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Providing Insights into the Markets for Bio-Based Materials with BioMAT

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Abstract: Knowledge-based policy making in the field of bio-based economy needs two elements: (i) a monitoring system for assessing the historical developments of bio-based industry and (ii) foresight capacities to provide prospects for the bio-based industry in the future and how it can contribute to achieving different targets. However, significant knowledge gaps in both areas exist, especially regarding the markets of bio-based materials in general and bio-based chemicals in particular. Against this background, a new consistent framework for the representation of the value chains of bio-based materials in the EU and its Member States is developed, i.e., BioMAT. This article aims to present the BioMAT database which (i) is used to track historical developments in the markets for bio-based chemicals and the demand for feedstocks and (ii) enables the construction of the BioMAT model to make future projections. The developed BioMAT database compilation procedure is described in detail. Results reveal that the production of bio-based chemicals in the EU reached 43 million tons or 14% of the total output volume of the organic chemical industry in 2018. The main application of bio-based chemicals is biofuels, followed by agrochemicals and surfactants. The main feedstocks are plant oils and starch.

Keywords: BioMAT; bio-based chemicals; material flow database; biomass use; bioeconomy

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1. Introduction

Shifting from fossil-based to bio-based feedstocks in the production of chemicals and other products reduces the dependency of an industry on non-renewable resources. At the same time, it can contribute to the reduction in greenhouse gas emissions and the achievement of other environmental and sustainability targets. A number of policy initiatives at the EU level such as the updated EU Bioeconomy Strategy [1] and the European Green Deal [2] emphasize the potential positive effects associated with the production of bio-based products in general. Moreover, other initiatives such as the "EU policy framework on biobased, biodegradable and compostable plastics" [3], have a more specific focus and aim at promoting the adoption of specific bio-based products. Bio-based chemicals are inputs for the production of many bio-based products and, therefore, are directly or indirectly addressed by different policy initiatives on bio-based products in most cases. For example, bio-based polymers produced by the chemical industry are used for the production of bio-based plastics, which in turn are inputs for the automotive or toy industries.

However, despite the expected positive effects associated with the replacement of fossil-based by bio-based feedstocks in the production of chemicals and other materials, negative effects can still occur. For example, a substantial expansion of the bio-based industry would require a considerable increase in the demand for biomass resources as production inputs and by further expansion of biofuels use (including the associated increase in the demand for biomass resources) would lead to tensions in the markets for certain biomass feedstocks or crops. Thus, the lack of a well-designed expansion of the bio-based industry could have negative effects on land use, biodiversity and food security [4]. Therefore, in order to guide policy making in the area of the bio-based economy, it is necessary to consider both the positive and negative aspects associated with the expansion of the bio-based economy. In other words, it is not enough to focus only on the bio-based industry itself; its linkages with the rest of the economy and in particular with the sectors that supply biomass as a feedstock, i.e., agriculture, aquaculture and forestry, must certainly be considered.

Knowledge-based policy making should be based on two pillars. The first one is the monitoring system that enables the assessment of the evolvement of bio-based industry and its past impacts and delivers a clear picture of the current situation. The second pillar regards foresight capacities, including quantitative models, which show what prospects bio-based chemicals and other materials can have in the future, how they can contribute to achieving different targets and how policy can help to follow a sustainable transition path [5].

At the EU level, in 2020, the European Commission (EC) through the Joint Research Centre launched the EU Bioeconomy Monitoring System [6]. Additionally, there are some initiatives to set up a national bioeconomy monitoring system at EU member state level [7–10]. Despite all these efforts, significant information gaps, especially with respect to bio-based materials and bio-based chemicals, remain. The main reason for this is that the required data is still missing in the official statistics. A number of projects and studies have emphasized this problem and tried to improve the situation by: (i) providing an overview of bio-based chemicals and their respective value chains; (ii) collecting or estimating some data for selected products; and (iii) applying different methodologies to estimate figures for the existing data gaps [11–17]. However, most of these studies either provide information on a very aggregated level or narrow their focus to the most relevant products and value chains but do not cover the whole bio-based production (i.e., bio-based production of the total chemicals industry). Commissioned by the Bio-based Industries Consortium (BIC), the report series "European Bioeconomy in Figures" [17] stands out from the available literature and provides some original and up-to-date data on the EU bio-based industry each year. However, it focuses mainly on the monetary value of bio-based production, associated value added and employment. Only the latest report published in autumn 2022 provides some data on production volumes. To sum up, at the time of writing this paper, there is no comprehensive and consistent database comprising basic information on production, trade and use of bio-based chemicals and other materials as well as the associated demand for bio-based feedstocks for individual EU member states and the EU27. Regarding foresight capacities, the review of existing tools reveals that bio-based materials and especially bio-based chemicals are poorly covered in the existing models [18]. The lack of a suitable database for bio-based chemicals and other materials is presumably the major obstacle.

In order to overcome the knowledge gaps mentioned above, a new consistent framework for the representation of the value chains of bio-based materials in the EU and its Member States is developed. This framework, named **BioMAT** (Bio-based MATerials), comprises two elements: (i) a comprehensive database (the **BioMAT database**); and (ii) a multi-regional partial equilibrium model (the **BioMAT model**).

The aim of this article is to present the BioMAT database which is not only used to track historical developments on markets for bio-based chemicals and the associated demand for bio-based feedstocks, but also as the basis for the construction of the BioMAT model. For this purpose, firstly, the concept of BioMAT is briefly presented. After that, the BioMAT database compilation procedure is described in detail. In the 'Results' section, historical developments based on the BioMAT database are presented and discussed. Finally, the paper closes with some discussion on the potential and limitations of BioMAT and draws some conclusions.

2. Materials and Methods

2.1. The Concept of BioMAT

BioMAT (Bio-based MATerials) is a newly build consistent framework representing value chains of bio-based materials in the EU and its Member States. It comprises two elements: (i) a comprehensive database (the **BioMAT database**); and (ii) a multi-regional partial equilibrium model (the **BioMAT model**).

The main source of inspiration for the development of BioMAT was the experience gained with the construction of the database and the subsequent modelling of the agri-food value chains in **AGMEMOD** (**AG**riculture **ME**mber state **MOD**elling) [19]. In general terms, AGMEMOD focuses on value chains in the agri-food sector at the EU member state level, starting with the distribution of land to different types of agricultural activities, through crops production and animal husbandry to the processing and distribution of agricultural output to different types of use (food, feed, seeds, trade, stocks, material and energy use). In a similar fashion, BioMAT has been designed to represent stylized bio-based product value chains. It starts with capturing biological feedstocks in the form of raw materials and their first processing step used for the production of bioenergy and bio-based materials, and moves downstream the stylized bio-based value chains through some intermediate steps to predefined product groups, mainly bio-based chemicals. Some main agricultural feedstocks covered in BioMAT (starch from wheat, corn and potatoes, sugar and plant oils) overlap with agricultural products that are available for material use in AGMEMOD (wheat, corn, potatoes, sugar beets and oilseeds) and, therefore, it is possible to 'link' both models and use BioMAT as an extension of AGMEMOD. AGMEMOD 'ends' with reporting on the quantities of wheat, maize, potatoes, sugar and plant oils available for energy and material use, while BioMAT takes it over, showing how they are utilized along predefined bio-based value chains for production of specific bio-based materials and bioenergy. Figure 1 presents the processing routes of the stylized bio-based value chains that are covered in BioMAT, with some details regarding agriculture feedstocks relevant for the linkage with AGEMEMOD.

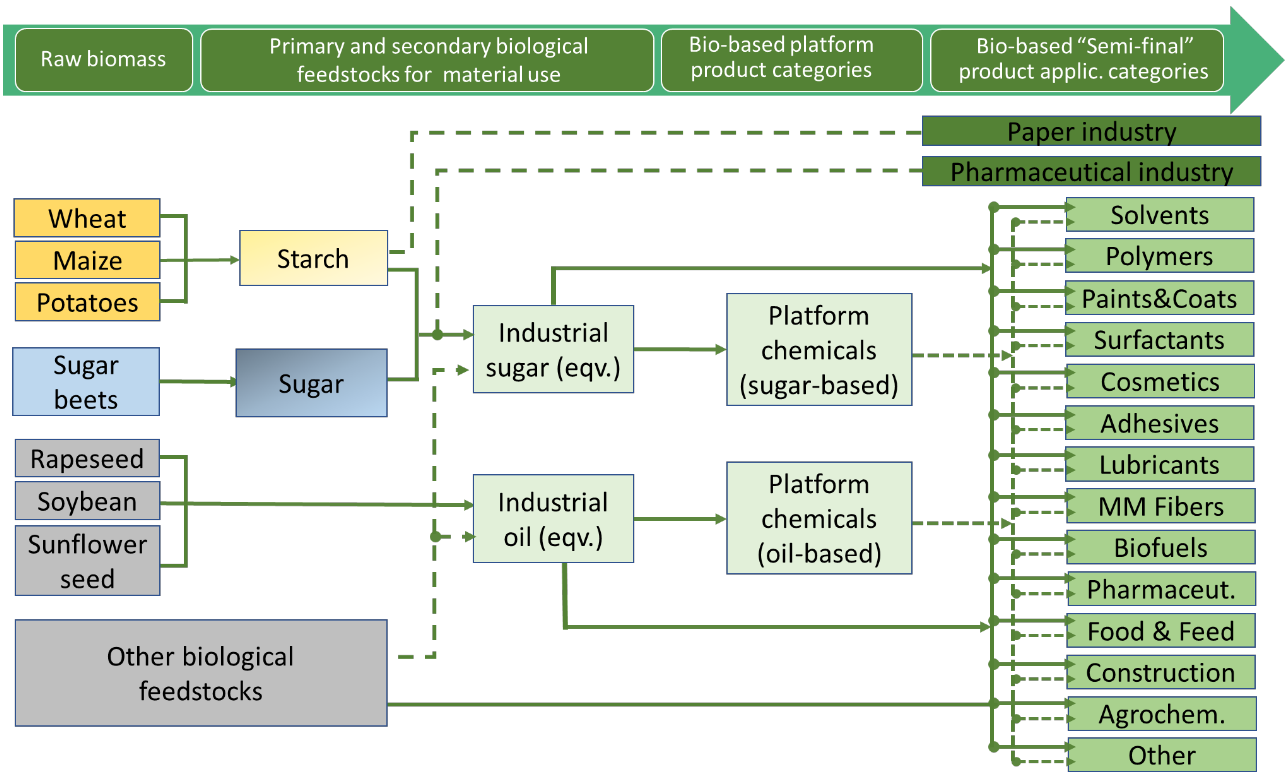


Figure 1. Bio-based value chains covered in BioMAT.

BioMAT depicts reality in a simplified way, focusing on a set of stylized bio-based value chains and markets for predefined product groups. This is so due to two facts. Firstly, there is a large number of bio-based products (bio-based chemicals) and it is impossible to depict the market developments for every single product. In official statistics, the production of chemicals is reported under the NACE C20 category, which includes over 550 codes, each of those referring to one or more chemical products, with often different positions in the value chain. Secondly, policy initiatives often address specific product categories; therefore, the grouping of bio-based chemicals according to their applications not only simplifies the analysis but also delivers insights in a way that is closely related to the areas of interventions of policy makers.

The BioMAT database and the BioMAT model are conceptualized to go hand-in-hand. Whereas the BioMAT database provides a clear picture of historical developments on the markets of bio-based products and tracks the use of feedstock in its recent history, the BioMAT model uses this information and projects their future developments. Being an economic model, BioMAT reflects in its projections the influence of demand and supply drivers and the policy framework. Further details on the key features of the BioMAT model are in the published model description [20]. In the context of the BioMAT model, the key explanatory drivers of the developments of the bioeconomy are economic and demographic factors, technological changes, consumer preferences, climate change, land availability and policy instruments. Thus, the full BioMAT database needs to include information related to those key drivers, besides specific indicators to measure key aspects of the markets for bio-based product application categories and biological feedstocks.

2.2. Objectives and Structure of the BioMAT Database

The **BioMAT database** is a comprehensive and consistent database for the EU member states and EU27, developed to fulfil two objectives:

- Firstly, to enable an assessment of the historical market developments for bio-based materials, in particular bio-based chemicals. In addition, the associated demand for biological resources used as production input should be tracked, and a set of indicators should be calculated for the past and the current state;
- Secondly, to provide the relevant data that allows for the econometric estimation of the BioMAT model, a partial equilibrium model which aims to provide projections for the market developments of bio-based materials within the EU27.

Keeping in mind the framework introduced in Section 2.1, the following information should be gathered for the construction of the database:

- Indicators on the markets of bio-based product application categories: quantities on production, trade and use and economic data, i.e., prices and production costs of bio-based products (and fossil-based counterparts);
- Indicators on the use of biological feedstocks and their markets: quantities of individual biological feedstocks used by each bio-based product application category; technical restrictions regarding conversion rates; substitution possibilities between feedstocks; and economic data, i.e., feedstock prices;
- Statistical data to measure exogenous drivers, such as GDP, inflation rate, population, exchange rates and oil and gas prices, as well as data on the existing policy framework.

The BioMAT database is a multi-dimensional database. Overall, most variables have the following dimensions: (i) time, e.g., 2000, 2001, etc.; (ii) region, e.g., The Netherlands, Germany, etc.; (iii) product application category, e.g., polymers for plastics, surfactants, etc.; and (iv) biological feedstock type, e.g., sugar, starch, etc. However, some variables have only a time dimension, e.g., the USD–EUR exchange rate, or two dimensions, e.g., GDP and population developments in different countries over time. The BioMAT database is designed to provide information on an annual basis, which is in the current version for the years 2008–2018. Table 1 provides an overview of the different categories that are included in each dimension. More explanatory details for chemical application categories and biological resources are in Appendices A and B, respectively.

Table 1. Dimensions of the BioMAT database.

Countries/Regions (c)	Chemical Application Categories (k)	Biological/Bio-Based Feedstock Types (j)
Austria,	Platform chemicals	Sugar
Belgium–Luxembourg,	Solvents	Starch
Bulgaria, Croatia,	Polymers for plastics	Plant oils
Czech Republic, Cyprus,	Paints, coatings, inks and dyes	Lignocellulosic from forestry
Denmark, Estonia,	Surfactants	Lignocellulosic from agriculture
Finland, France,	Cosmetics and personal care products	Animal biomass
Germany, Greece,	Adhesives	Aquacultures
Hungary, Ireland, Italy,	Lubricants	Other primary biological resources
Latvia, Lithuania,	Man-made (MM) fibers	Sugar-/Starch-based platform chemicals
Malta, The Netherlands,	Biofuels	Oil-based platform chemicals
Poland, Portugal,	Pharmaceuticals	Bio-naphtha
Romania, Slovenia,	Food and feed	
Slovakia, Spain,	Construction	
Sweden,	Agrochemicals	
United Kingdom	Other applications	

2.3. STEP-By-STEP Description of the BioMAT Database Compilation Procedure

Unfortunately, there are no official statistical sources providing all needed information in a consistent way. Building the BioMAT database required not only collating data from various sources (official statistics, literature reviews and expert knowledge) but also the further processing of data. More specifically, the BioMAT data compilation procedure is organized in the four steps as described in Figure 2.

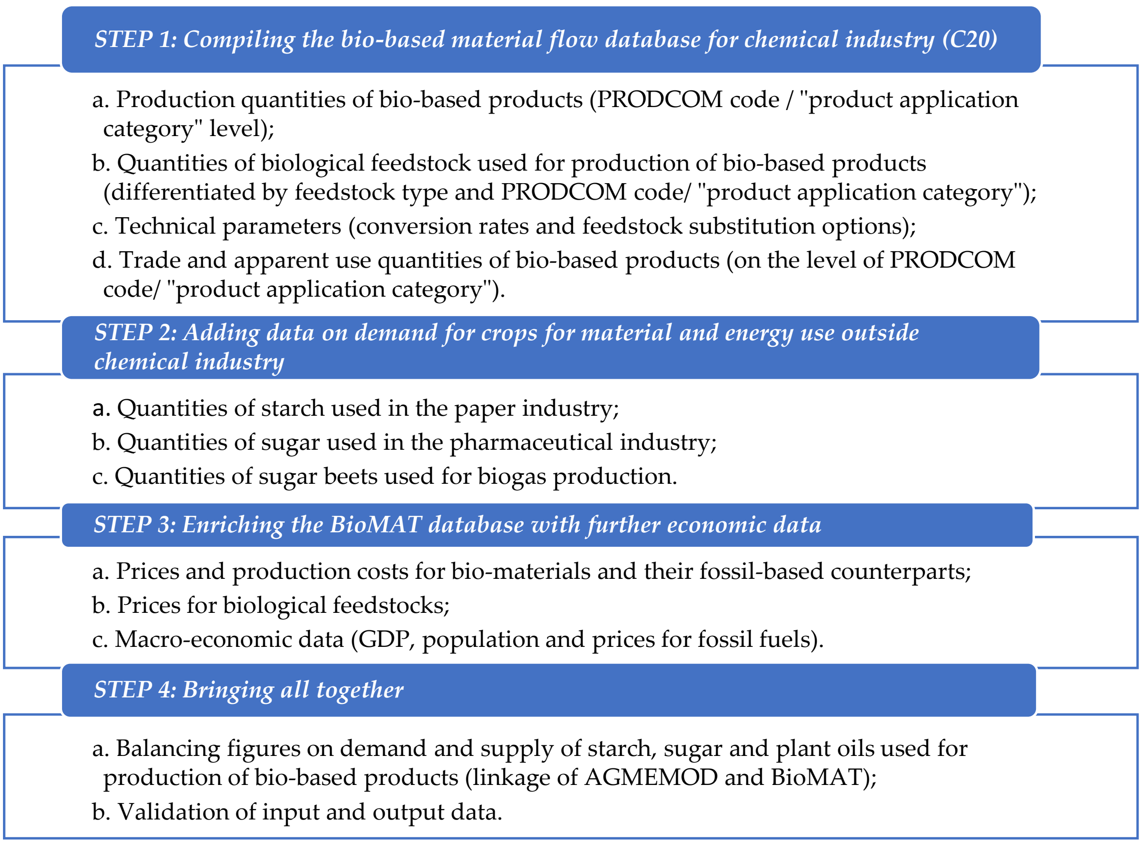


Figure 2. Steps in BioMAT data compilation procedure.

2.3.1. STEP 1: Compiling the Bio-Based Material Flow Database for Chemical Industry (C20)

Framing the Scope

The newly compiled database on bio-based material flow for the chemical industry is the key element of the BioMAT database. It delivers information in terms of physical quantities regarding:

- The total demand for biological feedstocks by the chemical industry;
- Their utilization along predefined value chains for the production of different products;
- The supply and use of bio-based chemicals within predefined product application categories either as semi-final products or as intermediate input for the production of other chemicals.

This information can be used for the creation of material flow diagrams (Sankey diagrams) and for the calculation of a set of bioeconomy indicators (e.g., average feedstock conversion rate, bio-based share in production and use of product application categories).

In addition, the compilation procedure of the database on bio-based material flows for the chemical industry is designed to comply with the following two requirements:

- Official statistics should serve as a starting and focal point to enable the continuation and updating of the database in future as well as to safeguard the consistency;
- It should be possible to process it directly for use in BioMAT.

The first requirement is fulfilled through the use of European official statistics on the production and trade of manufactured goods (PRODCOM [21], SBS [22] and COMEXT [23]) as primary sources of data. These statistics are very comprehensive, regularly updated and available at the level of the EU member states for a number of years.

The information on the production of manufactured goods (PRODCOM) is provided at the 8-digit level codes used in PRODCOM, which are linked to the 4-digit NACE codes (from 2008 onwards NACE Rev. 2). In NACE Rev. 2, section "C" covers "Manufacturing" and division "20" covers "Manufacture of chemicals and chemical products". We use the term "C20" to refer to the products associated with production activities "Manufacture of chemicals and chemical products" or simply "chemical industry". Official statistics provide consistent information on production and trade at the level of PRODCOM codes; therefore, we work with data at this disaggregation level. There are 563 PRODCOM codes grouped under C20, each of which covers one or more different chemical products.

Although the PRODCOM and COMEXT statistics are very comprehensive and regularly updated, they have still significant gaps. The main reason is the confidentiality issue of data reporting. For example, some product data are reported only at the level of the EU (total) but show gaps at the level of individual EU member states. To close the mentioned gaps, data from the official production and trade statistics for the C20 PRODCOM codes were first subjected to data imputation techniques (e.g., outlier detection, regional and product harmonization procedures and the entropy method) before being used for data generation [24].

The second requirement refers to the direct use of the database on bio-based material flows for the chemical industry in the BioMAT model. A key aspect in this regard is the harmonization of dimensions. Temporal (year), regional (country) and "biological/bio-based feedstock type" dimensions in the database on bio-based material flows for the chemical industry are the same as in the BioMAT database, Table 1. It was more challenging to make a "product" dimension of the database on bio-based material flows for the chemical industry aligned with that of the BioMAT model. The BioMAT model needs data at the level of the product application category, Table 1, whereas the PRODCOM statistic, which is the main source for data, provides information at the level of PRODCOM codes (a much more disaggregated level; however, with another grouping concept). To overcome this mismatch, a mapping technique has been applied within the database generation procedure.

Database Generation Procedure

As already mentioned, official statistics on the production of manufactured goods (PRODCOM) together with related external trade data (based on COMEXT) are the main data sources. As these sources provide insufficient information to generate the pursued bio-based material flow database, further information is incorporated to enable the construction of the bio-based material flow database. Before describing the technical side of the database generation procedure, we elaborate on the need for integration of additional data and how these are obtained.

Information on bio-based shares at the level of PRODCOM codes. Information on bio-based production, trade and apparent use cannot be directly extracted from the PRODCOM statistics in most cases. There are two reasons for this. Firstly, some bio-based products produced exclusively from bio-based raw materials (for example, PLA and lactic acid) do not have own dedicated PPRODCOM codes and are captured under PRODCOM codes that cover a number of different products [10,24,25]. Secondly, some products are produced from bio-based as well as from fossil-based feedstocks (for example, polyethylene glycol and lubricants) but are reported under the same PRODCOM code, as the structure of PRODCOM statistics does not foresee the distinction of products with respect to the type of feedstock. In order to overcome this problem, we incorporate information on bio-based shares for individual PRODCOM codes of C20 compiled by the nova-Institute [25,26]. Based on market monitoring, literature review and interviews with relevant industry stakeholders, quantities of bio-based production were estimated and then translated into bio-based shares for PRODCOM codes. Such a procedure helps to overcome confidentiality issues to some extent, but not completely. Thus, this database is not freely available and is subject to confidentiality in its full extent. The datasets on bio-based shares are available upon request for 2008.

Mapping matrix of PRODCOM codes to BioMAT application categories. Chemical products produced under PRODCOM codes can be used either for semi-final uses or as intermediates. These intermediates are inputs for producing other chemicals. It is essential to have such a distinction by the construction of the bio-based material flow database. It helps to track the material flow within the sector and prevents double-counting, which is especially important for the calculation of the demand for different bio-based feedstocks by the chemical industry. In the BioMAT database, two product groups are classified as intermediates ("Sugar-/Starch-based platform chemicals" and "Oil-based platform chemicals"), while the rest are considered as semi-final use product groups/application categories, Table 1. Based on the insights from the literature review [13–15,27–38], expert knowledge and some own assumptions (e.g., for PRODCOM codes for which no detailed application data was found, an equal distribution is assumed over the mentioned applications), a mapping matrix was compiled, providing information to which application category(ies) the output of each PRODCOM code must be assigned.

Mapping matrix of bio-based feedstocks to PRODCOM codes with the respective conversion rates. The bio-based material flow database aims to show which quantities of different biological feedstocks are used for the production of bio-based chemical products. There is no source providing such information for the EU countries either at the level of application categories or the PRODCOM code level. Therefore, such a database was compiled based on insights from the existing literature [13–15,27–42], expert knowledge and own assumptions. For example, for products produced via a fermentation process, it is assumed that both starch and sugar are used equally, as long as no additional information is available. Similarly, an equal distribution between the use of animal fats and plant oils is assumed when both can be used. Furthermore, the conversion rate for industrial by-products is assumed to be 0 to avoid double-counting; secondary feedstocks such as used cooking oil for biodiesel production are assumed to have a conversion rate of 1, and since it requires biomass for its production it is classified under the "other" category. The dry matter content for PRODCOM codes is included in the conversion ratio. The mapping matrix indicates the importance of different biological feedstocks for each PRODCOM code; respective conversion rates (based on stoichiometry including some losses) specify which quantity of feedstock (in tons) is required for the production of one ton of a PRODCOM product output. Combined, these data are used to calculate the demand for different types of bio-based feedstocks at the individual PRODCOM code level of C20.

Figure 3 explains the step-by-step procedure applied to generate the bio-based material flow data. The steps are applied for each EU member state, point of time and each PRODCOM indicator (production, imports and exports). As the statistics do not directly report on domestic uses, this variable is considered to be the element that closes the market at the country, product group and year levels. Thus, it is calculated in the additional fourth step via "Apparent use" = "Output" + "Import" − "Export".

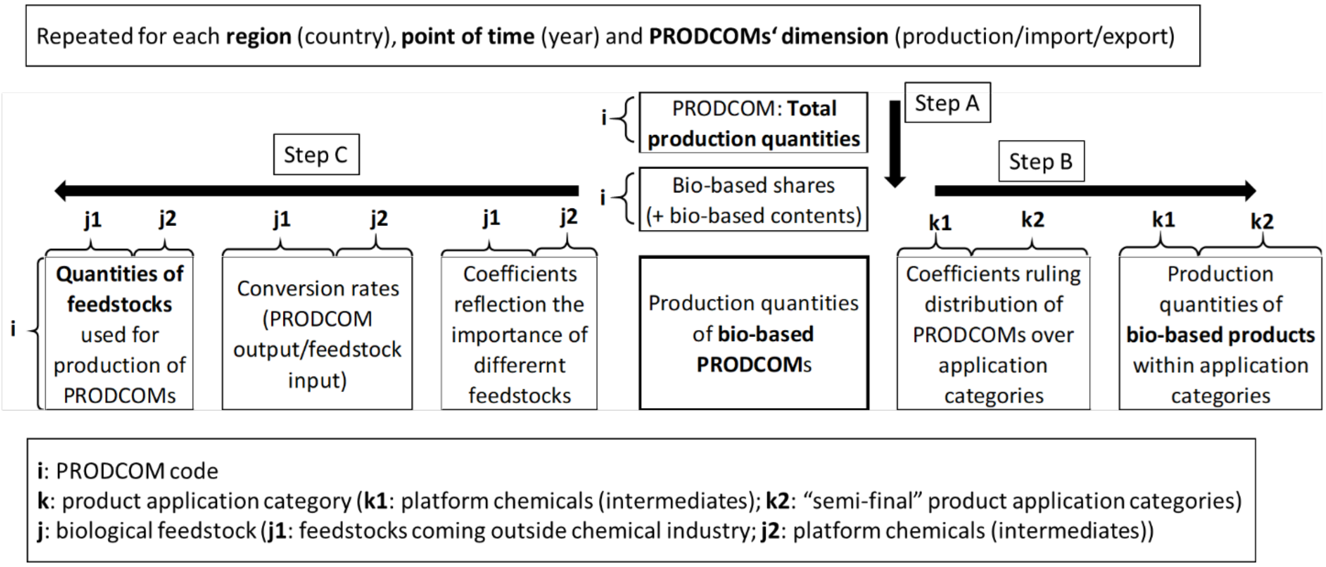


Figure 3. Database generation procedure for bio-based materials based on PRODCOM statistics.

In *Step A*, the PRODCOM statistics for production (as well as imports and exports) quantities are combined with the information on bio-based shares at the level of PRODCOM codes to calculate the bio-based production (and bio-based imports and exports) quantities for each PRODCOM code.

In *Step B*, the bio-based production (imports/exports) quantities from individual PRODCOM codes are distributed over different application categories. A mapping matrix of PRODCOM codes to the distinguished application categories is used. This matrix consists of coefficients that indicate the importance of each application category for each PRODCOM code. The sum of coefficients over all application categories for each PRODCOM code is equal to one. The multiplication of the bio-based production (import/export) quantities of each PRODCOM code with coefficients ruling the distribution over different application categories results in quantities of bio-based production (imports/exports) for each application category associated with production activities covered by individual PRODCOM codes. Summing up, all these quantities over all PRODCOM codes quantifies the total bio-based production (imports/exports) within each individual application category.

In *Step C*, the quantities of the different biological feedstocks used for bio-based production within each individual PRODCOM code are calculated. A mapping matrix of biological feedstocks to PRODCOM codes with their respective conversion rates is used. This mapping matrix consists of coefficients reflecting the importance of different feedstocks for each PRODCOM code, where the sum of coefficients over all biological feedstocks for each PRODCOM code equals one. An additional matrix on conversion rates determines how much of an individual feedstock is needed to produce one unit of bio-based output by individual PRODCOM codes. The multiplication of the bio-based production of each PRODCOM code with coefficients reflecting the importance of the different feedstocks within each PRODCOM code and their respective conversion rates results in the quantities of the individual biological feedstocks used for the production of bio-based products within each PRODCOM code. Finally, the quantities of different feedstocks used to manufacture bio-based products for each product application category are calculated (using the mapping matrix of PRODCOM codes to the application categories and the summation over the individual product application categories).

In *Step D* (not shown in Figure 3), the quantities of apparent domestic use are calculated ("Apparent use" = "Output" + "Import" − "Export"). Data on apparent use are calculated for each PRODCOM code as well as for each application category.

2.3.2. STEP 2: Adding Data on Demand for Crops for Material and Energy Use Outside the Chemical Industry

The amount of biomass from agriculture that is not used for food, seed and feed can be made available for energy and material use. The use of biological resources in the chemical industry is covered by the detailed bio-based material flow database for the chemical industry (C20) (see Section 2.3.1). STEP 2 focuses on the main uses of agricultural biomass outside the chemical industry (C20). This is needed to establish the link between the demand for agricultural crops for energy and material use on the one hand and their availability on the supply side provided by AGMEMOD on the other hand (see STEP 4 in Section 2.3.4).

The *material use* of agricultural biomass for the construction sector or production of polymers and man-made textiles does not occur directly, but through the intermediate use of bio-based materials processed by the chemical industry (C20). We assume that the additional demand for agricultural crops as feedstocks needed for the production of bio-based materials outside the chemical industry (C20) is limited to the use of starch by the paper industry and the use of sugar by the pharmaceutical industry.

Regarding the *use of starch by the paper industry* (C17), it is relevant to mention that the paper industry is an important consumer of starch and starch-based products, especially glues. Starch-based products are inputs to the paper industry from other sectors (e.g., starch-based glues are an output from the C20 chemical industry); therefore, the respective demand for starch is already covered by the demand from these sectors (e.g., C20). However, the paper industry also uses considerable quantities of starch as a direct input, which must be additionally considered in order to determine the total demand for material use of starch apart from its use in the chemical industry (C20). Since there are no official statistics on the direct starch use by the paper industry in EU countries, we have analyzed different sources providing information about the use of starch by the paper industry on national and EU level, i.e., information reported by associations which represent the starch industry (e.g., Starch Europe [43] for the EU and VGMS [44] for Germany) and associations which represent the paper industry (e.g., Cepi [45], Verband Deutscher Papierfabriken e.V. (VDP) or DIE PAPIERINDUSTRIE e.V. [46] in Germany), industry reports [47,48], other publications [12] and estimated data needed (see "Supplementary Materials").

In terms of the *use of sugar in the pharmaceutical industry* (C21), there is a need to highlight that official statistics on quantities of sugar used in the pharmaceutical industry are missing. Therefore, we estimate these figures based on the following consideration: sugar is used for the production of chemically pure sugar and also as a feedstock in fermentation processes. The production of chemically pure sugar is reported in the PRODCOM statistics. We assume that the figures on the production of chemically pure sugar are equivalent to the demand for sugar by this production activity. For the production of pharmaceutical products via fermentation, both chemically pure sugar and sugar in other forms and grades (i.e., starch-based sugars) can be used. Significant quantities of sugar are used in the pharmaceutical industry (C21), for example, for the production of amino acids such as lysine (mainly feed grade) and glutamic acid [10]. There are surely many more pharmaceutical products produced using sugar as a feedstock (e.g., vitamins, antibiotics, other drugs, etc.).

Using the available information, we estimated the lower bound of the total use of sugar in the pharmaceutical industry (see "Supplementary Materials").

The *use of crops for energy* is mainly associated with the production of biofuels and to a much lesser extent with the production of biogas. The production of biodiesel and bioethanol is reported within the chemical industry (C20) and is therefore included in the detailed bio-based material flow database for the chemical industry (C20). The production of biogas (biomethane) is, however, reported outside of C20. For the production of biogas, mainly liquid manure and maize silage or other fodder crops are used; to a much lesser extent, sugar crops are also used. In Europe, Germany is by far the most important producer of biogas, as two thirds of European biogas plants are located here [49]. There are no statistical surveys on the use of sugar crops in biogas production, but some es-timates for Germany exist [50] (see "Supplementary Materials").

Last but not least, in the context of material and energy use of crops outside C20, it is important to clarify the handling of **bio-naphtha** in BioMAT. Bio-naphtha is currently classified as a possible biological feedstock in BioMAT (see Table 1). From the description of PRODCOM statistics, it is not obvious whether the production of bio-naphtha is reported at all and, if it is, under which code the reporting takes place. Therefore, bio-naphtha is treated as a biological feedstock for C20, but its production and respective demand for biomass is not covered in the bio-based material flow database for chemical industry (Section 2.3.1). Currently, the BioMAT framework assumes that the respective demand for biomass as an input for bio-naphtha production is calculated separately based on data on production quantities of bio-naphtha, which should be obtained from different sources. At present, the production of bio-naphtha for material use is estimated to be almost equal to zero, though some companies have expressed their intention to increase the use of bio-naphtha as a feedstock for the production of chemicals in the future. Given the demand for bio-naphtha, its production in Europe could increase significantly over time with the corresponding increase in demand for biomass needed for its production. For the production of bio-naphtha, various types of biomass can be used. Although the production and the use of bio-naphtha is currently considered in BioMAT in a very 'rudimentary' way, the groundwork has been laid for its inclusion as soon as more data becomes available.

2.3.3. STEP 3: Enriching the BioMAT Database with Further Economic Data

Besides information on production, trade and use quantities of bio-based products and on quantities of biological feedstocks used for their production, the BioMAT database is enriched with further economic data:

- Market data for chemicals (prices and production costs for bio-based chemicals and their fossil-based counterparts, respectively);
- Prices for biological feedstocks;
- Macroeconomic data (GDP, inflation rates, population and oil prices).

Official statistics cannot be used directly to obtain information on prices for bio-based chemicals for the same reasons as they cannot be used to obtain information on their physical quantities (see Section 2.3.1). To generate these data, we proceeded as follows. Firstly, we took information on production values (in EUR) from PRODCOM statistics and calculated the respective values of bio-based chemicals using the same procedure as for the calculation of the data on physical quantities (based on bio-based shares for each PRODCOM code). Data on the production values are calculated for each PRODCOM code and each application category (see Section 2.3.1, Step A and Step B). Secondly, dividing the values of bio-based chemicals by their respective physical quantities, we estimated the unit prices of bio-based chemicals for each PRODCOM code and each application category. Note that separate information on the bio-based shares for production values per PRODCOM code is not available at the moment, which means that the data on bio-based shares for physical volumes are also applied for the production values. In doing so, we assume that the prices of bio-based and fossil-based products covered under the same PRODCOM code are the same. Such an assumption is not a problem if products covered by a PRODCOM code have roughly the same price and are predominantly bio-based. However, this gets more problematic if a PRODCOM code covers a mixture of products that differ considerably in price; bio-based products contribute only a small share and the prices of bio-based and fossil-based products differ substantially from each other. However, it seems that the unit prices of bio-based and fossil-based chemicals of the same application category differ substantially. The reason for this is a different composition of bio-based and fossil-based chemicals within the same application category with regard to PRODCOM codes. Products of one PRODCOM code (and their unit prices) can have a high relevance/weight for fossil-based chemicals and a very low one (or not at all) for bio-based chemicals within the same application category (and vice versa).

Even if the market prices for bio-based and fossil-based versions of a specific chemical product are very similar, the structure and level of their production costs could differ. To capture this, BioMAT relies on information on production costs from external studies [14,15,27,51]. Production costs consist of costs for biomass, energy, capital, labour and other materials, and have been calculated for the chemical, plastic and pharmaceutical sectors—both for the bio-based and fossil-based product options—as an average in the EU.

Prices of the main biological feedstocks used as input for the production of bio-based products in BioMAT are estimated based on prices of their respective crops that are taken from AGMEMOD.

Developments in GDP and population, as well as world prices for fossil fuels, are important drivers for the whole economy as well as for the bio-based industry. Therefore, the BioMAT database also incorporates this type of information, which is directly taken from the AGMEMOD database.

2.3.4. STEP 4: Bringing All Together

As described above, in STEP 1 and STEP 2 (Sections 2.3.1 and 2.3.2), we estimated the demand for different biomass resources used as feedstocks for the production of bio-based products through backward calculation, moving from the production of bio-based products through conversion efficiency rates to the demand for feedstocks. Moreover, through access to the AGMEMOD database we have data on the availability of specific agricultural crops and their subsequent products for the production of bio-based energy and material products. This availability can be recalculated following the logic of forward calculation, moving from land that is allocated to crops through production and trade of crops to their use for food, feed, seed, energy and materials. Combining information from both databases (and models) enables us to track the movement of the most common agricultural feedstocks along their entire value chain, i.e., from the land used to grow crops for industrial use to the bio-based products made from them. In order to establish this linkage between BioMAT and AGMEMOD, three types of raw biomass feedstock—starch, sugar and vegetable oils—are used as common reference and balancing items. In BioMAT, these three types of feedstocks belong to the list of predefined feedstocks, and in AGMEMOD, the supply of crops and products thereof for material and energy use is mapped to them. Figure 4 illustrates the general idea of the establishment of the intersection by aligning BioMAT and AGMEMOD databases.

In the central part of Figure 4, three types of biological feedstocks that have been selected as common reference and balancing items (starch, sugar and vegetable oils) are placed. The left side shows which kind of information on the availability/supply for industrial use of related bio-based resources AGMEMOD provides. The right side shows how the demand for these bio-based resources for different applications comes off within BioMAT. Possible discrepancies between the BioMAT and AGMEMOD figures on demand and supply, respectively, for starch, sugar and vegetable oils for material use are calculated as “feedstock balancing gaps” (a positive figure indicates that the demand for material use as calculated in BioMAT is higher than the supply for material use as calculated in AGMEMOD). The main explanation for the arising of such “feedstock balancing gaps” is that AGMEMOD covers the main crops (and products thereof) harvested in the EU, but not crops harvested in the EU that are of minor importance (e.g., linseeds) or crops entirely imported to the EU (e.g., palm oil). Below, we describe how "feedstock balancing gaps" for starch, sugar and vegetable oils are calculated and explained from the conceptual point of view.

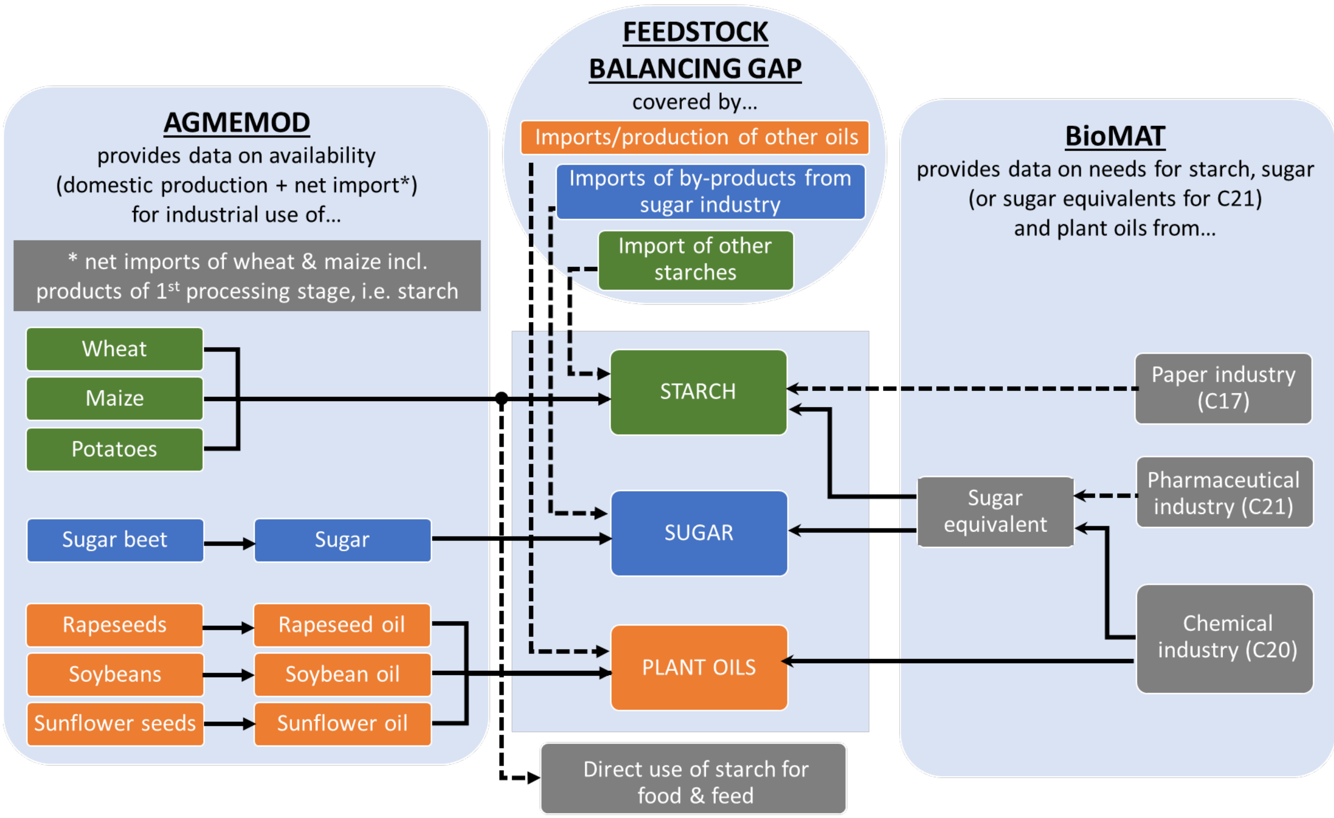


Figure 4. Calculation of supply, demand and "balancing gap" for starch, sugar and plant oils.

Starch: AGMEMOD provides data on quantities of wheat, corn and potatoes available for processing, material and energy use. To be in line with the defined processing routes (Figure 1) we use these data to calculate the total quantity of starch produced from the respective feedstocks. According to Starch Europe, approximately 60% of the total starch available in the EU is allocated to food and feed [43]. Therefore, we assume that circa 40% of the available starch calculated based on AGMEMOD data can be potentially used as a feedstock for the applications covered by BioMAT. The processing routes defined in BioMAT foresee that starch is used either directly (mainly by the paper industry) or as a starch-based sugar (in particular, glucose) obtained by hydrolysis of starch. The total demand for starch by the bio-chemical industry calculated in BioMAT exceeds the supply of starch calculated based on data from AGMEMOD; this calculated difference is assigned to a "feedstock balancing gap" for starch. From a conceptual point of view, this gap can be explained as follows. While the trade of starch from wheat and corn is covered by AGMEMOD (in terms of respective crop equivalents as products of the 1st processing stage), the trade with starch from other raw materials (peas, rice, cassava, etc.) and trade with glucose (2nd processing stage of wheat and maize) is not captured. Therefore, the "feedstock balancing gap" estimated for starch is attributed to the imports of starch-based sugar for material use, in particular glucose, and starch produced from other raw materials (peas, rice, cassava, etc.) that has become available for material and energy use.

Sugar: AGMEMOD provides data on quantities of sugar available for industrial/material use. The total demand for sugar calculated in BioMAT and the total supply of sugar for industrial/material use from AGMEMOD are mostly balanced. From a conceptual point of view, a possible "feedstock balancing gap" for sugar in historical data can be covered by imports of products for industrial use from the sugar industry (e.g., molasses) not explicitly covered by AGMEMOD.

Plant oils: AGMEMOD provides data on quantities of oils produced from rape, sunflower and soybean seeds available for industrial use. The supply of plant oils identified in AGMEMOD is much lower than the demand for plant oils from the chemical industry calculated in BioMAT. The main explanation is that AGMEMOD does not cover oilseeds of minor importance harvested in the EU (e.g., linseeds) or oils entirely imported to the EU (e.g., palm oil), which, however, are important feedstocks for the production of bio-based materials. Furthermore, the supply of tall oil from the wood industry is not taken into account. As volumes of palm oil and palm kernel oil are by far the most significant feedstocks for the bio-based industry not covered by AGMEMOD, the calculated "feedstock balancing gap" for plant oils is practically closed via imports of these oils for industrial use.

Besides the conceptual aspects mentioned above, the occurrence of "feedstock balancing gaps" can partly be attributed to uncertainties in both models. AGMEMOD is an established database and model that undergoes regular validations with industrial and policy stakeholders. BioMAT, on the contrary, is a newly developed database (and model) and builds mainly on processed data and therefore is more subject to uncertainties.

The following information in BioMAT is subject to uncertainties and can be continuously adjusted if better knowledge and data become available:

- Information related to data for the chemical industry, such as:
  - Bio-based shares;
  - Mapping individual PRODCOM codes to application categories;
  - Mapping bio-based feedstock types to PRODCOM codes;
  - Conversion rates (relation between feedstock use and bio-based material output), also with regard to water content in output product.
- Information NOT related to data for chemical industry, such as
  - Use of starch by paper industry;
  - Use of sugar for pharmaceutical industry;
  - Use of crops for biomethane (biogas) production;
  - Other (potential) material uses of crops.

The BioMAT database is undergoing a continual validation and improvement process, based on expert knowledge from agricultural and chemical industries as well as academic expertise, but it is still at an early stage. The first experience shows that stakeholders find it quite difficult to validate results, mainly because they often have a specific product or technology focus and are less familiar with the markets of application categories, which are the focus of BioMAT. They usually ask for more background information and clarification. This is where preparing the output in an appropriate format and according to the needs of the different stakeholders can help. In general, as the experience with AGMEMOD has shown, the establishment of a validation process requires patience and, in addition to one's own time and resources, the willingness of stakeholders to be involved and to contribute.

3. Results

This section aims to present some examples of the type of data insights that the newly developed BioMAT database can offer. A number of detailed results will be soon publicly available at the "Data-Modelling platform of resource economics" of the European Commission via a link to the DataM area dedicated to the BioMonitor project (https://datam.jrc.ec.europa.eu/datam/project/BIOMONITOR) (accessed on 30 January 2023).

Figure 5 presents our results in a very condensed way. It shows volumes of different types of biological feedstocks (on the left side) used by the chemical industry in the EU27 in 2018 to produce bio-based chemical products, and their volumes within different application categories (on the right side). In terms of volume, "plant oil" (30%) and "starch" (25%) are the main agricultural feedstocks for the production of bio-based chemicals. Regarding the bio-based production of the chemical industry, again in terms of volumes, "biofuels"

(42%) is by far the most important application category, followed by "agrochemicals" (21%), "surfactants" (12%) and "cosmetics and personal care products" (6%). Other application categories have a share of only 2–3% of the total output volume. It needs to be clarified that as average product prices within each application category can differ, this distribution can also differ in terms of production values. Furthermore, Figure 5 shows the quantities of platform chemicals used as intermediate input by the chemical industry (yellow loop).

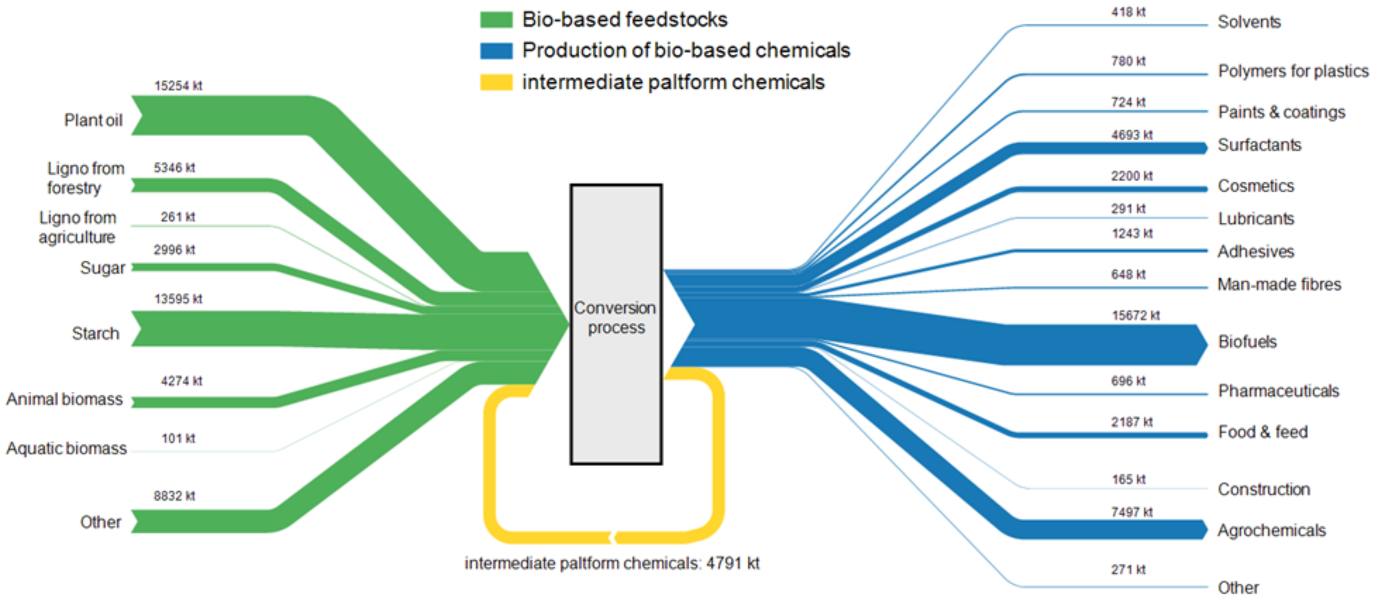


Figure 5. Use of biological resources for production of bio-based chemicals in the EU in 2018.

In addition, the BioMAT database provides more detailed information, for example, the quantities of different biological resources used for the production of products within one specific application category. Figure 6 shows the use of bio-based feedstocks for the production of surfactants. While part (a) of Figure 6 lists intermediate "platform chemicals" as a feedstock type, it is replaced in part (b) by associated quantities of biological resources that are directly associated with biomass needs. The total quantity of feedstocks (sum over all feedstock types) in part (b) exceeds the total quantity of feedstocks (sum over all feedstock types) in part (a). The reason for this is that for replacing of quantity x of "platform chemicals" quantity x*cr of bio-based resources is need, where cr is an average conversion rate of biomass to platform chemicals and as a rule cr > 1. However, the total sum of feedstock volumes in (a) and (b) is lower than the production volume of "surfactants" (cr < 1). The reason for such an effect is the use of coproducts from other production processes (i.e., glycerol from bio-diesel production) as an input for the production of "surfactants", which are assumed to require no biomass for their own production (to avoid the double counting of biomass needs). The total production volume of "surfactants" presented in Figure 6 refers to "pure" product volume (water content equal to zero). As for several products included in "surfactants" data reported by PRODCOM are assumed to tolerate some water content in volumes, the production volume of "surfactants" estimated by applying bio-based shares is higher than production volume reported in Figure 6.

Another interesting way to look at the results is to track the use of certain biological feedstock types for the production of bio-based chemical products. Figure 7 reports on the use of plant oil for the production of bio-based chemicals. Moreover, here, in part (a), the category "platform chemicals" is explicitly listed under the application categories that use plant oils as input and in part (b), the quantity of plant oil associated with the production of "platform chemicals" is redistributed over the "semi-final" application categories.

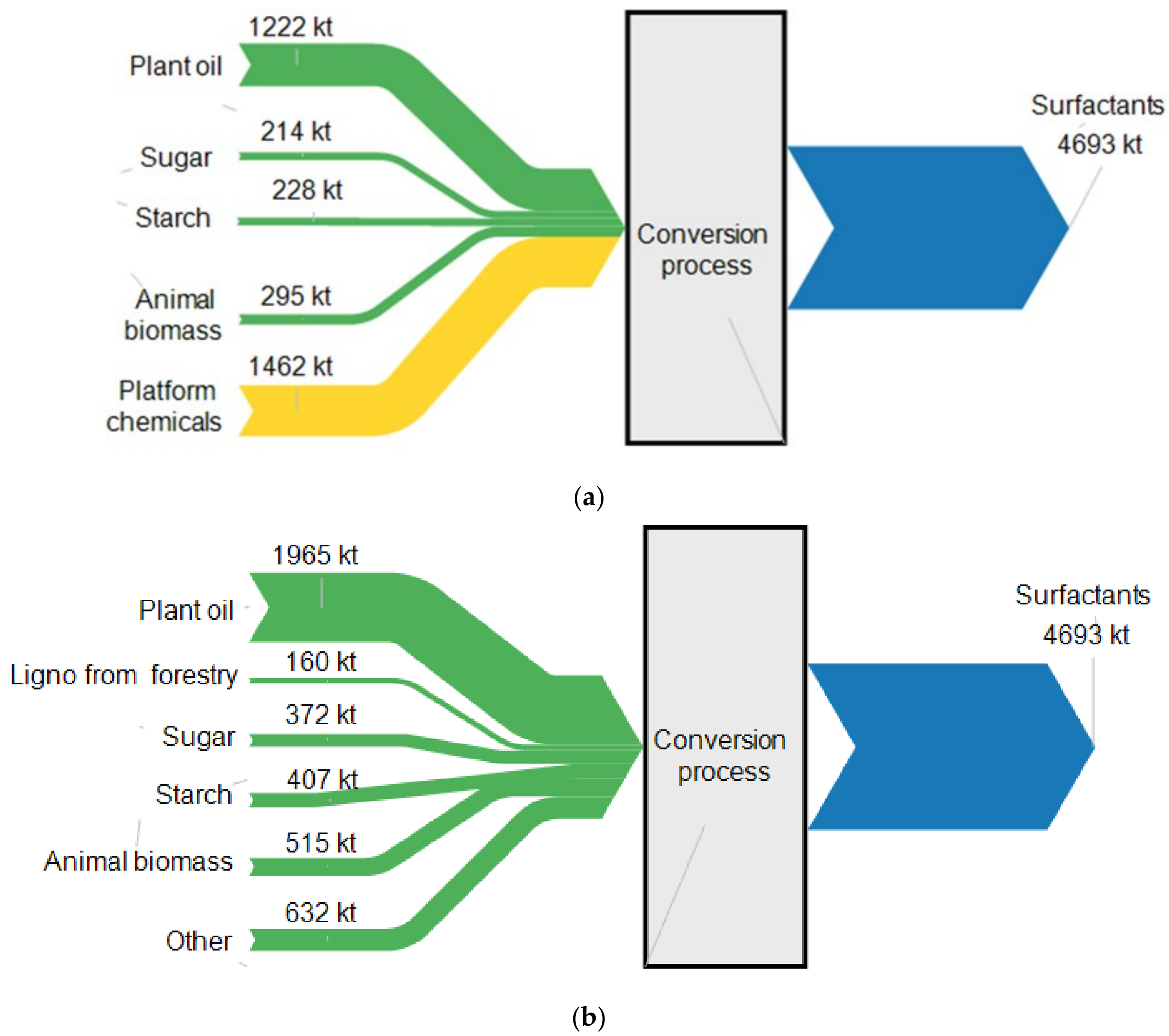
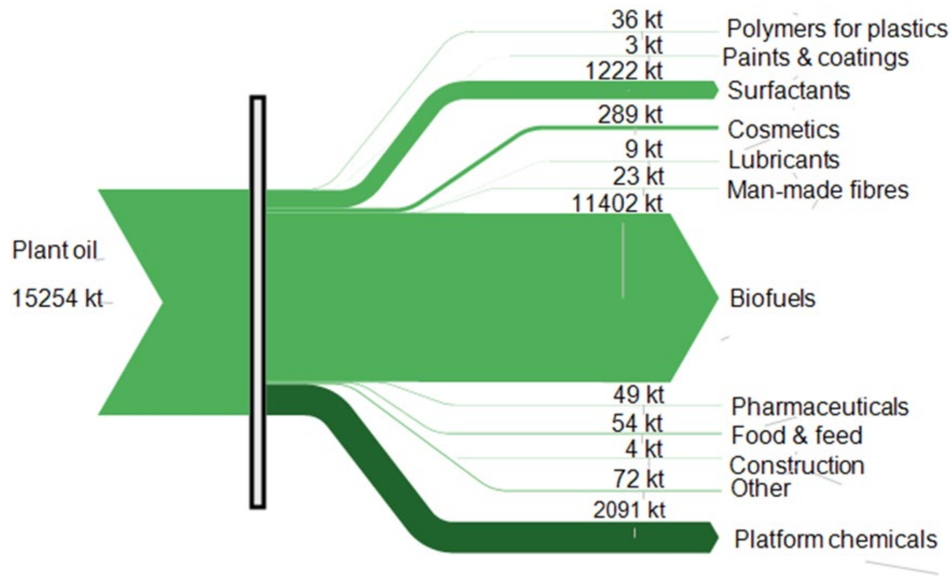


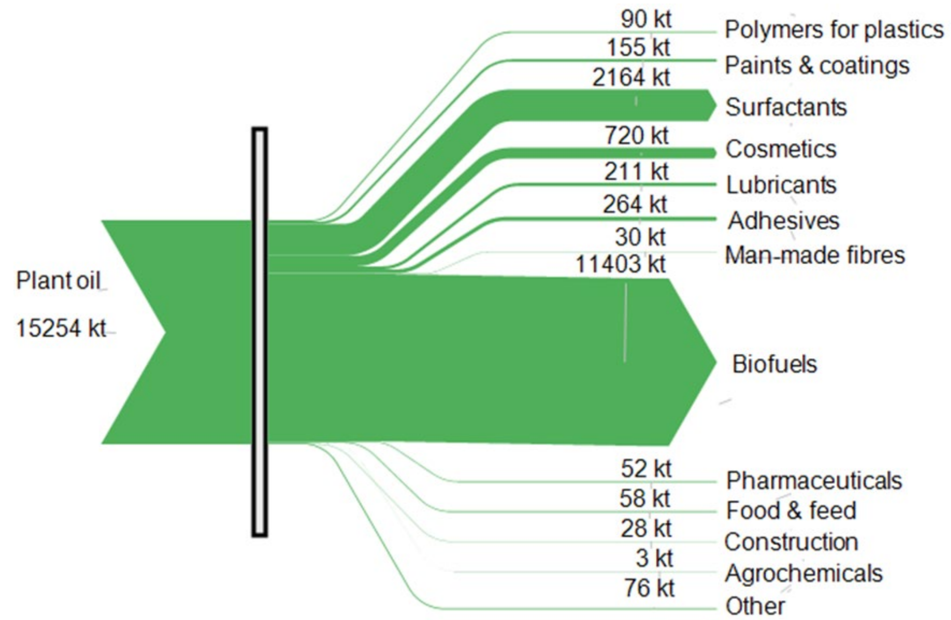
Figure 6. Use of biological feedstocks for the production of surfactants in the EU in 2018 with (**a**) and without (**b**) explicitly listing "platform chemicals" as a feedstock type.

Figure 8 shows the development of the total market of bio-based chemicals (C20) in the EU over time. Part (a) shows the development of production, net-trade and apparent use volumes as well as an average unit price (calculated as production value of bio-based products divided by the respective production volume). Part (b) shows the development of the estimated bio-based share in the production volume of the total (organic) chemical industry (including biofuels). In general, no strong dynamics could be observed in 2010–2018; production and use volumes of total bio-based chemicals increased somewhat, but the bio-based shares remained due to the overall increase in total chemicals being quite stable.

Figure 9 presents the development of biological feedstock use for the production of bio-based chemicals in the EU. A distinction is made between feedstock quantities used for the production of biofuels and non-biofuels (or bio-based chemicals excluding biofuels), respectively. The calculated share of feedstock used for the production of biofuels was 43% in 2018. This clarifies that the production of biofuels had a great impact on the total use of biomass by the chemical industry (C20). Additionally, it is obvious that the composition of feedstocks used for the production of biofuels, more specifically the dominant use of plant oils as feedstock (ca. 50%), greatly impacts the composition of the total feedstocks used for production of all bio-based chemicals.



(**a**)



(**b**)

Figure 7. Use of plant oils for the production of bio-based chemicals in the EU in 2018 with (**a**) and without (**b**) explicitly listing "platform chemicals" as a product application category.

Often in studies focusing on bio-based chemicals, a distinction between biofuels and other bio-based chemicals is made. Therefore, Figure 10 shows the development of use of different feedstock types for the production of bio-based chemicals excluding biofuels.

The geographical scope of BioMAT is the individual EU member state, i.e., country level. Therefore, the results presented in Figures 5–10 can be generated also at the level of EU member states. However, these findings should be treated with caution, as the bio-based shares are EU averages and country-based details are missing. This implies that if no production under a specific PRODCOM code takes place (=0), the bio-based production is also equal zero. However, if production under a specific PRODCOM code takes place, the quantity of bio-based production is determined via the EU average bio-based share. In reality, the share of bio-based production in a specific EU member state might differ from the average.

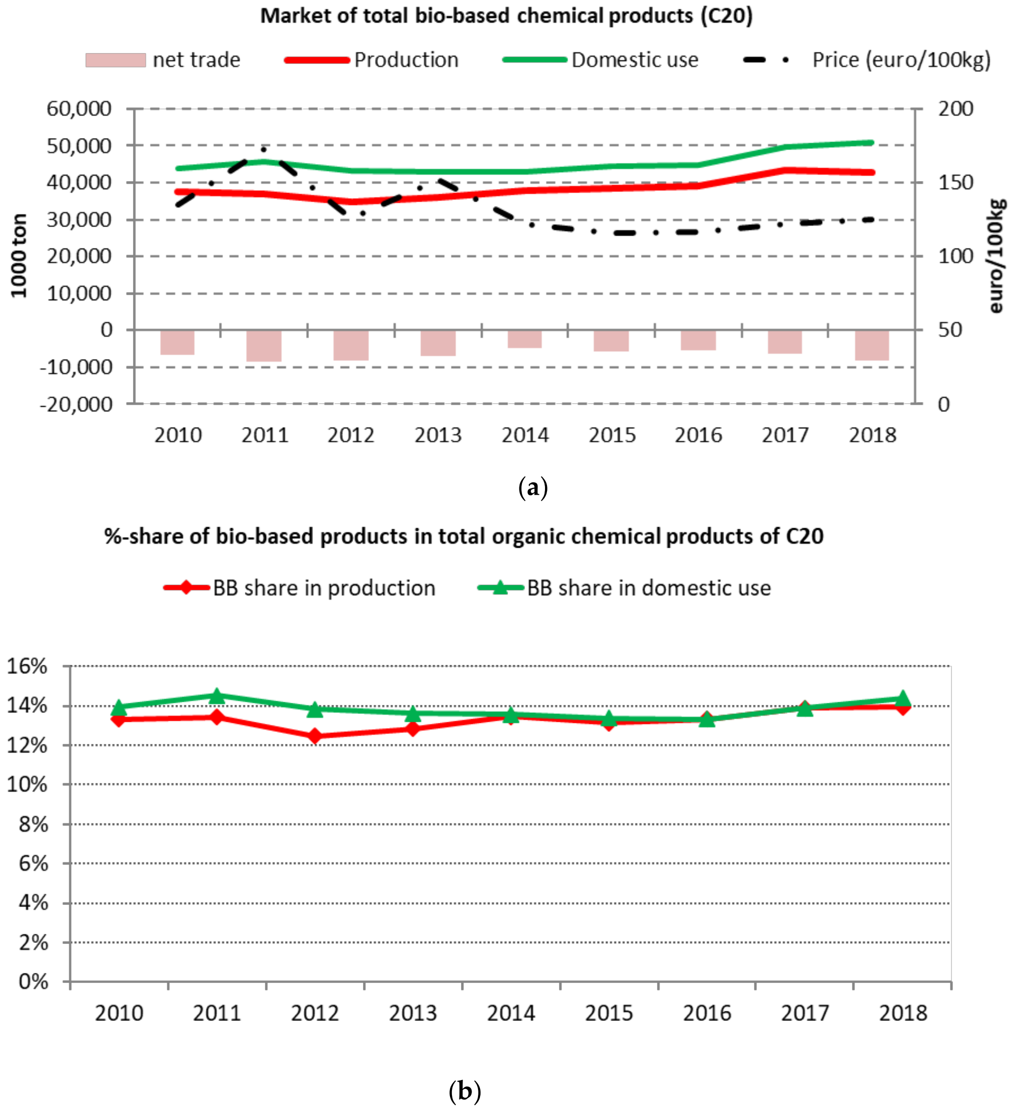


Figure 8. Development of the market of bio-based chemicals in the EU: (**a**) production, net-trade and apparent use volumes as well as an average unit price, and (**b**) the estimated bio-based share in the production volume of the total organic chemical industry.

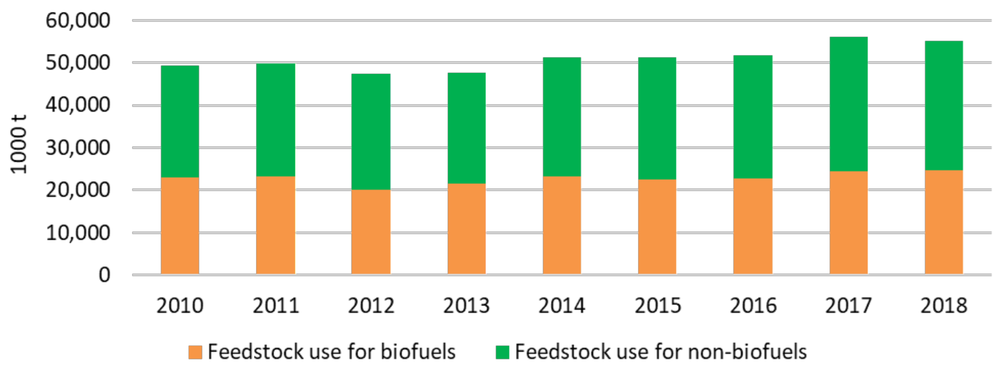


Figure 9. Development of total biological feedstocks use by chemical industry in the EU.

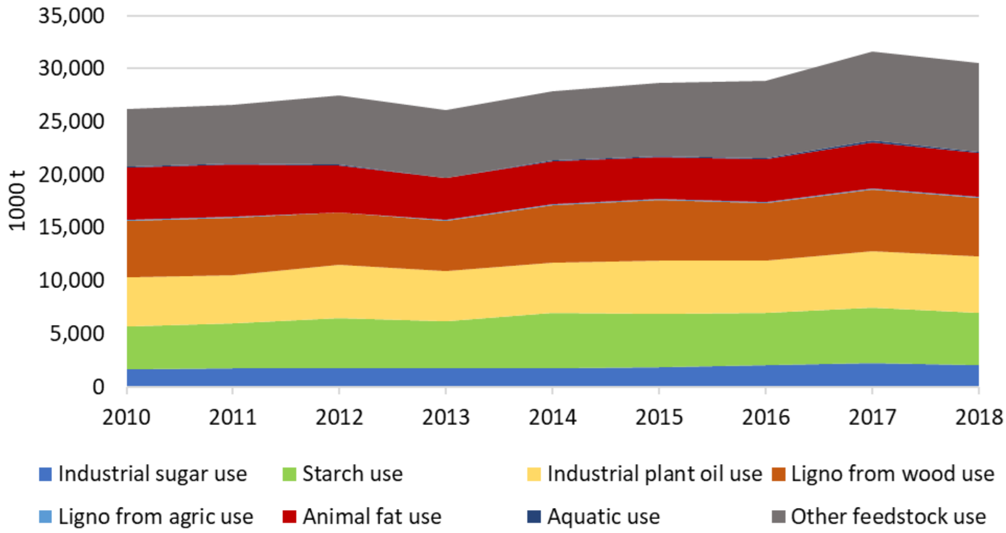


Figure 10. Development of use of different feedstocks by chemical industry (excl. biofuels) in the EU.

Figure 11 provides insights into the distribution of the production of bio-based chemicals in terms of volume over different EU member states. It shows that Germany, France, Spain and Italy were the main producing countries (in terms of volume) and covered, together with The Netherlands, Poland and Belgium, ca. 75% of total bio-based production in the EU in 2018. Thus, the most important producers of bio-based chemicals in terms of volume are countries that have a strong overall chemical industry (i.e., production of fossil-based chemicals). However, it should be recalled that if no country-specific data are available, the estimation of production volumes for bio-based chemicals in individual EU member states is based on the average EU bio-based shares, which largely also evokes precisely this correlation.

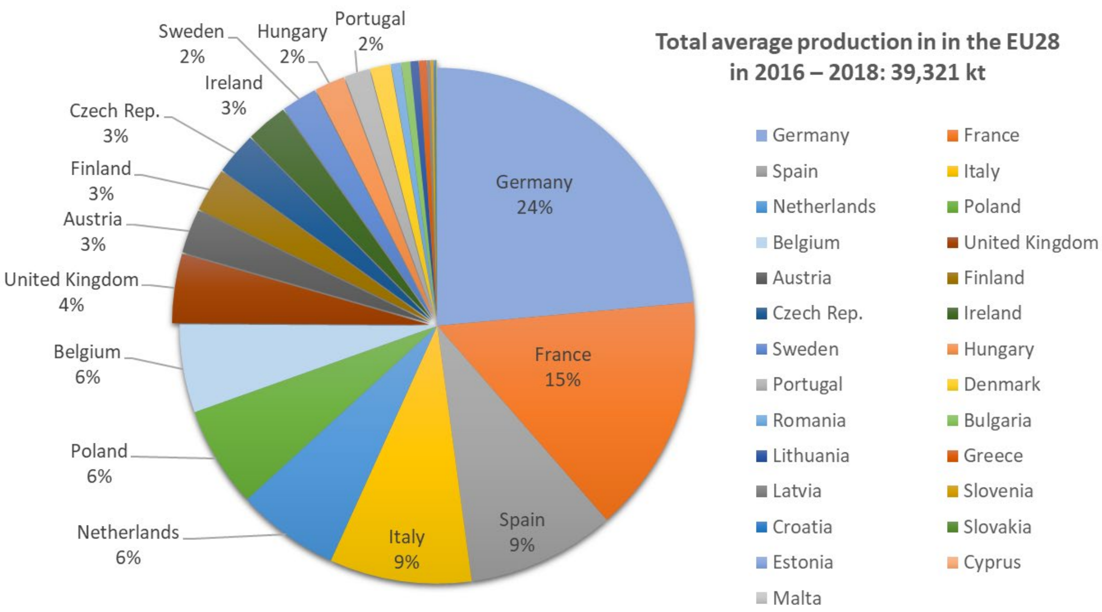


Figure 11. Distribution of production of bio-based chemicals over member states in the EU.

As shown in Figure 11, Germany is the most important producer of bio-based chemicals (as covered by C20) in terms of volume. Figure 12 shows the development of the German bio-based chemical production over time. The total production of bio-based chemicals reached 9500 kt in 2018. Moreover, in Germany, most of the produced bio-based chemical products were used in the application category “biofuels” (in 2018 this was 35% of the total output volume), followed by the categories "platform chemicals", "agrochemicals" and "surfactants" (16%, 13% and 9% of total output volume in 2018, respectively). Products assigned to the application categories "food and feed" and "cosmetics and personal care" each account for 6%. Output volumes covered by each other categories are below 3%.

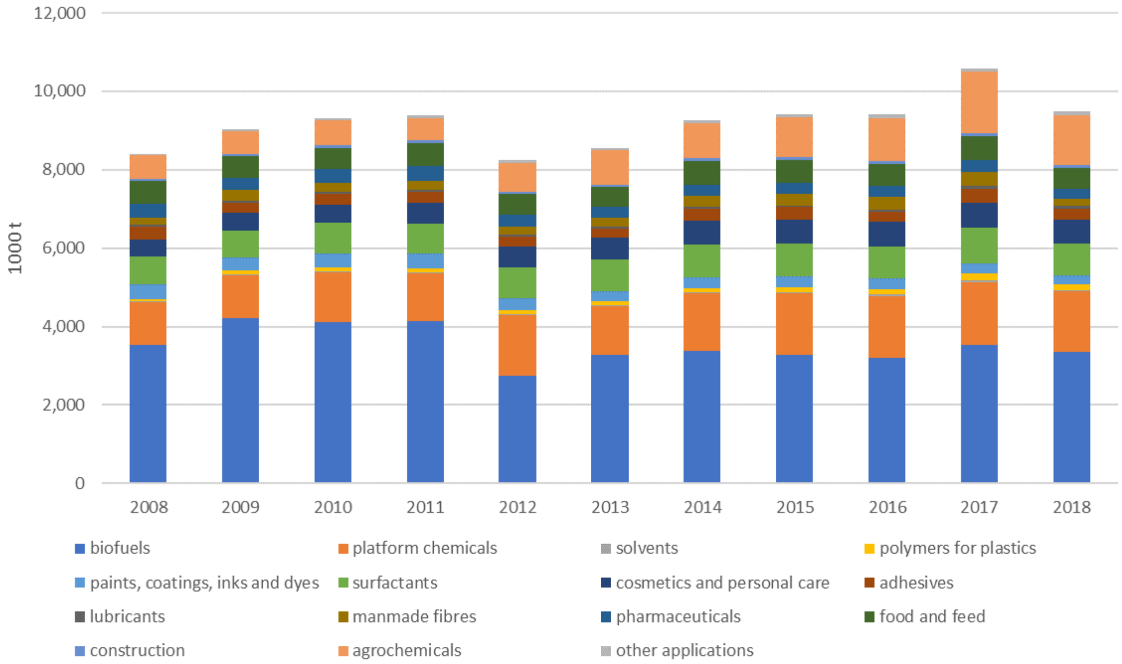


Figure 12. Development of production volumes of bio-based chemicals in Germany (2008–2018).

4. Discussion

The BioMAT database provides information that gives a picture of the historical development of the bio-based chemical industry in the EU, which has been missing so far. It shows how the whole market for bio-based chemicals has evolved, its size in comparison to the total market for chemicals and which quantities of biomass are used for producing them. Furthermore, it provides more detailed information by showing which quantities of different feedstock types are used for manufacturing of products of different application categories. However, despite many interesting features, the proper use and interpretation of BioMAT results requires some understanding of the concept. The first initiatives to validate results with the stakeholders have confirmed this. In this respect, exchange and cooperation with industry representatives, statisticians and policy makers, as well as the establishment of a regular validation process has to be further settled.

The BioMAT database has also some methodological limitations. The main limitation is its reliance on expert knowledge to fill in some of the gaps in the existing statistics. This creates two kinds of limitations: (i) the need to accept the uncertainties associated with the use of expert knowledge and (ii) the dependence on experts by updating the data. Information based on expert knowledge was added in several stages in compiling the BioMAT database (see Section 2.3); however, the entry of information on bio-based shares is the most critical one, as this information was used at the beginning of the data compilation procedure and thus has a great influence on the overall outcome. The current version of the BioMAT database uses the data on bio-based shares in output volumes in the total EU for the period 2008–2018 provided by the nova-Institute. Since no additional data on bio-based shares in trade flows are available, these shares are also applied in the calculation of bio-based imports and exports. It is, however, quite likely that in reality, bio-based shares in trade flows differ from shares in production. As the apparent use is calculated as production plus imports minus exports, incorrect data in trade flows also have an impact on figures on apparent use of bio-based chemicals. Therefore, obtaining more accurate information regarding the actual bio-based shares within the trade flows will make a great improvement to the database. If such additional information becomes available, current estimates in the database can be easily replaced due to the systematic set-up of the database. A similar situation exists for data at the EU member state level and for bio-based values of production and trade flows. If no additional information is available, the bio-based shares in output volumes in the total EU are applied. Hence, more precise information will help to improve the database. Such information can be gathered through primary collection tools, i.e., surveys, or by extending the official statistics to cover these items.

Therefore, last but not least, the presented approach for data generation is proposed as a short-term solution. To better measure the development of the bio-based economy in the long term, it is necessary to safeguard the collection of the needed data via statistical authorities. A recent study [25] described an approach that could be used to improve long-term data collection and reporting on bio-based economy. In particular, it foresaw the introduction of new codes for dedicated bio-based products and thus changes in the existing statistical classifications.

5. Conclusions

The BioMAT database is a novel scientific asset with a number of interesting features. For the time being, and as long as the official statistical data cannot directly be used for monitoring the development of the bio-based chemical industry and the associated markets, the BioMAT database could be used as a reference to provide some valuable insights. The proposed approach for the data generation procedure enables the extension of historical time series data in the BioMAT database and the use of official statistics as a starting point, additionally, ensure the consistency of the database. Moreover, the BioMAT database has also enabled us to build the BioMAT model [20].

The results for the historical developments reveal rather weak dynamics in the markets for bio-based chemicals in the EU. This suggests that more action, especially from industries and the policy makers, needs to be taken if a stronger expansion of bio-based production is desired in the future. Combination of both the BioMAT database and the BioMAT model can be an appropriate tool to guide policymaking in the field of the bio-based economy by showing prospects of the bio-based industry and how it can contribute to achieving different targets, but also revealing its limitations and the associated trade-offs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15043064/s1, Use of agricultural biomass by paper, pharmaceutical and biogas industries.

Author Contributions: Conceptualization, V.S. and M.v.L.; methodology, V.S., M.v.L., N.H., N.d.B. and D.V.; software, D.V.; validation, N.H., N.d.B. and D.V.; formal analysis, V.S., N.H., N.d.B. and D.V; writing—original draft preparation, V.S., A.G.-M. and M.v.L.; writing—review and editing, V.S., A.G.-M. and M.v.L.; visualization, V.S. and M.v.L.; project administration, M.v.L.; funding acquisition, M.v.L. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from official statistics (PRODCOM, COMEXT) used in the analysis can be downloaded here: https://ec.europa.eu/eurostat/ (accessed on 30 January 2023). Data on bio-based shares for 2008 for the EU and mapping matrices used for data generation procedure are available on request. A number of detailed results of the BioMAT database are available at the "Data-Modelling platform of resource economics" of the European Commission via a link to the DataM area dedicated to the BioMonitor project (https://datam.jrc.ec.europa.eu/datam/project/BIOMONITOR) (accessed on 30 January 2023).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Description of chemical application categories in BioMAT: BioMAT covers all bio-based chemical products classified under NACE C20 "Manufacture of chemicals and chemical products" by assigning products of each PRODCOM code to one or more application categories. In total, there are 15 application categories (also "product groups"). Each application category is classified as a "semi-final" or "intermediate" product group. Currently, "platform chemicals" is the only product group classified as "intermediate".

Platform chemicals: This product category is currently the only "intermediate" product group and includes chemicals that are used for production of other chemicals, as a considerable part of "semi-final" products are not produced in a single step (directly from biomass), but by using other chemical products ("intermediates") as an input. Among others, this category includes fatty acids, diols, ethers and ketones, but also resins and many other substances.

Solvents: Chemical products used to dissolve a solute resulting in a solution. Solvents are used by industry to produce a wide variety of products such as paint thinners, nail polish removers and perfume. Among others, this category includes ethanol.

Polymers for plastics: Chemical products used for production of plastics (C22). Among others, this category includes polyamines, derivates of natural rubber and cellulose.

Paints, coatings, inks and dyes: Chemical products used for production of paints, coatings, inks and dyes. Among others, this category includes oils and fatty acids for oil-based paints, but also binders, pigments, structurants and rheology modifiers.

Surfactants: Blends that lower the surface tension of a medium in which they are dissolved in. Within this category, surface active agents, soaps and detergents and washing preparations are included.

Cosmetics and personal care products: This category includes a wide variety of "final" and "semi-final" products with applications in cosmetics and personal care. Examples include perfumes, but also shampoo, dental products, polishes and creams. Please note that some of the "semi-final" products within this application group contain surfactants, but the surfactants are classified in the surfactant group. Among others, this category includes lip and eye make-up, shampoo and deodorants.

Adhesives: Includes substances which are used to bind items together to resist their separation, for example, starch-based glues, epoxide resins and other resins.

Lubricants: Products used to reduce friction between two surfaces. Among others, this category includes lubricants and anti-knock preparations.

Man-made fibers: To this category belong chemical products used for the production of fibers, such as polyesters, viscose and cellulose acetate, which are used in the textile industry as well as in non-woven applications or industrial uses (for example, cigarette filters are produced from cellulose acetate).

Biofuels: Bio-based products used as fuels, for example, biodiesel and bioethanol, but also fuel additives such as anti-knock preparations.

Pharmaceuticals: Products used for the production of pharmaceuticals (C21). For example, enzymes, ion-exchange resins and peptones. This category also includes many molecules from which pharmaceutical active ingredients are produced.

Food and feed: Chemical products used by the food and feed industry, for example, as antioxidants, preservatives or rheology modifiers. The most important product that belong to this category is citric acid, which is used as a preservative. Among others, this category also includes flavors for food application and sorbitol.

Construction: Products used for construction such as buildings, infrastructure and industrial facilities. Examples of products used in this application are a range of polymers (polyamides and polyurethanes), resins, insulation materials and also wood polishes.

Agrochemicals: This category encompasses many chemicals used in agriculture. It includes, among others, herbicides, pesticides, insecticides, animal and/or vegetable derived fertilizers, as well as urea and several chemicals required for the production of herbicides, pesticides and insecticides.

Other applications: Due to the wide range of applications for chemical products, this category is used for applications of chemicals which do not fit in any of the categories above. This includes, for example, substances used as refrigerants, in military applications, fireworks, fuses, waste water treatment and photographic plates.

Appendix B

Description of biological/ bio-based resources used as feedstocks in BioMAT: There are 10 feedstock types in BioMAT which are used for production of bio-based products. A distinction is made between "primary feedstocks" and "intermediates". "Primary feedstocks" are sugar, starch, plant oils, lignocellulosic from forestry, lignocellulosic from agriculture, animal biomass, aquacultures and other primary feedstocks. The demand for these feedstocks directly reflects the demand for biomass. There are two further feedstock types that are assigned to "intermediates": "Sugar/Starch-based platform chemicals" and "Oil-based platform chemicals", which in further steps, however, are aggregated into one category, "Platform chemicals". As already mentioned in Section 2.2 (Bio-based products in BioMAT), these feedstock types are also "product groups", which are not used for semi-final use but only as inputs/feedstocks for other products, however. The use of "intermediates" as production inputs does not directly result in additional demand for biomass (bio-resources) by respective "semi-final" product categories; however, the production of "intermediates" as output products requires the use of biomass (bio-resources) itself.

Sugar: Sugars produced from sugar beets or sugar cane (imports).

Starch: Starch and starch-based sweeteners produced from maize, wheat, potatoes and other raw materials. Through the hydrolyzation process, starch can be converted to sugar; therefore, starch is also used as a feedstock for processes that require primary sugar as feedstock (fermentation process). In such cases, an intermediate step of the calculation—the conversion of starch into "industrial sugar equivalent"—is carried out first.

Plant oils: Plant oils produced from rape, sunflower seeds, flax seed oil, etc., but also imported oils (palm oils, etc.)

Lignocellulosic from forestry: Wood or processed wood that includes a lot of cellulosic fibers (dissolving pulp), theoretically also wood sugar, but also wood charcoal and wood tar, for example, methanol as a by-product of the pulping process or tall oil.

Lignocellulosic from agriculture: Straw and other by-products from, for example, flax, and also theoretically short rotation crops.

Animal biomass: Animal fats, mainly from swine, poultry, cows, etc., coloring maters from animal origin, activated carbon (from burning of bones) and also some proteins (caseins) could be side products from animal husbandry.

Aquacultures: Mainly algae biomass (currently mainly from the sea). Additionally, agar-agar used mainly for production of natural and modified polymers such as alginic acid.

Other feedstocks: Includes everything not included elsewhere, for example, vanillin, plant extracts, essential oils, fragrance substances and also rubber. Additionally, animal or vegetable fertilizers (i.e., manure) and used cooking oil are included in this category.

Sugar-/Starch-based platform chemicals: Sugar-/starch-based platform chemicals used as input for the production of other chemical products (see the description for product categories).

Oil-based platform chemicals: Oil-based platform chemicals used as input for the production of other chemical products (see the description for product categories).

Bio-naphtha: It is currently classified as a feedstock in BioMAT. From the description of PRODCOM statistics, it is not obvious whether the production of bio-naphtha is reported explicitly in the statistics and, if it is, under which code the reporting takes place. Therefore, bio-naphtha is treated as a bio-based feedstock for C20, but its production and respective demand for biomass is not covered by the BioMAT database for C20. It should be calculated separately based on production quantities of bio-naphtha, which should be gained from different sources as the official statistics do not provide such data.

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