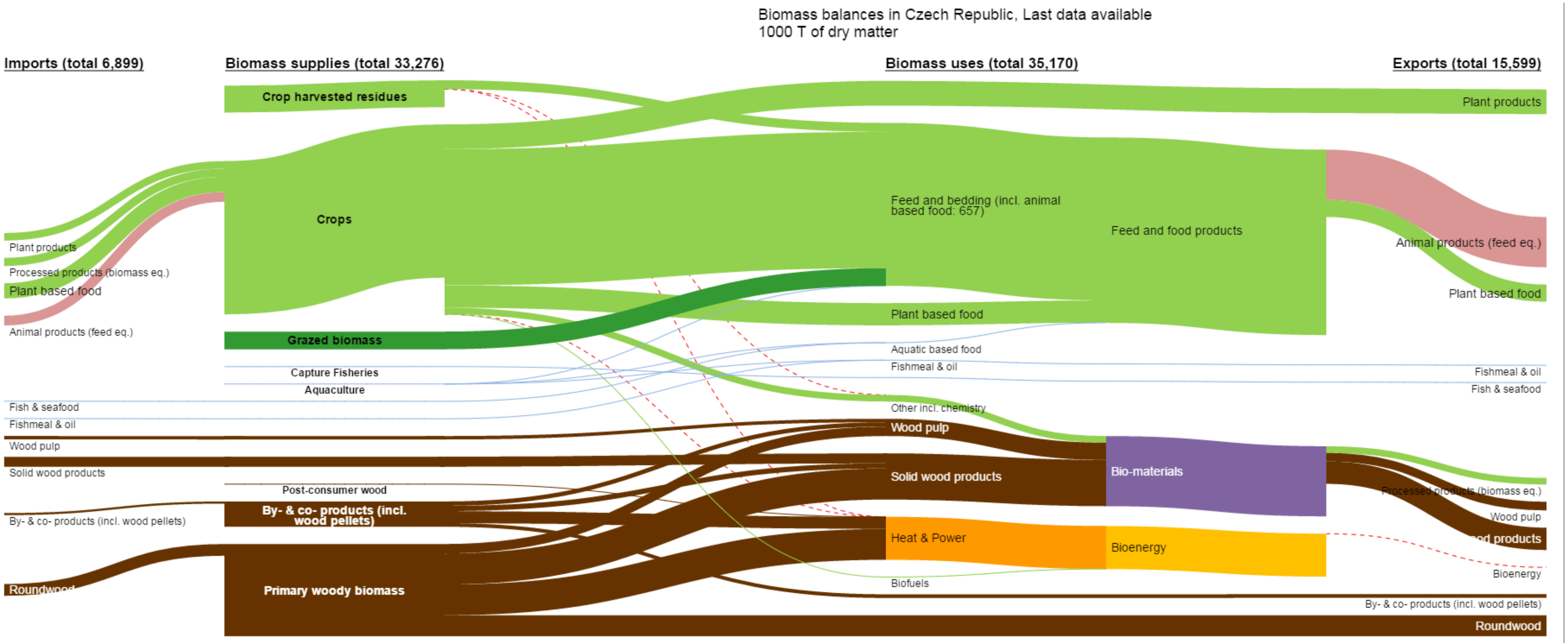
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Cyprus, Full trade



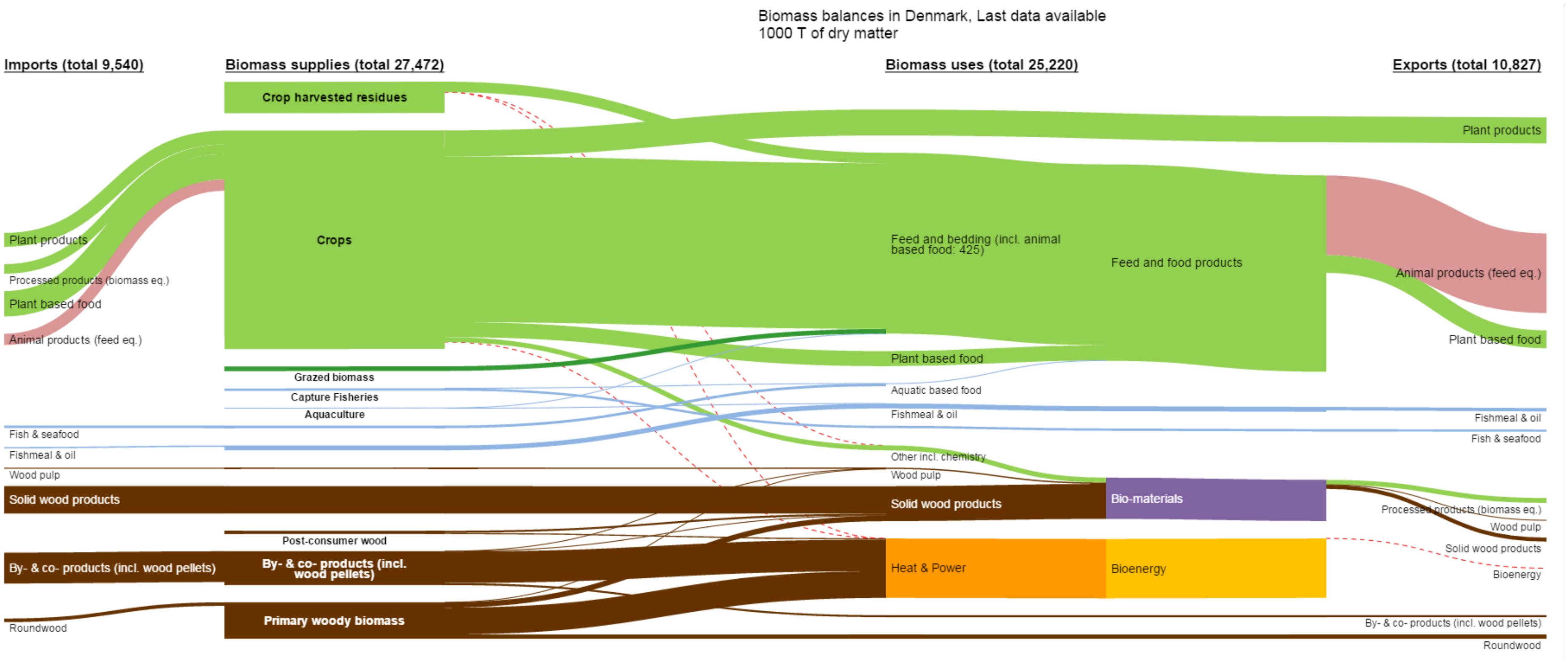
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Czech Republic, Full trade



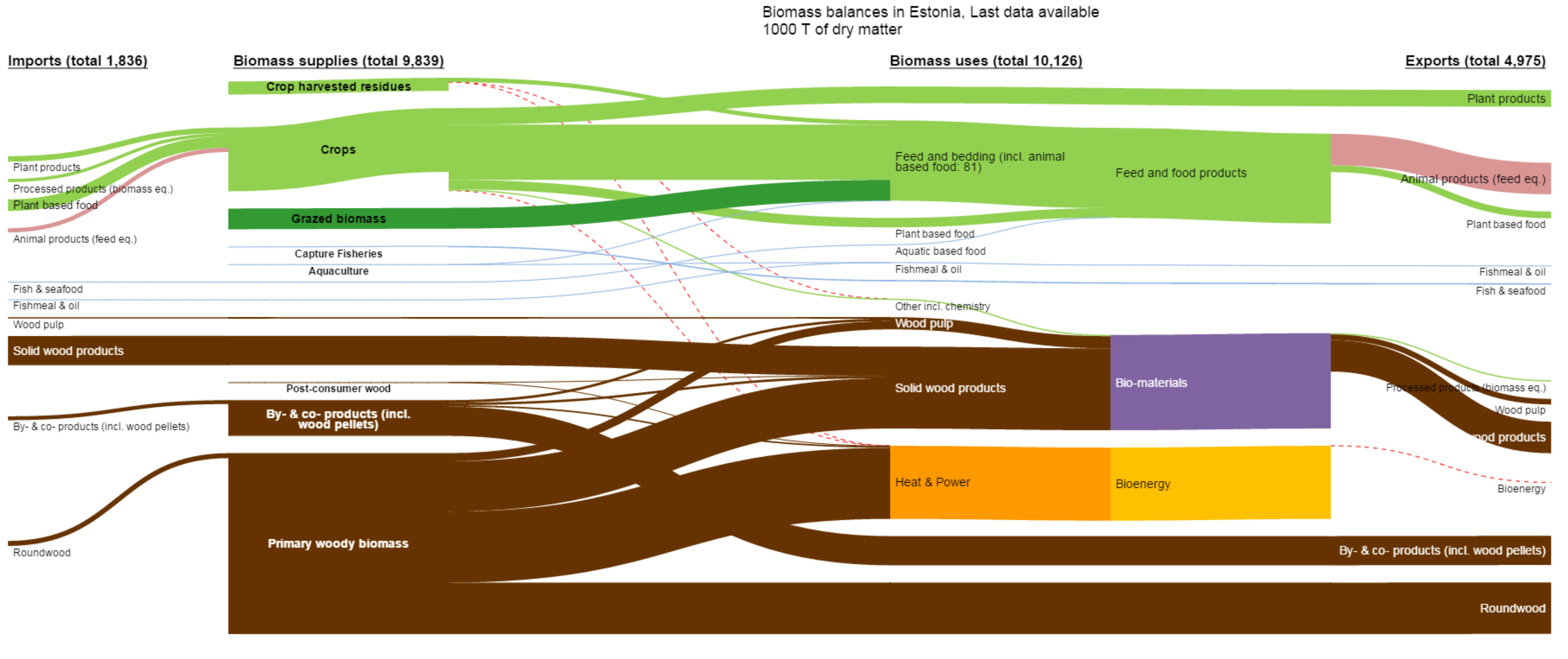
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Denmark, Full trade



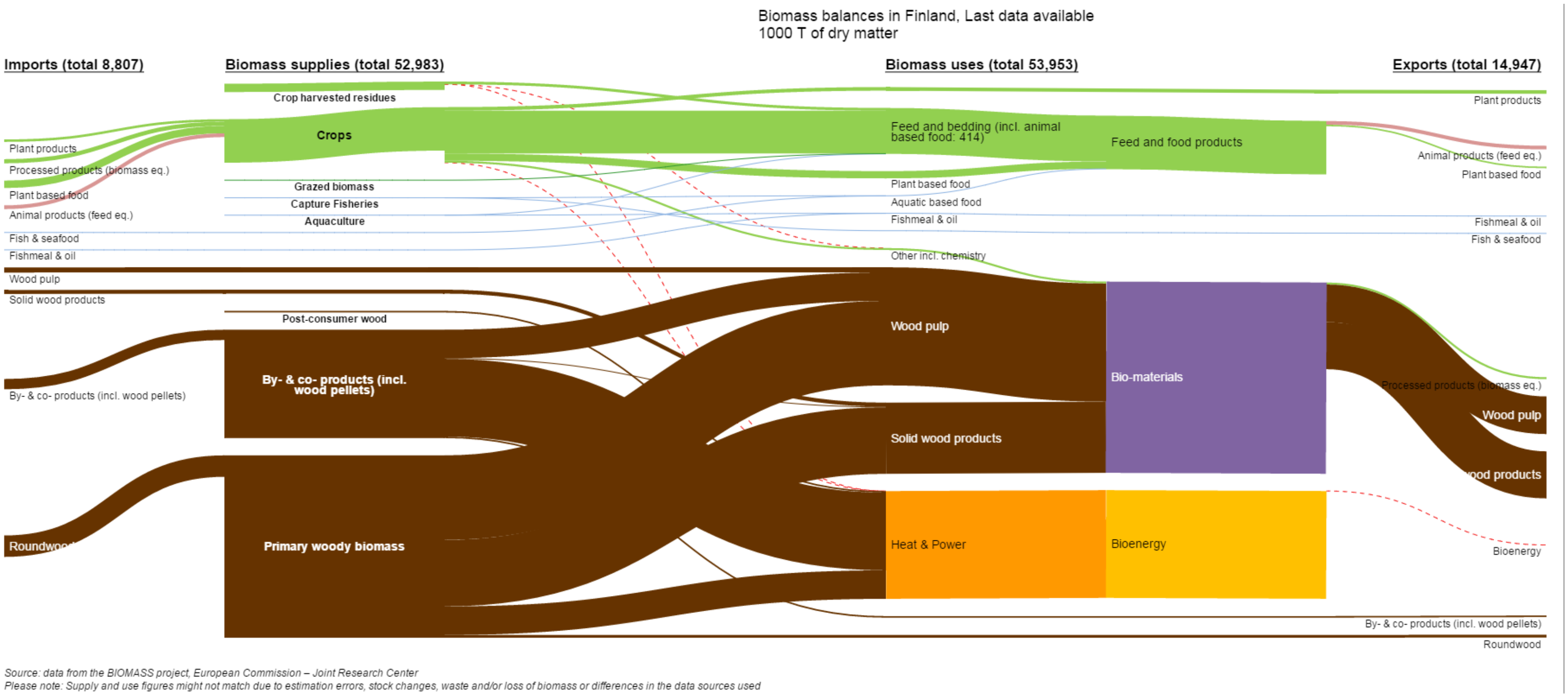
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Estonia, Full trade



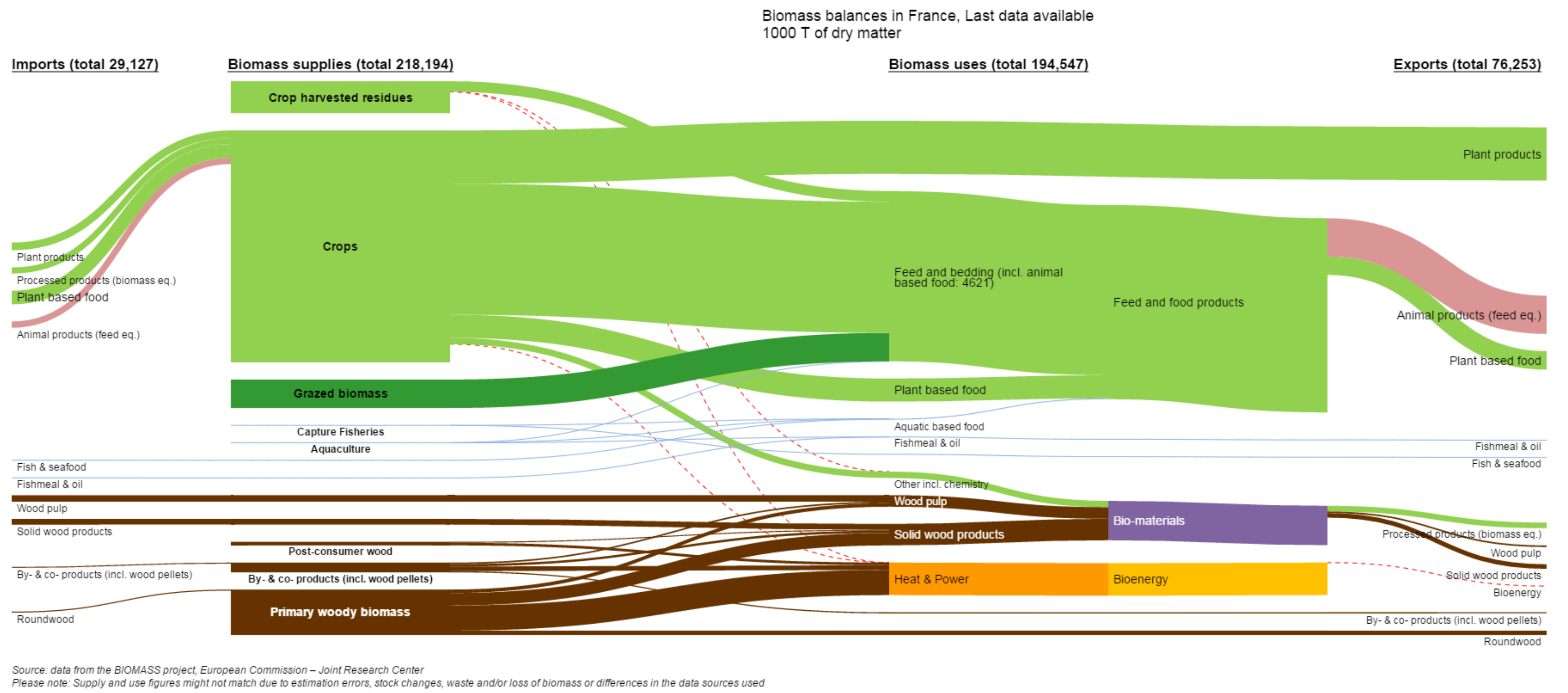
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Finland, Full trade

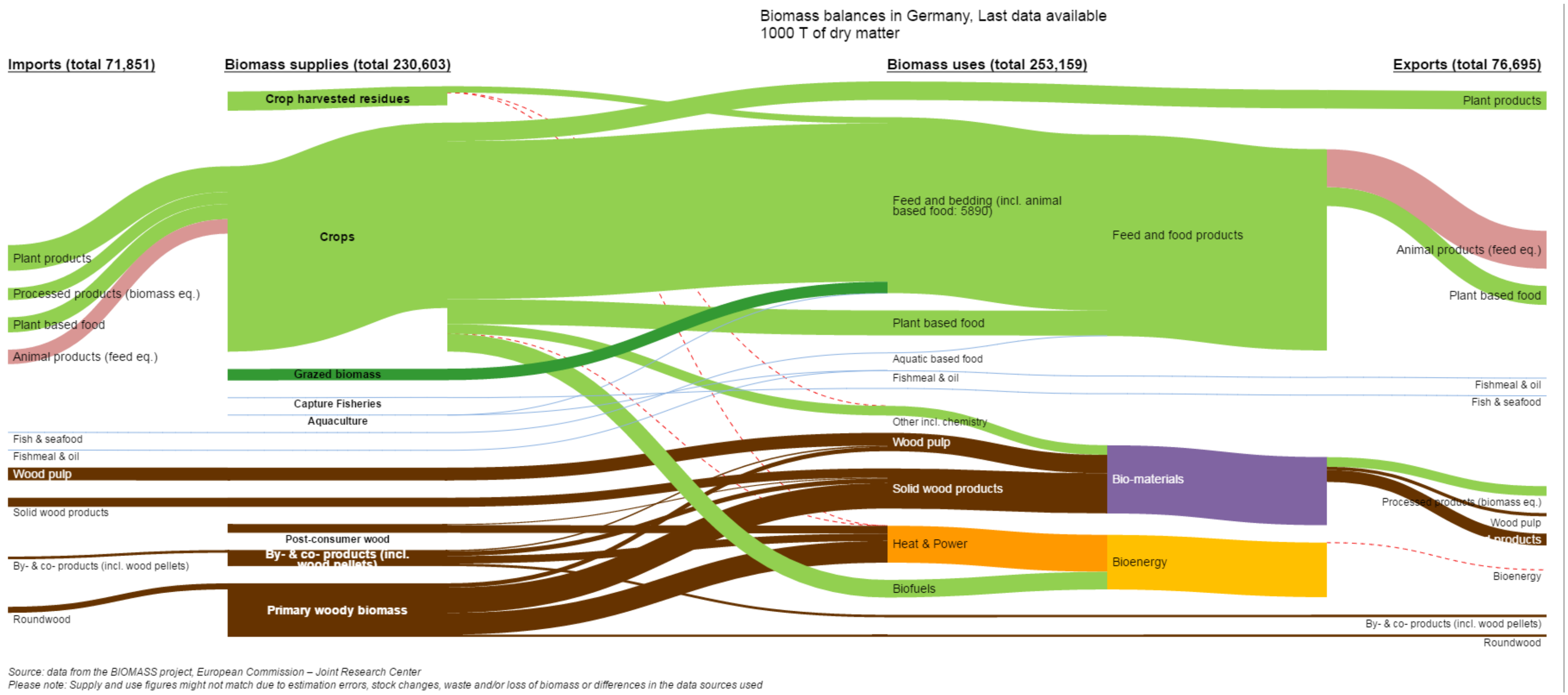


Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

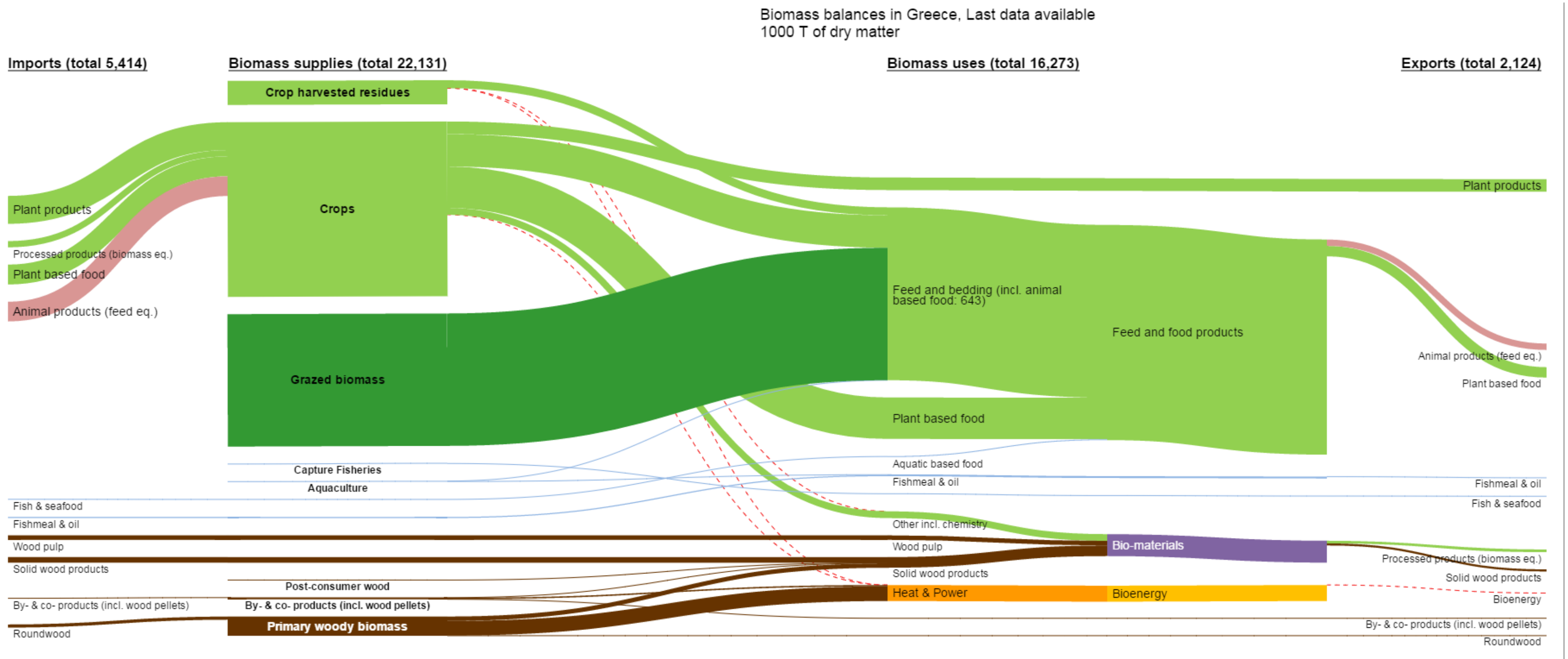
France, Full trade



Germany, Full trade

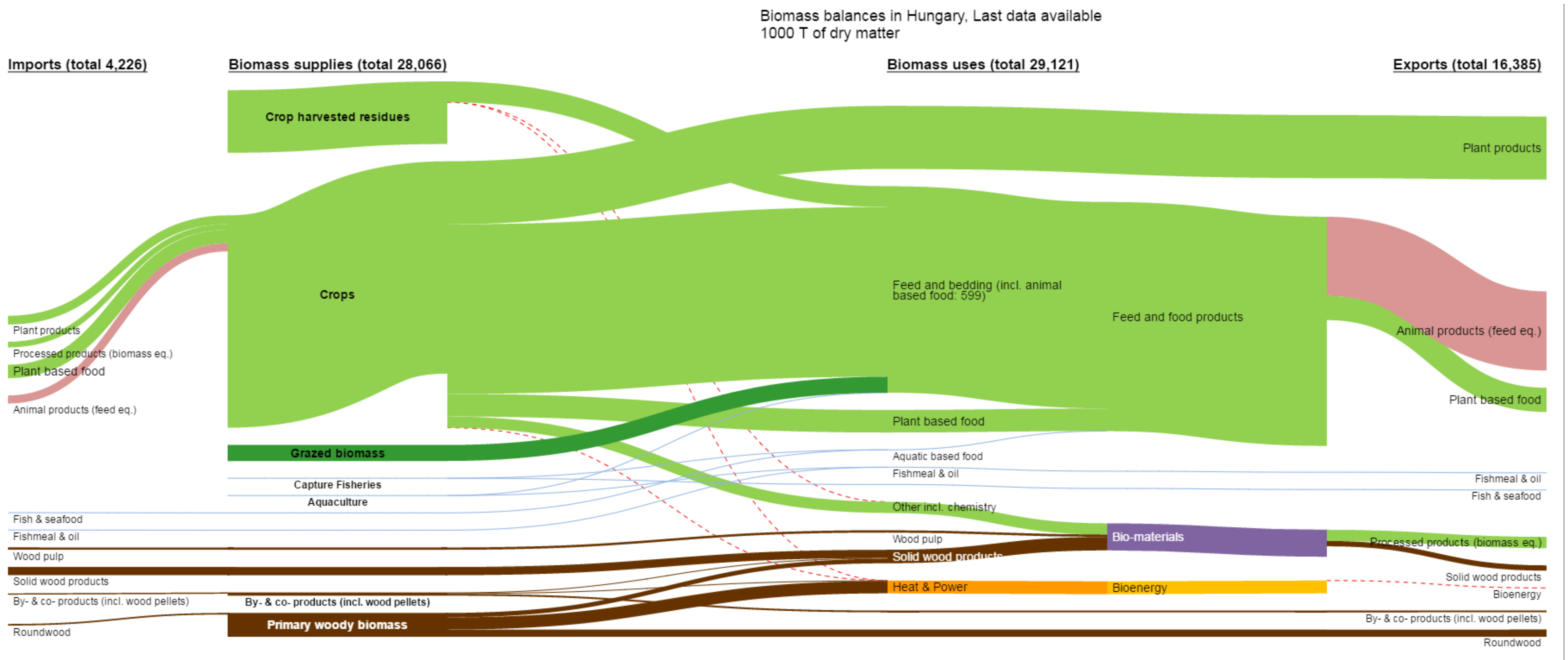


Greece, Full trade



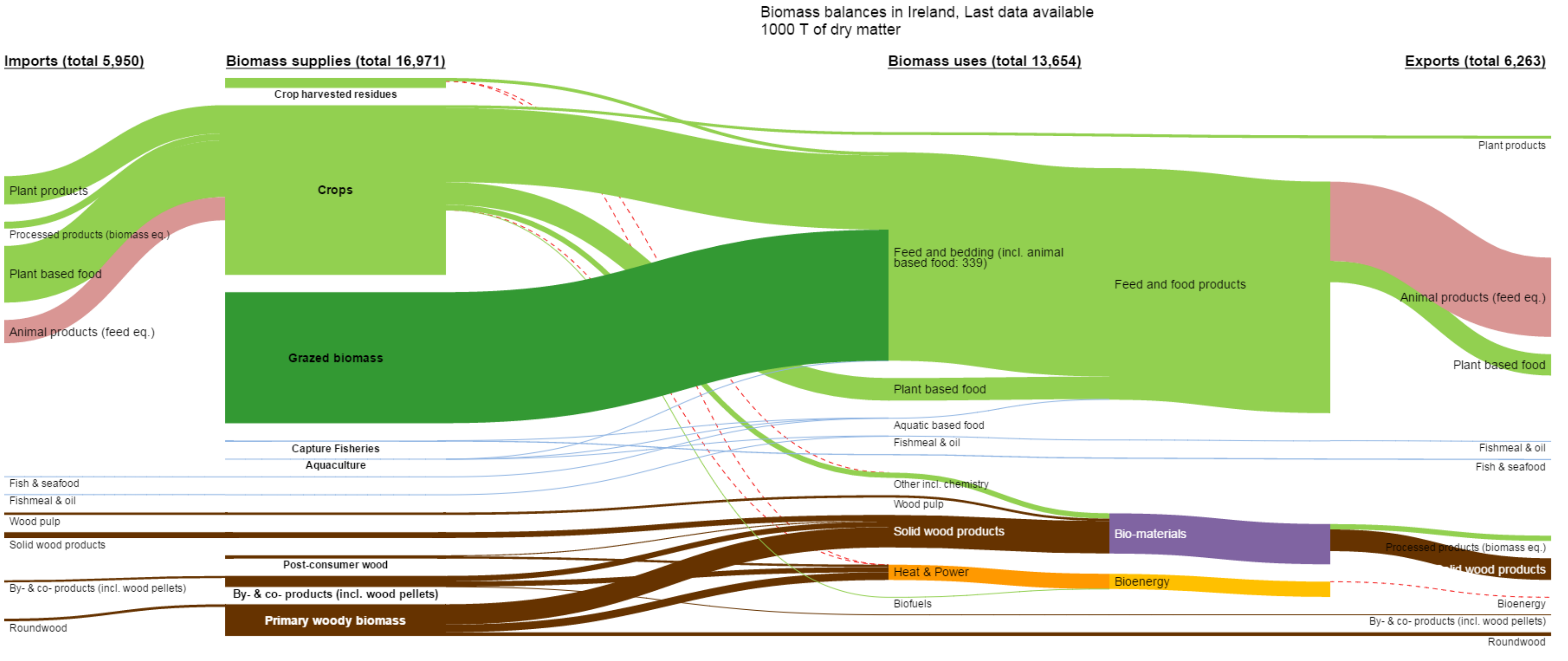
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Hungary, Full trade



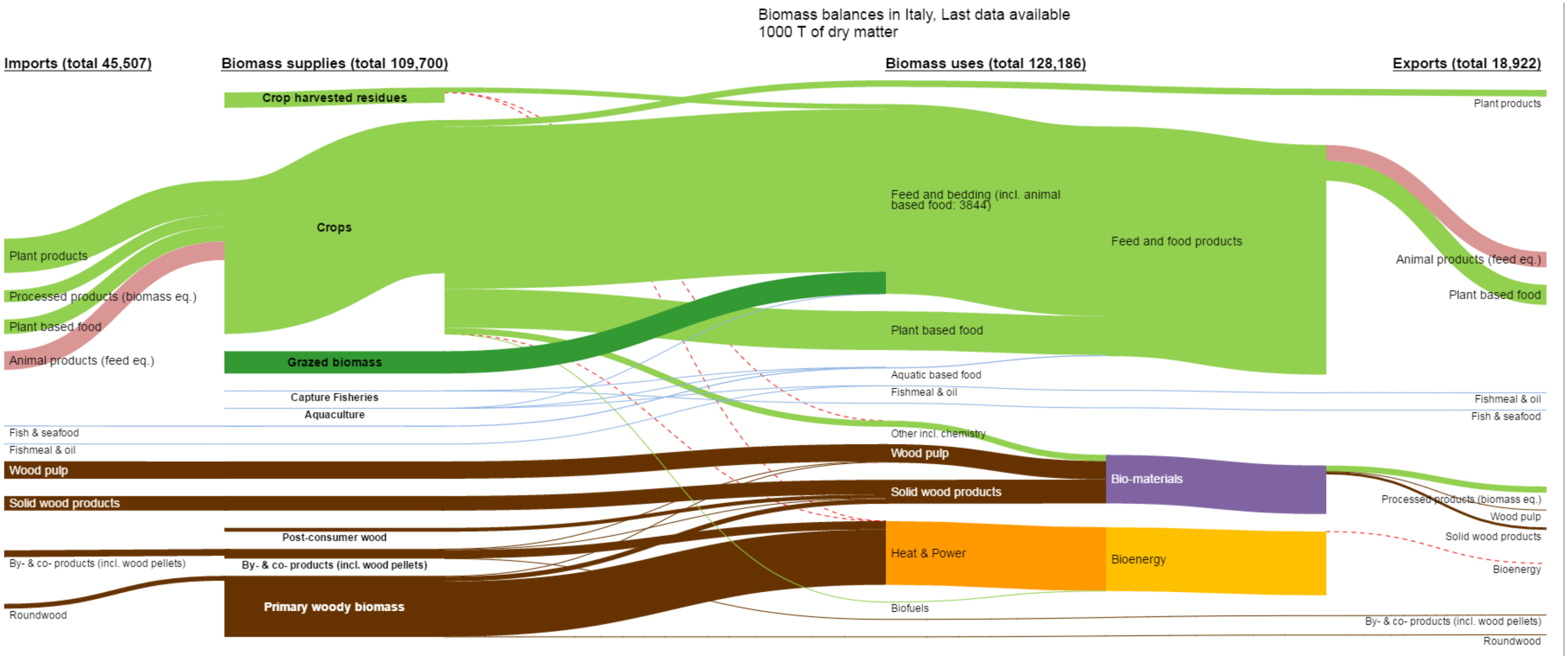
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Ireland, Full trade



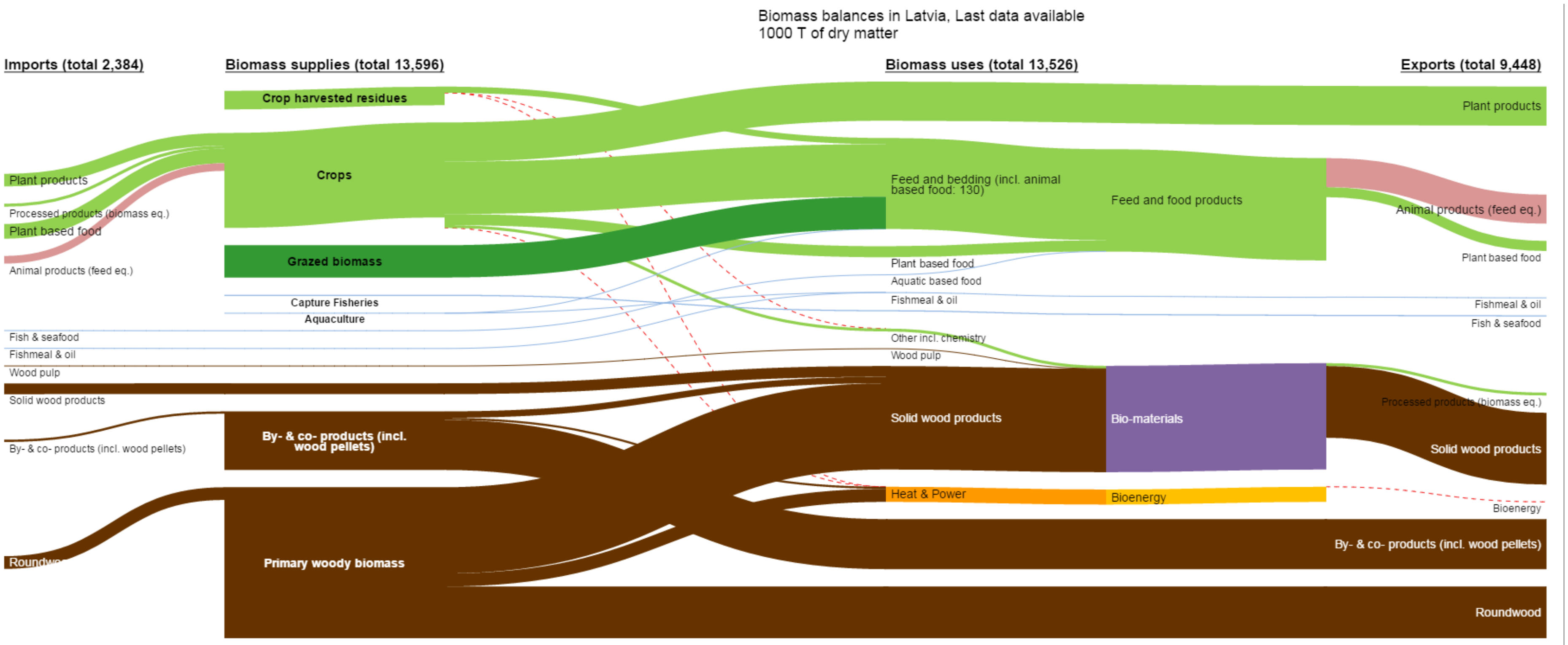
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Italy, Full trade



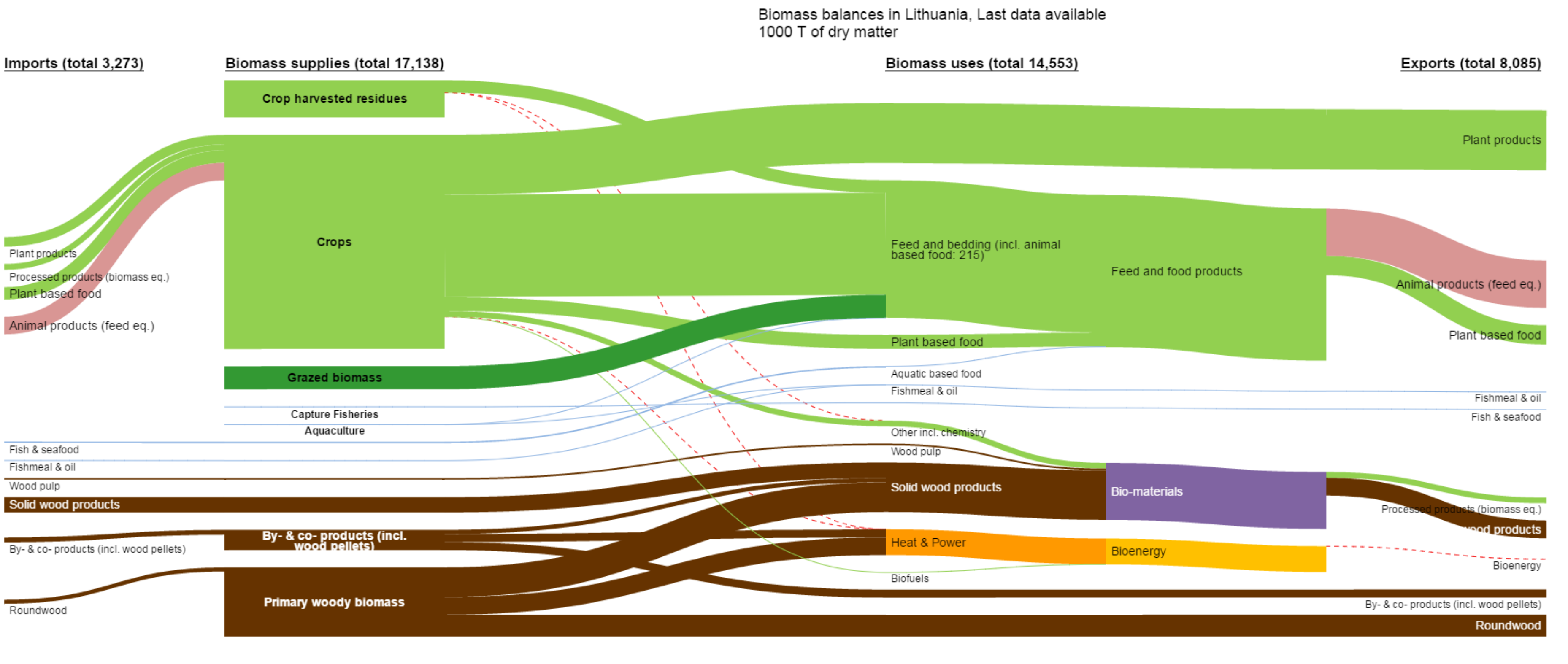
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Latvia, Full trade



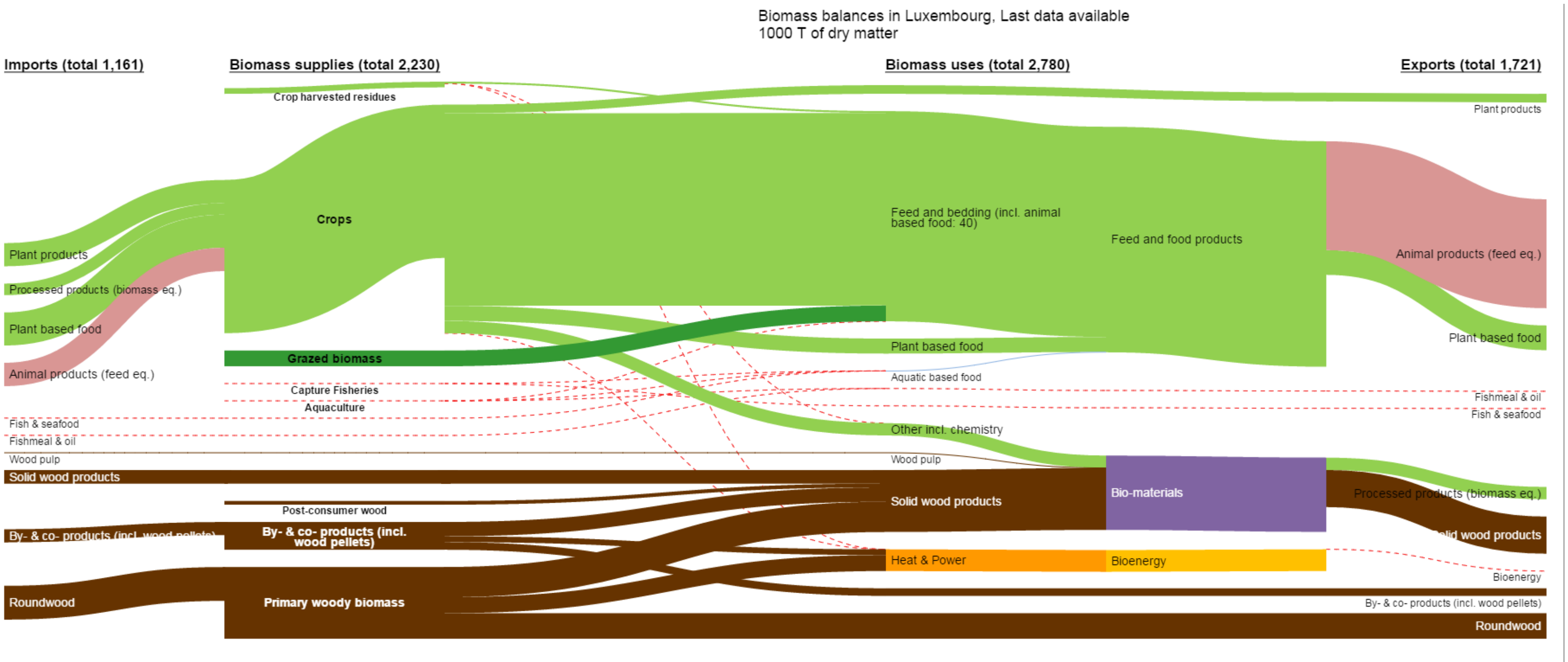
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Lithuania, Full trade



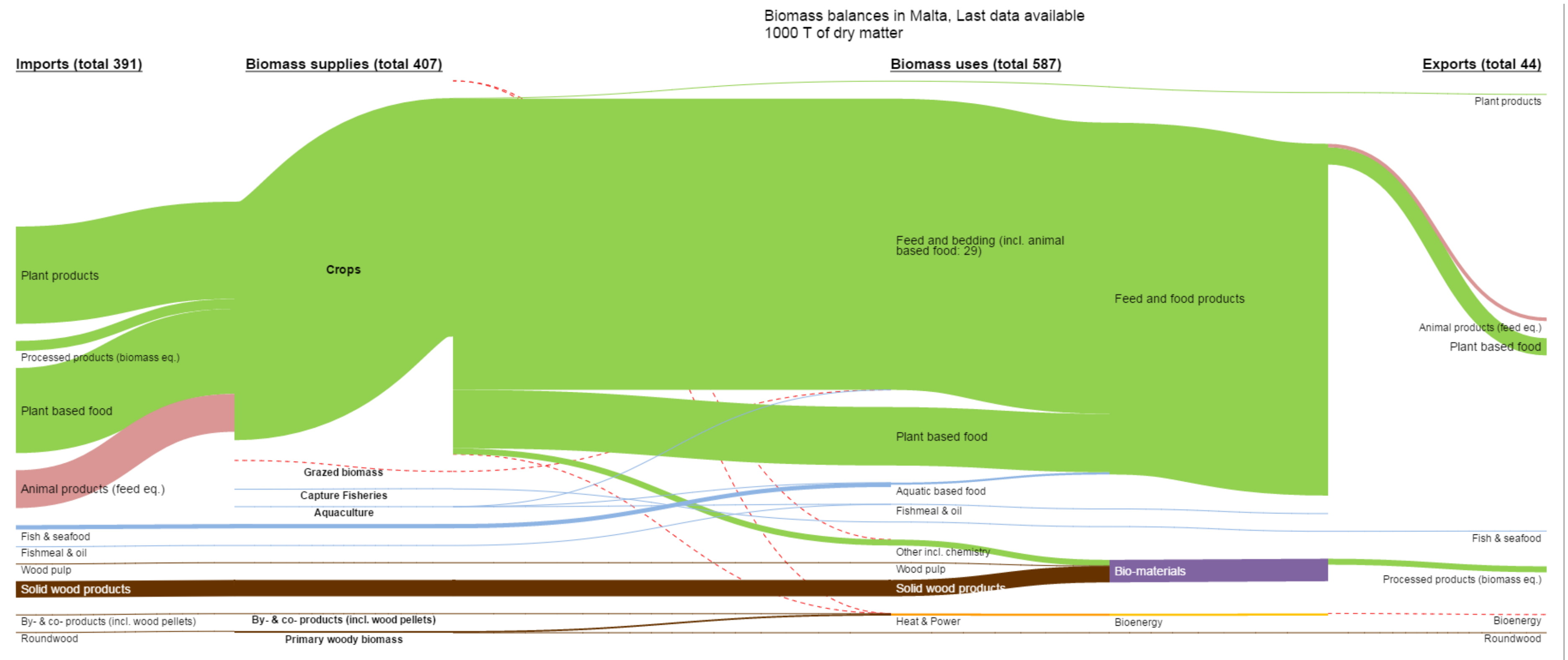
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Luxembourg, Full trade



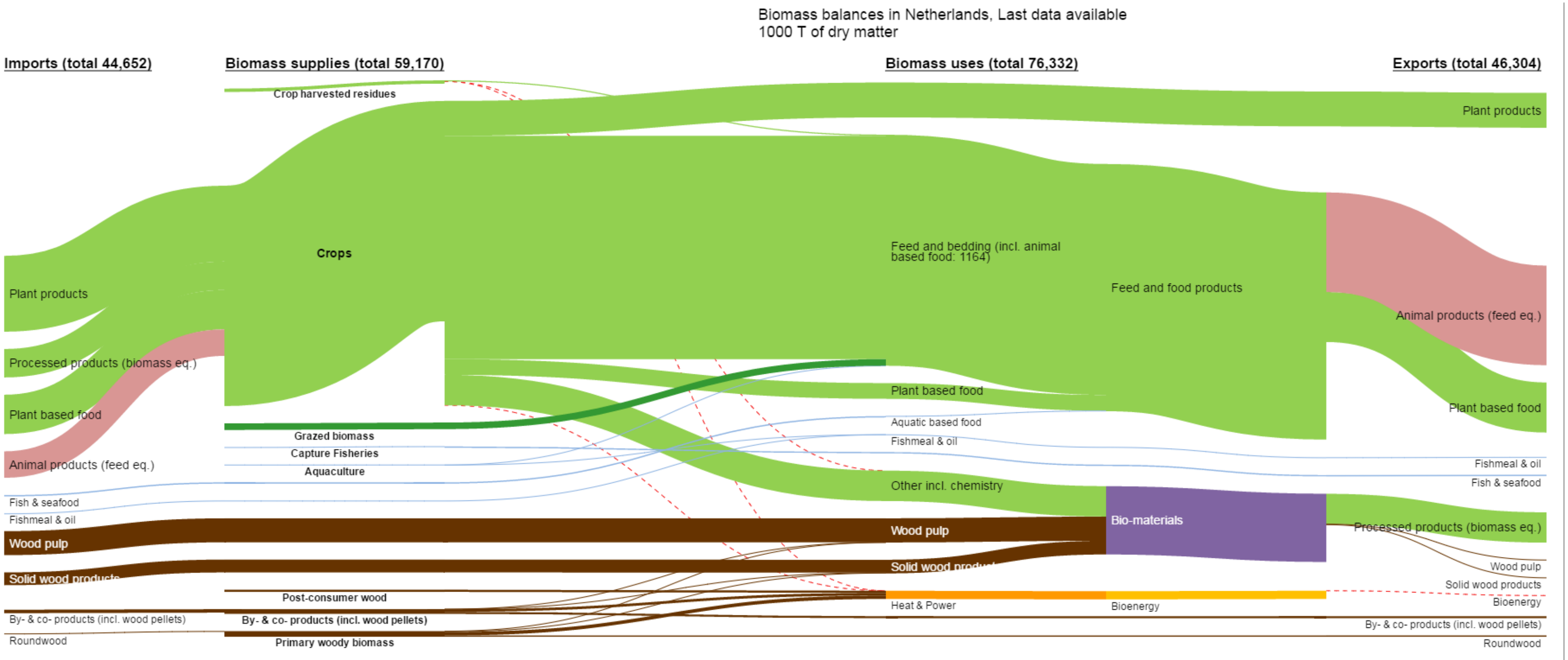
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Malta, Full trade



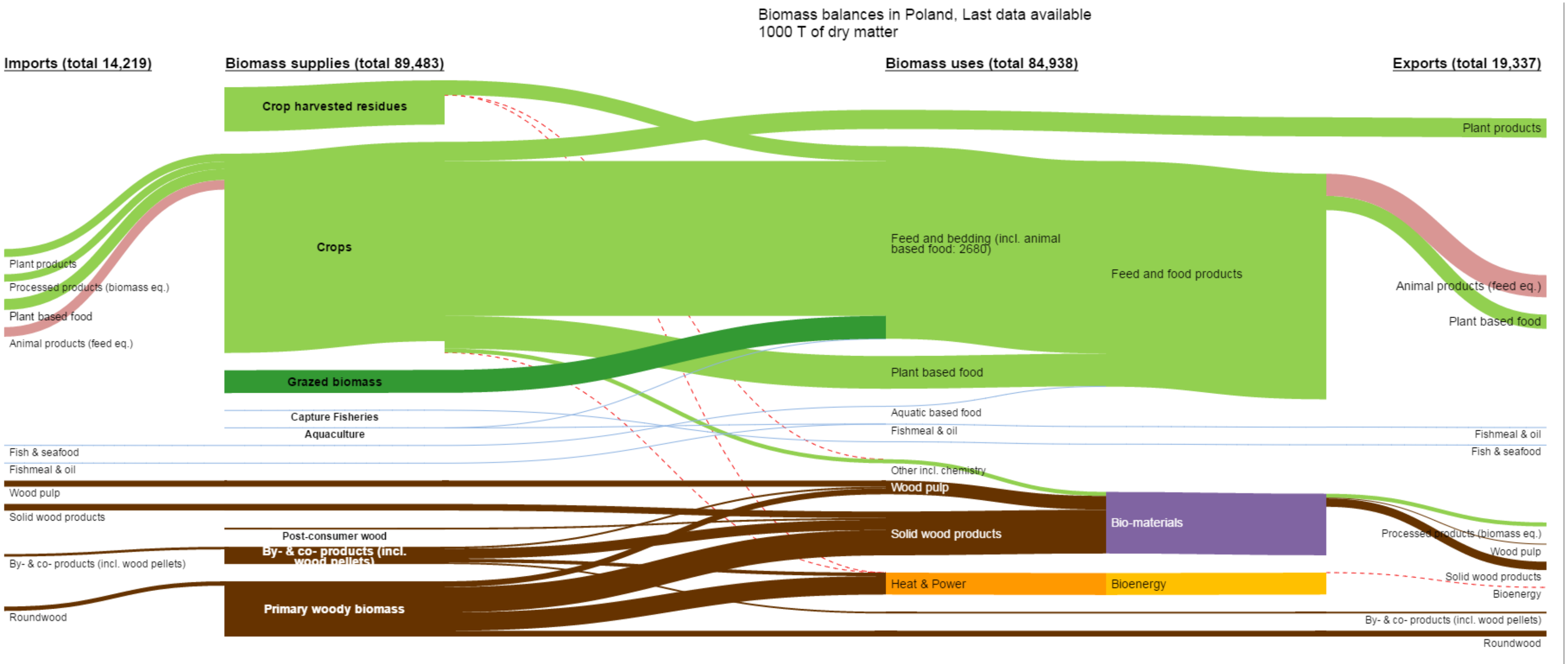
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

The Netherlands, Full trade



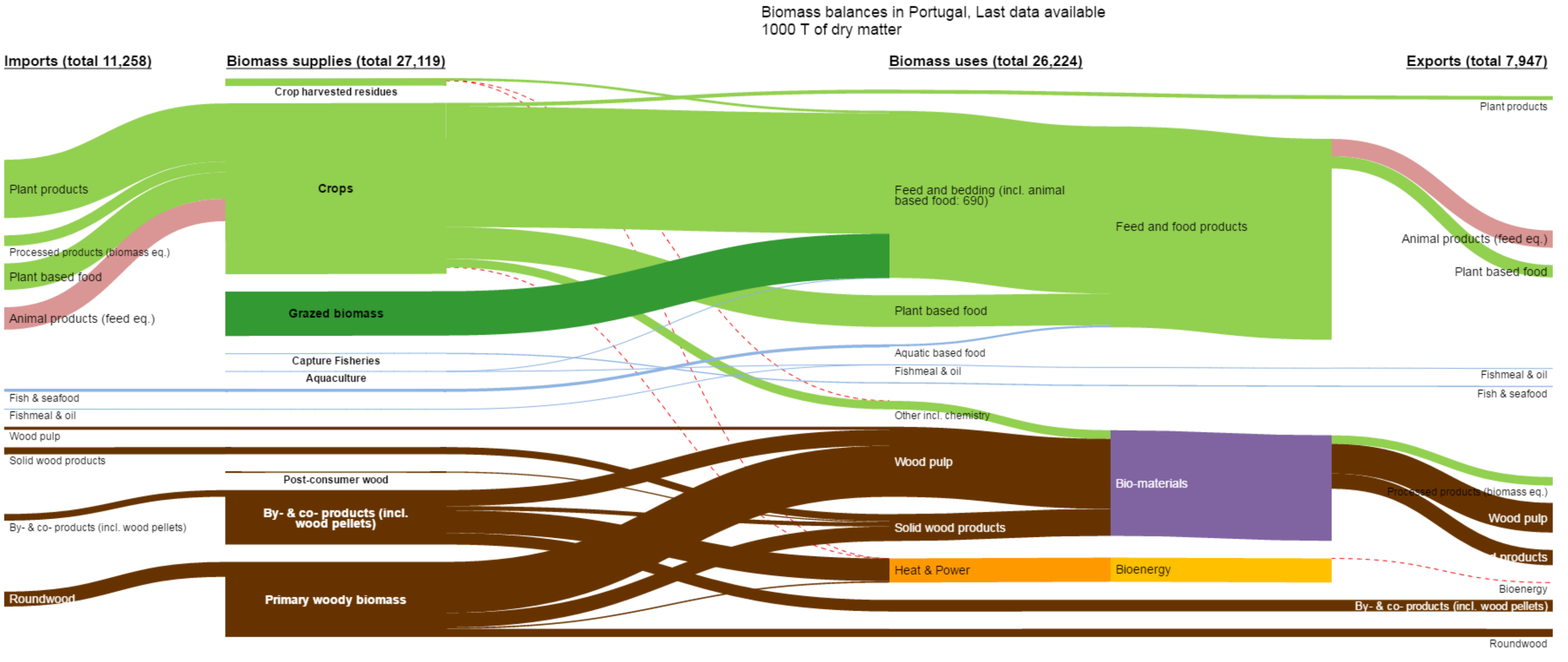
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Poland, Full trade



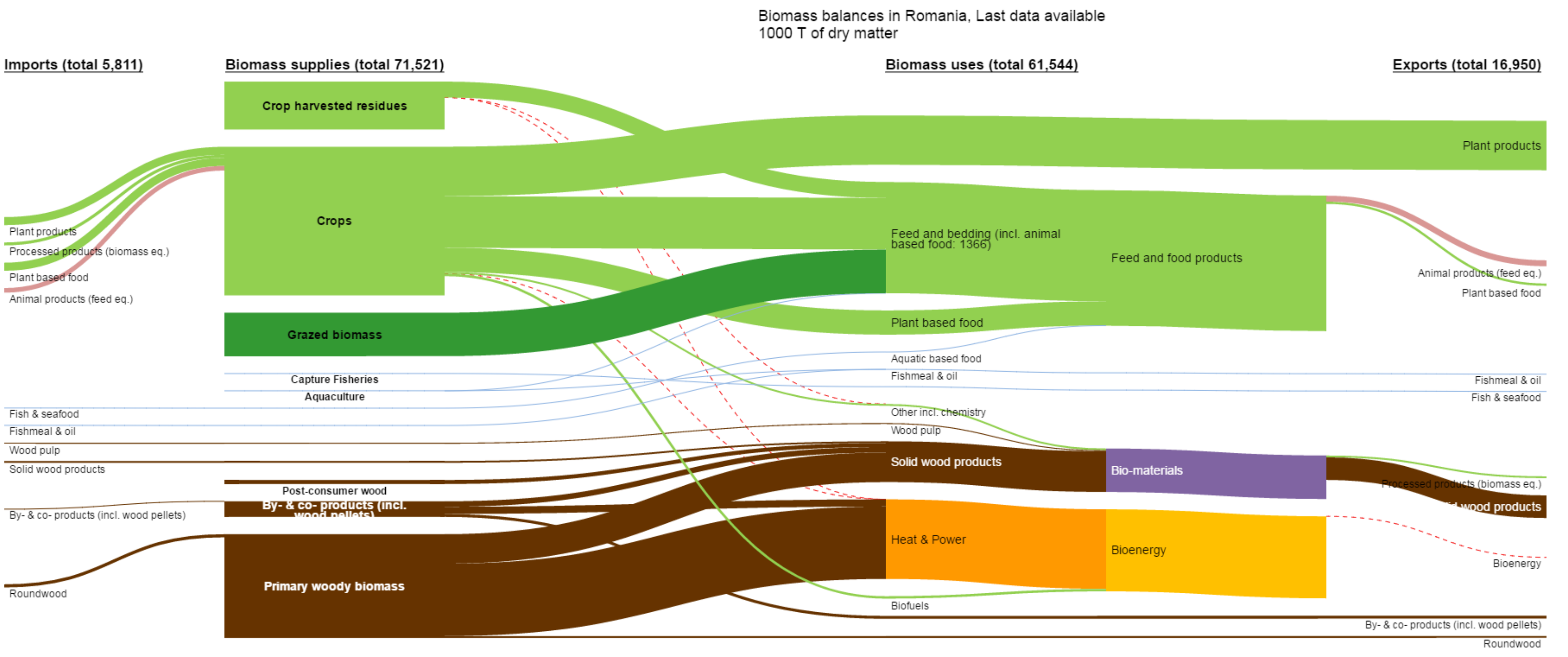
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Portugal, Full trade



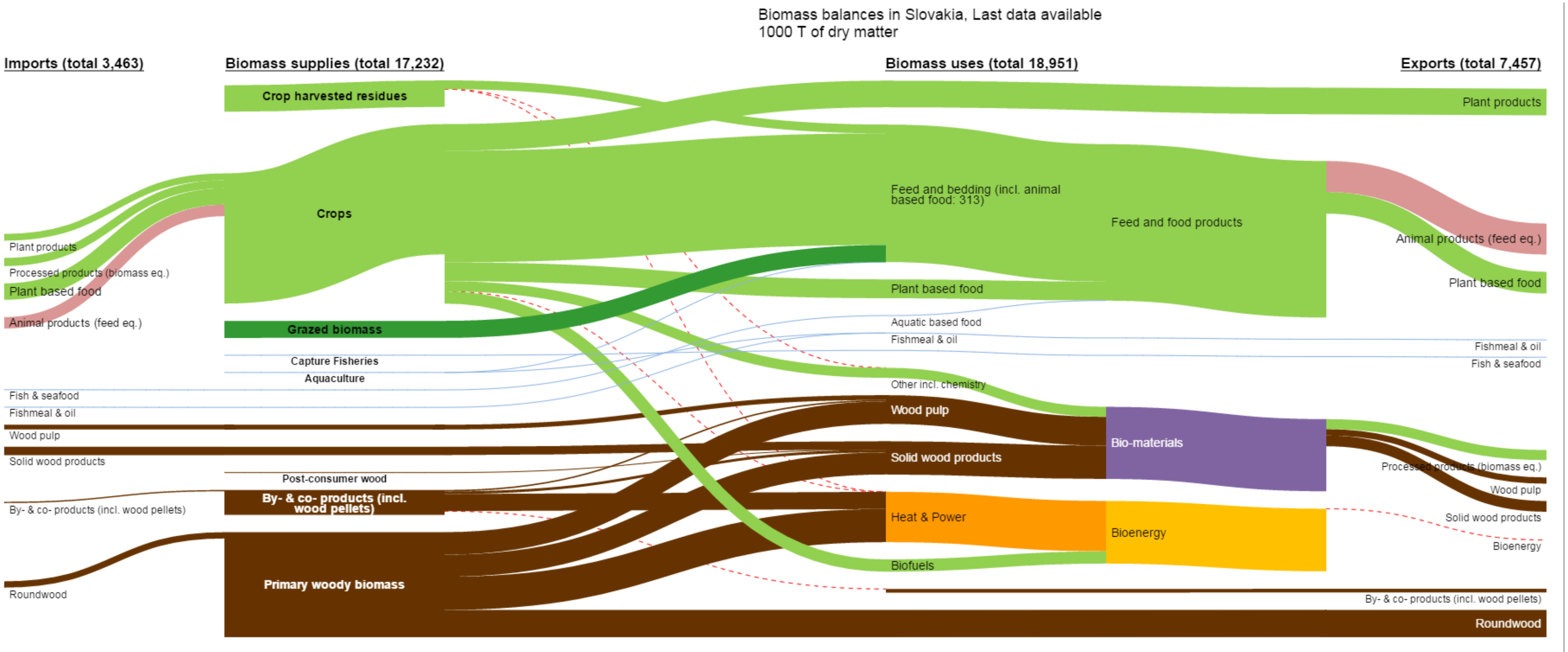
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Romania, Full trade



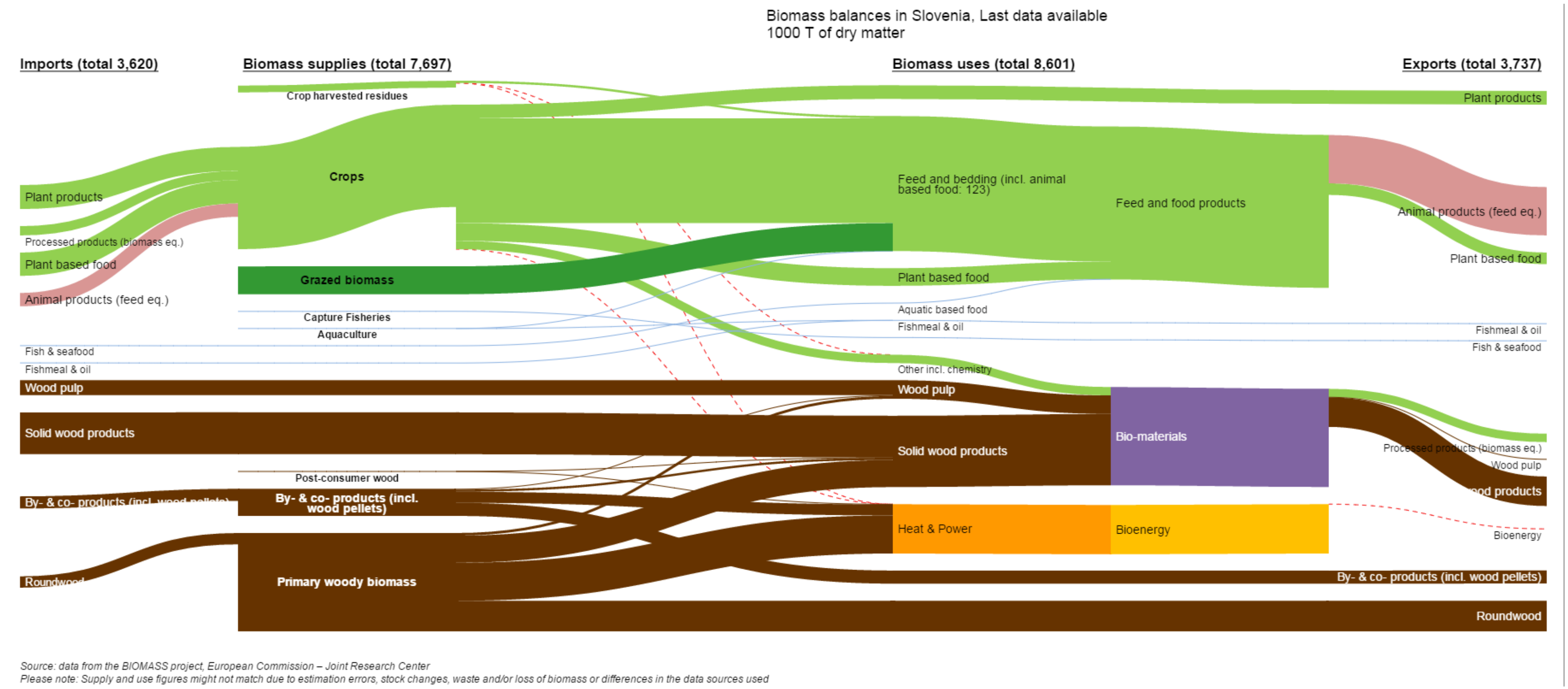
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Slovakia, Full trade

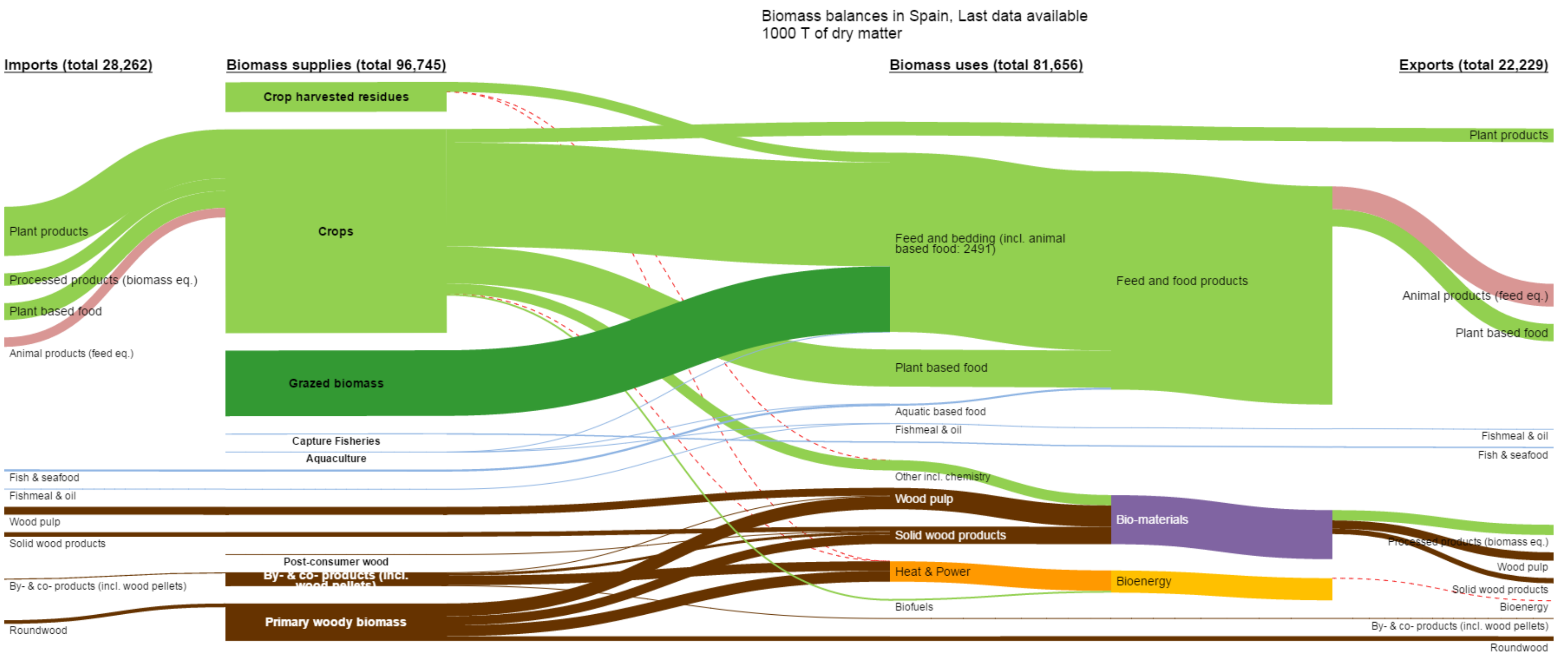


Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Slovenia, Full trade

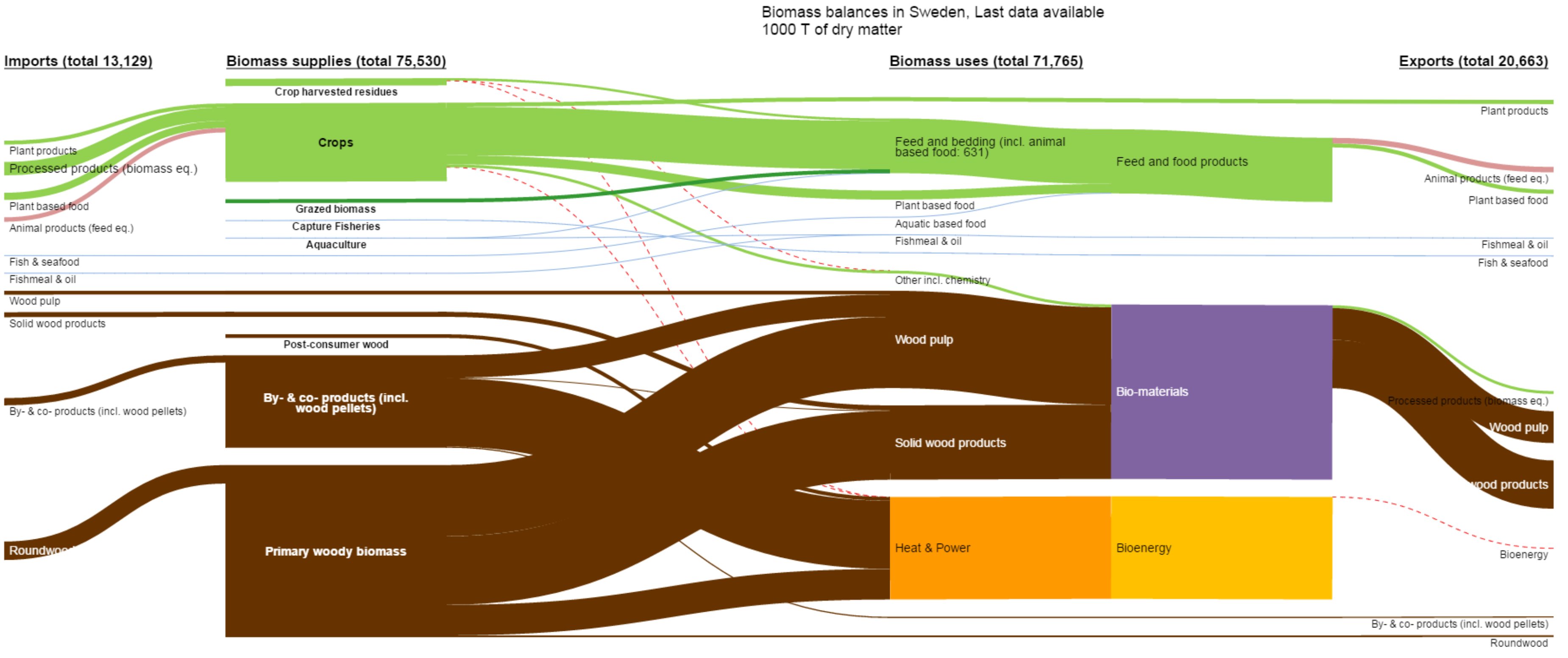


Spain, Full trade



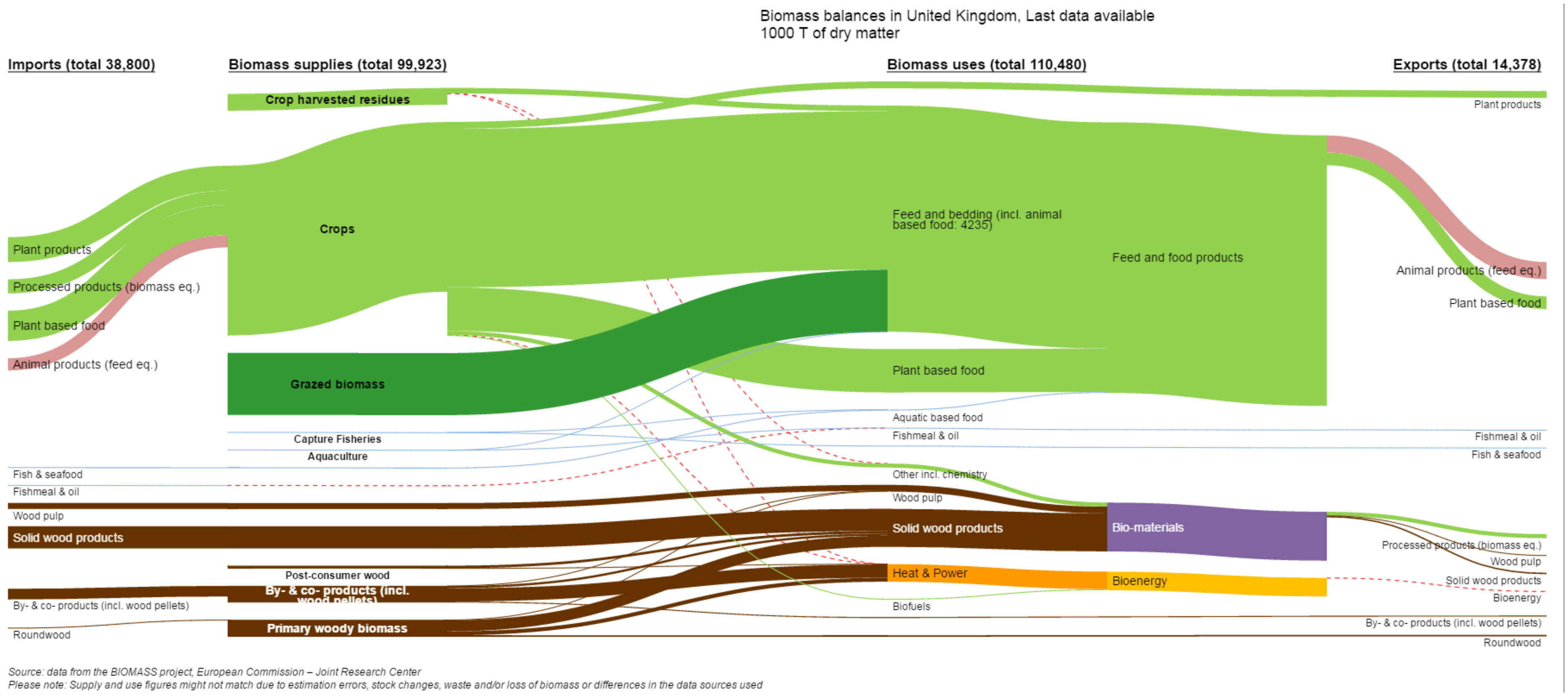
Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

Sweden, Full trade



Source: data from the BIOMASS project, European Commission – Joint Research Center
Please note: Supply and use figures might not match due to estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used

United Kingdom, Full trade



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