Future market outlooks for new bio-based products

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D5.2: Report on the development of BioMAT and EFI-GTM for medium-term projections and simulations for bio-based products

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Monitoring the Bioeconomy

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1. Summary

Based on an analysis of existing bioeconomy modelling capacities, some gaps have been identified in existing bioeconomy modelling capacities to represent the development of bio-based materials. To address these gaps, the BioMonitor Model Toolbox has been designed. This report documents improvements made to two of the models included in the Toolbox, which focus on market developments of bio-based chemical applications and new wood-based applications. Part I of this report presents the new BioMAT model that has been developed to close the gaps on bio-based chemical applications. Part II is devoted to the EFI-GTM model that has been extended with new wood-based products and updated to capture structural changes in markets of traditional wood products.

The new BioMAT model and database

BioMAT is a new multi-regional partial equilibrium model for innovative bio-based product markets with a focus on the EU as a whole and its individual Member States. It can provide projections for the bio-based markets based on current trends and policies as well as simulate the impacts of changing trends and policy options on these markets in the medium-term (2030) and long-term (2050). More specifically, BioMAT can address following sort of questions:

- How did the production of bio-based materials evolve in the past and which historical trends can be identified?
- Which sizes of these bio-based materials are currently produced and where, and what are plausible magnitudes in 2030 and 2050?
- What is the expected biomass feedstock need of these innovative materials in 2030 and 2050 respectively? How does it correspond when compared with current and future availability of biomass feedstock produced in the EU? What are implications for EU trade with rest of the world?
- Which drivers can influence the development of future bio-based material markets in terms of policy measures, changes in technical economic, environmental and consumer trends?

The main challenge when developing the BioMAT model concerned the creation of a database with market related data for bio-based products that preferably departs from publicly statistical sources, and how to deal with incomplete – or more obviously - missing statistical data sources on bio-based products. A mixture of techniques has been used to close gaps, including data imputation algorithms, bi-proportional balancing method (so called RAS method), and the use of information from literature and stakeholder interviews to cope with incomplete and missing statistical data sources on bio-based products. Despite the use of multiple methods to close data gaps, there remains a certain level of uncertainty in the numbers included in the BioMAT database. Nevertheless, these data processing activities in BioMonitor are valuable to derive in a consistent way a set of bio-based market indicators at EU member state level and for a time period. There is openness about the assumptions used, which can be adapted when better knowledge becomes available. Last but not least, the data generating process is repeatable in case statistics or assumptions come up with updates.

The BioMAT database is at the heart of the BioMAT model. It is a multi-dimensional data processing tool equipped for market analysis for bio-based materials, in particular bio-based chemicals. The BioMAT model can generate projections for chemical markets and associated indicators in EU member states, EU27 and UK to 2030/2050. The model can track the associated demand for biological resources used as production inputs for the bio-based chemicals and it enables the calculation and monitoring of a set of related sustainability indicators for the past and current state. The key elements of database and model results are available on the BioMonitor Data Platform (WP3 and WP6), which are production, demand and trade (in volumes) and prices (in euros) of the analysed chemical applications. Finally, the BioMAT model is an integrated module of the AGMEMOD framework, which is regularly updated and stored in a cloud environment. AGMEMOD is maintained and owned by a consortium.

The improved EFI-GTM model

The EFI-GTM model is a multi-regional and multi-periodic partial equilibrium model of the global forest sector. It depicts the system consisting of wood supply, forest industries (sawmilling, wood-based panels, pulp and paper industries) and production of wood-based energy and biofuels, demand for forest industry products and woody biomass for energy, and international trade in wood and forest products. The model has a detailed representation of European countries and considers other countries in global regions; in total there are 57 countries and regions covering the world. The model includes about 30 forest industry and energy sector products, five roundwood categories, three categories for forest chips, four recycled paper grades, and the main by-products of the forest industries, such as sawmill chips, sawdust and black liquor. EFI-GTM can cover the following aspects:

- Future global and European forest products markets development (production, consumption, trade and prices) given the identified past market development and current policies.
- Changes in the global forest products markets under alternative policies (e.g., climate, biodiversity, energy, trade), thus providing information on the market impacts of the alternative policies.
- Information on economic availability of different woody biomass feedstock to be used in the external models.

EFI-GTM has been improved by (1) updating demand functions for existing products to take into account structural changes in selected paper products markets (e.g., graphic and packaging), and (2) extended to cover emerging or novel wood-based products, such as wood-based textile. The updated model disaggregates printing and writing papers into three paper grades, and estimates a separate demand function to link per capita consumption with GDP per capita and countries' population internet adoption rates as additional driver. The latter allows to capture declining trends in graphic paper consumption. To estimate demand function for wood-based textile fibres, additional data on various textile fibres and consequently, wood-based textile shares within total textile supply have been collected. Per capita wood-based textile consumption are estimated with GDP per capita, real price and relative share of wood-based textile fibres.

Projected bioeconomy market developments

BioMAT and EFI-GTM have been applied to project future market outlooks for bio-based commodities under reference (business-as-usual) conditions until 2030 and 2050. To ensure consistency, the two models have been aligned as much as possible with regard to input data, level of aggregation, and scenario definitions. Accordingly, the reference development assumes the continuation of trends in macroeconomics, demographics, biomass availability, policy, consumer preferences and technology.

According to BioMAT, the expected annual growth rate of production and consumption of the average bio-based chemical from 2018 to 2030 is nearly three times higher than its fossil-based counterpart (3.5% versus 1.2%). This is explained by a declining bio-based/fossil-based price ratio for chemical products until 2030, which has been projected by the CGE MAGNET model and used as a driving factor in BioMAT. Further, the EU has been a net-importer (in terms of volumes) of chemical product applications during the historical period 2008-2018, and is expected to keep that position in the medium term. This is mainly due to huge amounts of imported fertilizers and organic chemical products within the C20 chemical sector.

The reference projections by EFI-GTM indicate a strong decline in the graphic papers demand in Europe and globally, which reflects a continuation of current trends. Conversely, the global demand for packaging papers is projected to grow substantially until 2050, although only a modest grow is expected for EU. At the global level, the total paper and paperboard demand is projected to grow by 40% in 2050 compared to 2020, whereas chemical pulp production is expected to decline by 15% due to an expected strong (48%) increase in global supply of recycled paper. This result is also linked to the increasing global share of other paper & paperboard in the total paper consumption (from 76% in 2020 up to 87% in 2050). In the EU27 region the production of paper & paperboard is expected to slowly decline until 2050 due to decline in graphic paper demand and slow increase of other paper & paperboard consumption. As a result, the use of recycled and chemical pulp fibres will slowly decline. The latter leads to less pulpwood demand for paper leaving more pulpwood available for production of dissolving pulp and MMCF, especially after 2030. Altogether, the projected trends in the consumption and production of forest products in the EU27 suggests a rather stable level of industrial roundwood harvest, compared to projected increase in the industrial roundwood harvest globally by 28% between 2020 and 2050. This growth is mainly driven by a substantial growth of wood-based panels (55% of the global production increase over 2020 – 2050 in Asia and only 5% in EU27 and 16% in Russia) and to a lesser degree by global sawnwood production growth (36% of the global production increase over 2020 – 2050 in Russia and only 3% in EU27 and 21% in Asia and North America each).

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2. Introduction

2.1 Background

The updated EU Bioeconomy Strategy (European Commission,2018a) adopted in October 2018 aims to develop a sustainable bioeconomy for Europe, strengthening the connection between economy, society, and the environment. The updated Bioeconomy Strategy addresses the competing use of biological resources (animals, plants, micro-organisms, and derived biomass, including organic waste), encompassing multiple sectors and policies with a view to achieving policy coherence and synergies. To guide and support the transformational change to a sustainable bioeconomy, knowledge and forward-looking capacities are needed (O'Brien et al., 2017; Wesseler and Braun, 2017; Angenendt et al., 2018). In this context, the overall objective of the BioMonitor project is to establish a robust and effective framework to develop statistics and modelling tools for the bioeconomy. This framework will enable the quantification of the bioeconomy and its economic, environmental, and social impacts in the EU. Within the project, an analysis has been made of existing bioeconomy modelling capacities (D4.1), as well as an analysis of requirements and priorities for improved bioeconomy modelling (D4.2). Based on these analyses, D4.3 presented the design of the BioMonitor Model Toolbox, which to be built from existing tools, but which must be enhanced for bioeconomy analyses, as well as new tools that need to be developed in order to fill specific gaps on bioeconomy analysis.

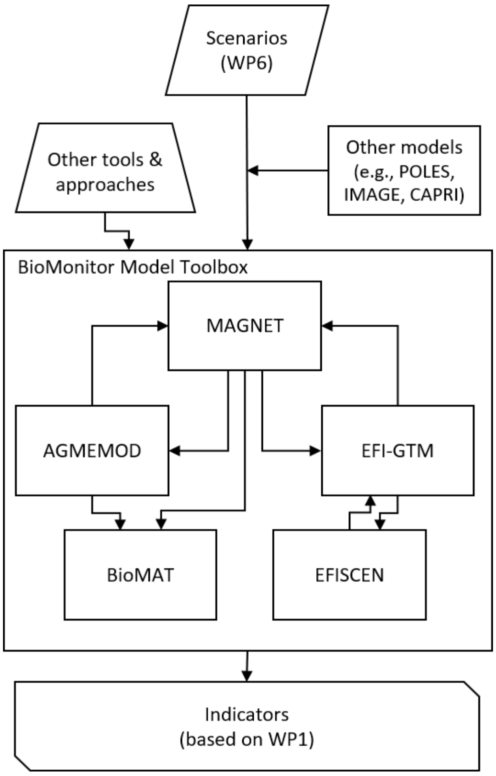

Figure 1 - BioMonitor Model Toolbox (Source: Deliverable 4.3)

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Taking the design of the BioMonitor Model Toolbox (D4.3; **Error! Reference source not found.**) as starting point, Task 5.2 of the BioMonitor project develops methodologies to improve medium-term and long-term simulation models as solutions for the gap issues identified in WP4, This deliverable provides potential future market outlooks for new bio-based commodities produced by the enhanced AGMEMOD and EFI-GTM and the new developed BioMAT model.

2.2 Role of BioMAT in the BioMonitor Toolbox

The BioMAT model applies the same framework as AGMEMOD (Deliverable 4.3) and accounts for supply, imports, exports, uses and prices of innovative bio-based products in EU Member States. It obtains input data from AGMEMOD (agricultural biomass from end-stages of the agri-food value chains available for material uses) and EFI-GTM (woody biomass) to begin with the representation of the bio-based product value chains. These then flow downstream to two subsequent processing stages: (i) bio-based platform products (or feedstocks) for the chemical industry like technical starch, industrial sugars, and plant oils (2nd processing stage in the value chain); and (ii) semi-final products (3rd processing stage in the value chain). The focus of BioMAT is on (chemical) products that dominantly use fossil-based feedstock so far, but have potential to replace fossil-based feedstock by bio-based feedstock. As there are hundreds of (composite) products that have potential to be transferred into bio-based products (see PRODCOM database), individual chemical products are clustered into application groups (e.g. chemical platforms, surfactants, polymers, solvents, paints, cosmetics and lubricants), as well as linked to feedstock needs. It is important to highlight that the variety of data collection methodologies developed in WP3 of the BioMonitor project form the base for the compiled BioMAT database. Moreover, studies conducted by Spekreijse *et al.* (2019) and Nova-Institute (2015a, 2015b) have been used to validate the reliability of the BioMAT database.

Table 1 gives an overview of the tasks that have been conducted (partly still ongoing process) to develop the BioMAT model, which includes the compilation of the database, the set-up of model equations and its estimation process, the projection of bio-based product markets under reference and alternative scenarios in the EU and its member states, and the validation of model results with internal and external stakeholders.

Table 1 - Development procedure of the BioMAT model

Tasks	Output
Developing the BioMAT conceptual framework	
Setting the conceptual model framework for bio-based product markets.	Flow chart with market and price relations describing EU bio-based products.
Specifying commodity market equations, and determining BioMATs' data needs.	Generic set of equations appliable to all bio-based products and all countries covered in BioMAT.
Developing the IT framework of BioMAT.	Menu based user-interface that deals with data reading, defining assumptions and scenarios, estimating equations, processing data, running the model, and showing output.
Building the BioMAT database	
Collecting data, processing and compiling market balances (link to WP3).	Preliminary set of market balances for bio-based products over 2010-2018 for EU members and UK.
Validating bio-based product market balances with BioMonitor experts and external stakeholder. Collecting and integrating feedback (link to WP3).	Improved set of market balances for bio-based products of EU members and UK over 2010-2018. The balances are a key part of the BioMAT database.
Building the BioMAT model	
Estimating/calibrating equations for bio-based product markets.	Preliminary set of estimated/calibrated equations for bio-based product markets of EU members and UK.
Running the model and providing projections for bio-based product market variables.	Preliminary set of market projections (price, production, consumption and trade) for bio-based products of EU members and UK, up to 2030, in a reference situation.
Validating market projections with BioMonitor experts and external stakeholders. Collecting and integrating feedback. Re-estimating equations.	Improved set of market projections (price, production, consumption and trade) for bio-based products of EU members and UK, up to 2030, in a reference situation.
Impact assessments	
Analysing the impacts of bioeconomy issues in the reference and alternative scenarios (link to WP6).	Reference situation, and impacts of alternative situations on future markets of bio-based products in EU members and UK, up to 2030.

Source: Authors.

2.3 Role of EFI-GTM in the BioMonitor Toolbox

The EFI-GTM model is a multi-regional and multi-periodic partial equilibrium model of the global forest sector. It depicts the system consisting of wood supply, forest industries (sawmilling, wood-based panels, pulp and paper industries) and production of wood-based energy and biofuels, demand for forest industry products and woody biomass for energy, and international trade in wood and forest products. The model has a detailed representation of European countries and considers other countries in global regions; in total there are 57 countries and regions covering the world. The model includes about 30 forest industry and energy sector products, five roundwood categories, three categories for forest chips, four recycled paper grades, and the main by-products of the forest industries, such as sawmill chips, sawdust and black liquor.

2.4 Structure of this report

This report reports on the elaboration of future market outlooks for new bio-based commodities and consists of two parts. Part I is devoted to the BioMAT model. Chapter 3 describes the current status of the penetration of bio-based products for specific chemical product categories in the EU and motivates the selection of application groups to be modelled. Chapter 4 elaborates on the model structure of the BioMAT model, while Chapter 5 describes the set of equations used for bio-based chemical applications, as well their connection to biomass feedstock markets. Chapter 6 describes the development of the BioMAT database. Finally, Chapter 7 shows a selection of trends and projections based on the BioMAT model. Part II is devoted to the improvement of the EFI-GTM model (Chapter 8) and also highlights market outlooks of the newly included wood products.

Part I: Development of the BioMAT model

3. Bio-based chemical markets

3.1 General considerations

In general terms, bioeconomy sectors deal with the production of renewable biological resources and convert these into food, feed, bio-based products and bioenergy. More specifically, Deliverable 1.1 of the BioMonitor project provides a list of sectors that belong to the bioeconomy. They are partly traditional bioeconomy sectors, e.g. agriculture, forestry, fishing, food processing, wood products, and paper (which was already fully bio-based), and partly considered as emerging bio-based sectors, e.g. textile, chemicals, plastics and pharmaceutical sectors (partly bio-based).

Ronzon et al. (2022) provide estimates of the number of people employed (17.5 million) and the value added generated (614 million €) by the bioeconomy sectors in the EU and its Member States (Table 2). The bioeconomy contributes to around 8.2% of the EU labour force and about 4.5% of the EU GDP taking into account all fossil-based and bio-based activities.

Table 2 - Number of persons employed, value added), and apparent labor productivity by sector of the bioeconomy in the EU27, 2019

	Persons employed (1000)	Value added (€ Mio)	Labour productivity (€1000/person)
Agriculture	9303	215294	23.1
Food, beverage and tobacco	4399	189699	43.1
Wood products and furniture	1288	59929	46.5
Bio-based textiles	790	43652	55.2
Paper	605	43410	71.7
Forestry	529	25466	48.1
Bio-based chemicals, pharmaceuticals, plastics and rubber (excl. biofuels)	405	23512	58.1
Fishing and Aquaculture	169	6342	37.6
Bio-based electricity	23	4209	186.6
Liquid biofuels	20	3211	156.9
Total Bioeconomy	*17531*	*614725*	*35.1*

Source: Ronzon et al. (2022)

The use of biomass, or bio-based feedstock, for material applications can play an important role in making economies sustainable and in the transition towards a CO_2-neutral and circular economy in 2050. Biomass has the potential to reduce climate impacts of chemical and construction sectors in particular. This is obviously mentioned in e.g. the EC Circular Economy Strategy (2019) and also advised by the Social and Economic Council to the Dutch government in 2020. The use of bio-based feedstock for food and feed applications is a high priority within the value added pyramid, followed by the deployment of biomass for material applications and as feedstock for the chemical industry. In this context, BioMonitor intends to give insights into the current status as well as in the potential

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growth of bio-based product value chains related to the material application (especially bio-based chemicals) in EU Member States.

Schipfer et al. (2017) estimate fossil-based material production of respectively bio-bitumen, lubricants, bio-degradable polymers, solvents and surfactants (high value chemicals) in the EU. The authors also identify the status quo of advanced bio-based materials in 2015, and calculated their growth potential in 2030 and 2050 (Figure 2) under a reference scenario (which assumes no major breakthrough in research) and a transition scenario (which considers a 70% substitution to bio-based feedstock for all products in 2050). The study finds that bio-based surfactants show the lowest potential for growth as it already has a significant market share. Bio-based lubricant production is assumed to grow from 0.2 Mt to 3.1 MT in the reference scenario, as well as reaching 6.8 MT in the case of the transition scenario. While demand for bio-based materials in the EU was estimated to be about 4.1 Mt in 2015, Schipfer et al. (2017) calculate that the need for reaching production as outlined in Figure 2 would have to increase to 8.9 Mt and 25 Mt in 2030, and up to 24 Mt and 117.8 Mt in 2050 in the reference and transition scenario respectively.

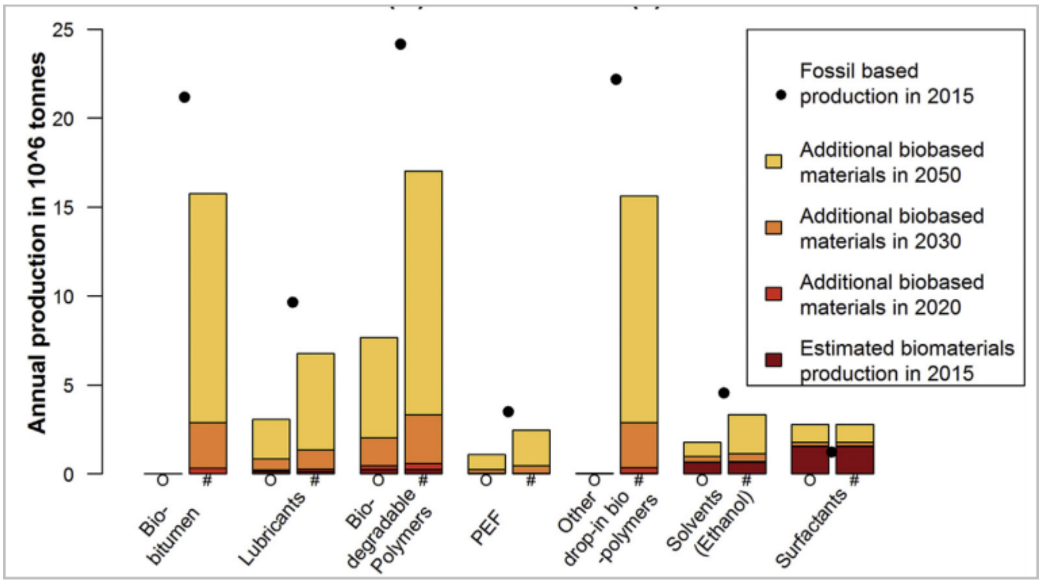

Figure 2 - EU cumulated production capacities of advanced bio-based materials in Reference (O) and Transition (#) scenario (Source: Reproduced from Schipfer et al., 2017)

In light of emphasizing the role of the chemical sector within the development of the bio-based economy, the study by Spekreijse et al. (2019) map 50 products that fall under the NACE C20 chemical sector (PRODCOM statistics) over ten product application groups. According to this study, platform chemicals and polymers for plastics both have the highest share (39%) in the total C20 production value of the EU28 in 2016. The third column in Table 3 shows the estimated EU bio-based production, while the last column displays the estimated bio-based content share per chemical product group. With an overall EU bio-based production of 4.7 Mton, the overall bio-based share amounts to 3% of this EU total (around 155 Mton).

Table 3 - EU28 total and bio-based production (1000t) and biomass feedstock use in NACE C20

Product application groups in chemical industry	EU total production	*% group in total C20*	EU bio-based production	*% bio-based in group total*
Platform chemicals	60791	*39%*	181	*0.3%*
Solvents	5000	*3%*	75	*1.5%*
Polymers for plastics	60000	*39%*	268	*0.4%*
Paints, coatings, inks and dyes	10340	*7%*	1002	*9.7%*
Surfactants	3000	*2%*	1500	*50.0%*
Cosmetics, personal care products	1263	*1%*	558	*44.2%*
Adhesives	2680	*2%*	237	*8.8%*
Lubricants	6764	*4%*	237	*3.5%*
Plasticisers, rubber/plastic stabilisers	1300	*1%*	67	*5.2%*
Man-made fibres	4500	*3%*	600	*13.3%*
Total	*155638*	*100%*	*4725*	*3.0%*

Source: Spekreijse et al (2019). Note: Since authors could not find EU total production data, they assumed that EU total production (fossil and bio-based) equals EU total market (fossil and bio-based consumption).

Apart from that, Spekreijse et al. (2019) also provide estimates for the biomass feedstock use (i.e. starch and sugars, oil plants, wood and others) of the bio-based products for each of the ten chemical product application groups (Table 4). In particular, almost two thirds of the feedstock used relate to vegetable oils, one fifth to sugar and starch and around 17% to woody biomass. The reader should note that findings do not correspond to a specific year and thus must be considered as proxies/estimates given the best knowledge available at the moment.

Table 4 - Total feedstock use (kton/year) and share of domestic and imported feedstock (%) for EU28 production of bio-based product application groups

Product application groups in chemical industry	Sugar/ starch	Vegetable oils	Wood	Other	Total	*% Imports in use*
Platform chemicals	169	93	0	0	262	*34%*
Solvents	30	0	57	0	87	*3%*
Polymers for plastics	284	0	0	0	284	*10%*
Paints, coatings, inks and dyes	0	593	0	0	593	*79%*
Surfactants	284	1460	0	0	1744	*68%*
Cosmetics, personal care products	65	378	2	10	456	*67%*
Adhesives	0	12	171	49	232	*6%*
Lubricants	0	189	3	0	192	*78%*
Plasticisers, rubber/plastic stabilisers	54	52	0	0	106	*44%*
Man-made fibres	0	24	532	0	555	*3%*
Total feedstock use	886	2802	765	59	4511	*51%*
% Feedstock type in total use	*20%*	*62%*	*17%*	*1%*	*100%*	

Source: Table 23 in Spekreijse et al. (2019).

3.2 Defining bio-based products

In a similar fashion as the studies by Schipfer et al. (2017) and Spekreijse et al. (2019), the focus of BioMAT is on analysing supply, use, trade flows and prices of bio-based chemical markets in EU Member States in the medium and long-term. On top of that, the BioMAT model makes important additional contributions compared to aforementioned studies, namely:

- It considers all products of PRODCOM's C20 group and maps them to bio-based shares and to chemical applications.

- It distinguishes a high detail of chemical applications (Table 5).
- It calculates market items of bio-based applications at the EU Member State level and for the period 2008-2018.
- It links bio-based applications to feedstock types via conversion efficiency rates.
- It makes forward looking projections for markets of bio-based applications under scenarios.

According to Eurostat's PRODCOM database, the chemical sector (NACE C20) encompasses more than 550 eight-digit numerical codes (PRRODCOM code), each of which cover one or more chemical products. For individual chemicals products the first six digits of their PRODCOM code are identical to their Statistical Classification of Products by Activity (CPA) code. The PRODCOM codes list is thus fully consistent with the CPA, while further detailing the CPA product categories. The mapping of PRODCOM codes to the codes of the Combined Nomenclature (CN), used to compile international trade in goods statistics, enables the linkage of industrial production statistics and trade statistics.[1] Though it is obvious that chemical products are quite diverse in terms of features, functionalities or position in the value chain, it is not meaningful to develop forward looking market models at the – sometimes very small - individual product level. As solution for covering the complete set of C20 chemical products reported in PRODCOM, output of each individual PRODCOM code is assigned to an overarching product application group. Table 5 gives the typology of distinguished application groups within the chemical industry used in BioMAT. Table 6 describes the types. Section 6 describes the process of mapping the PRODCOM codes to application categories. At this point, however, two important issues should be mentioned:

- Each application group is identified to be either a semi-final product group or an intermediate group. In this context, the group 'platform chemicals' is the only intermediate application variant and used as feedstock for production of other chemicals downstream the value chain.
- Output of each PRODCOM code can be assigned to one or more application categories. If a specific product is assigned to more than one application categories, this is either to a semi-final or intermediate category or to a mixture of both.[2]

Table 5 - Fifteen bio-based product application groups in chemical sector covered in BioMAT (Source: Authors)

Adhesives	Agro-chemicals	Biofuels	Construction	Cosmetics
Food & feed	Lubricants	Manmade fibres	Paint & coatings	Pharmaceuticals
Platform chemicals	Polymers for plastics	Solvents	Surfactants	Other applications

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[1] Available at: https://ec.europa.eu/eurostat/web/prodcom.

[2] 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 belong the category "intermediates": (i) sugar/starch-based platform chemicals; and (ii) oil-based platform chemicals.

Table 6 - Typology and description of the fifteen bio-based product applications within 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 product application categories** (also 'product groups'). Each product 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: covers the 'intermediate' product group and includes chemicals that are used for production of other chemicals. It is a large group (in terms of volume and value), as a considerable part of 'semi-final' products is not produced in a single step (directly from feedstock), but through other chemical products (intermediates) as input. Among others, this category includes fatty acids, diols, ethers, ketones but also resins and many other substances.

Solvents: chemical products used to dissolve a solute, resulting in a solution. Solvents are mainly used by industry to produce inks but also paints and varnishes. The EU bio-based consumption for this product grew from 60 kt in 1998 to 630 kt in 2008 compared to 4.4 Mt fossil-based solvents.

Polymers for plastics: chemical products used for production of plastics (C22). Plastics are used in a wide range of products due to their low costs and good shape-abilities. Bio-based PET or polyethylene furanoate (PEF) is considered to substitute fossil-based PET. The EU bio-based consumption and production for bio-based polymers exhibited a growth from 25 kt in 1998 to 130 kt in 2008 compared to 48 Mt fossil-based complements. The Institute for Bioplastics and Biocomposites[3] states an EU bio-based production capacity of 261 kt in 2014. A growth rate of about 50% for the six years period between 2008 and 2014 can be outlined.

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. This property makes it applicable for example for soaps, herbicides, wetting agents, cosmetics, fabric softeners and any other application where two dissimilar types of compounds are mixed. The EU bio-based consumption for this product grew from 1.18 Mt in 1998 to 1.52 Mt in 2008 compared to 1.2 Mt fossil-based surfactants (see Schipher et al., 2017). Within this category, surface active agents, soaps and detergents and washing preparations are included.

Cosmetics; personal care products: a wide variety of 'semi-final' products with applications in cosmetics and personal care. Examples include perfumes, but also shampoo, dental products and polishes and creams. Please note that some of the 'semi-final' products within this application group contain surfactants, but other surfactants are classified in the surfactant group.

Adhesives: substances used to bind items together to resist their separation. For example, starch-based glues but also epoxide resins and other resins belong to this category.

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[3] https://www.ifbb-hannover.de/en/

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Lubricants: products used to reduce friction between two surfaces. Because of the lower toxicity and biodegradability compared to the fossil-based reference product, some countries have banned the use of non-biodegradable lubricants in sensitive areas at least in applications where oils are lost into soil and surface waters. EU bio-based consumption for this product grew from 100 kt in 1998 to 150 kt in 2008 compared to 9.3 Mt fossil based.

Man-made fibres: chemical products used for production of fibres such as polyesters, viscose and cellulose acetate which are used in 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. *Note that the fossil-based fuels are not in C20 but reported in C19.*

Pharmaceuticals: products used for 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 & feed: chemical products used by the food and feed industries, for example as antioxidants or preservatives or rheology modifiers. The most important product that belong to this category is citric acid, which is used as a preservative. It also includes flavours used for food applications.

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, polyurethanes), resins, insulation materials, but also wood polishes.

Agrochemicals: chemicals used in agriculture. It includes, among others, herbicides, pesticides, insecticides as well as urea and several chemicals required in the production of herbicides, pesticides and insecticides.

Other applications: due to the wide range of application fields 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 refrigerant, military applications, fireworks, fuses, waste water treatment and photographic plates

The production volume of all C20 products amounts to 562 Mio ton for the EU28 in 2018 (Table 7). A significant share (46%) of the 550 products are ‘inorganic’ (without carbon contents) products and thus not transmittable from fossil-based carbon (^{12}C) into bio-based carbon (^{14}C). Therefore, the potential production volume of C20 organic products, which are substitutable into bio-based carbon, is restricted to 305 Mio ton in 2018 (see first column of Table 7) The second column shows the contribution of each application group to the total C20 production volume of organic products in the EU28 in 2018. One third of the organic C20 products are platform chemicals, one quarter are polymers for plastics, 7% are paints and coatings, 6% are surfactants, while the last quarter is scattered over the other applications (second column). The third and fourth columns reports on the estimated production volume of bio-based products and the bio-based share within the application group respectively. Insights on the development of bio-based contents and bio-based shares is gathered from an annual stakeholder survey, organised by nova-Institute. The process of calculating the bio-based production of each PRODCOM codes is also described in section 6. Note that the two largest application groups, i.e. platform chemicals and polymers for plastics, so far perform rather low bio-based shares with 5.2% and 1.3% respectively. Overall, about 14% of the EU chemical industry rely on biological resources in 2018, where biofuels and food and feed are far above this average, followed by surfactants, pharmaceuticals and adhesives.

Table 7 - Production volume (1000t) of total and bio-based C20 product groups in EU28 in 2018, used in BioMonitor

Product application groups in chemical industry	Total production (bio-based and fossil-based)	% in total C20		Bio-based production	% Bio-based in total production
Platform chemicals	103145	*34%*		4770	*4.6%*
Solvents	6069	*2%*		1031	17.0%
Polymers for plastics	78130	*26%*		780	1.0%
Paints, coatings, inks and dyes	20312	*7%*		724	3.6%
Surfactants	18560	*6%*		4693	25.3%
Cosmetics; personal care products	7341	*2%*		2803	38.2%
Adhesives	5392	*2%*		1242	23.0%
Lubricants	4624	*2%*		291	6.3%
Man-made fibres	5934	*2%*		648	10.9%
Biofuels	16429	*5%*		14067	85.6%
Pharmaceuticals	2421	*1%*		681	28.1%
Food & feed	4246	*1%*		2547	60.0%
Construction	4766	*2%*		164	3.4%
Other applications	8248	*3%*		271	3.3%
Agrochemicals	19321	*6%*		7497	38.8%
Total organic products in C20	*304939 (54%)*	*100%*		*43586*	*13.8%*
Total inorganic products in C20	*257053 (46%)*				
Total organic and inorganic product in C20	*561991*				

Source: Own calculations and estimates based on PRODCOM statistics, literature and expert knowledge.

One of the most popular indicators used to show the contribution of the bioeconomy in chemical industry is the bio-based share in production volume. In the Biomonitor project we estimate that bio-based products make 13,8% of total organic products in C20. In comparison, Spekreijse et al. (2019) estimate the bio-based share to be 3%. However, findings on bio-based shares of Spekreijse et al. (2019) (Table 3) and those gained in the Biomonitor project (Table 7) can be compared only to a limited extent as the figures on the total (bio-based and fossil-based) production volume as well as figures on bio-based production volumes are quite different. Estimated in the Biomonitor project figure on bio-based total production (43 Mio. tons) is much higher than those reported by Spekreijse et al. (4.7 Mio. tons). But also, the respective “Total” (bio-based and fossil-based) used in Spekreijse et al. is much lower than calculated in the Biomonitor project (“Total C20” = 562 Mt, “Total organic” = 305 Mt). There are two main reasons for that: 1) **different product coverage** and, 2) **different calculation approaches**. With respect to product coverage, Spekreijse et al. look at just 50 chemical products within the C20 industry, whereas BioMonitor considers all products. Spekreijse et al. exclude the rest due to time constraints and mention that there are more bio-based products than the ones they investigate[4]. This different product coverage can be an explanation why total and bio-

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[4] See their statement in section 2.6 on page 27.

This project has received funding from the European Union’s Horizon 2020
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based production differ also within the same category. This apart from the issue that mappings used by Spekreijse et al. and in the Biomonitor project are not entirely similar. Some product categories defined in the Biomonitor project ('biofuels', 'pharmaceuticals', 'food & feed', 'construction', 'agrochemicals' and 'other applications') are not considered in Spekreijse et al. Therefore, it is logical that figures on total volume of bio-based production estimated by Spekreijse et al. are lower than those estimated in the Biomonitor project, although the magnitude of the difference is a bit surprising (4.7 Mt and 43,5 Mt respectively). Regarding the calculation approach: in the BioMonitor project we usebio-based shares for each C20 PRODCOM code estimated based on a stakeholder survey as a starting point and then calculate the bio-based production of the specific PRODCOM code by linking the shares to its total production in PRODCOM. In their approach, Spekreijse et al. first estimate the bio-based production of the 50 products based on literature and market reports about available product sites located throughout the EU. For some products all sites and production capacities are disclosed, whereas for other products no data could be obtained. In the next step, Spekreijse et al. derive the bio-based share for the 50 products by relating the calculated bio-based production volume to the total production volume. Table 8 shows the shares of the EU Member States in the total EU production volume of C20 products in 2010 and 2018. Seven countries, i.e. Germany (25%), France (13%), Italy (13%), Spain (10%), Netherlands (13%), Belgium (7%) and Poland (4%) are responsible for 85% of total C20 production (fossil and bio-based) in 2018.

Table 8 - Production volume (1000t) of C20 product groups in EU member states, in 2010 and 2018

Member states	2010	*% in EU*		2018	*% in EU*
Austria	6923	2.5%		5834	1.9%
Belgium	22029	7.9%		21599	7.1%
Bulgaria	851	0.3%		1245	0.4%
Croatia	498	0.2%		287	0.1%
Cyprus	51	0.0%		38	0.0%
Czech Rep.	4291	1.5%		4580	1.5%
Denmark	1194	0.4%		1249	0.4%
Estonia	206	0.1%		395	0.1%
Finland	3108	1.1%		3694	1.2%
France	34700	12.4%		38488	12.6%
Germany, Fed. Rep.	75493	27.0%		76119	25.0%
Greece	857	0.3%		802	0.3%
Hungary	3043	1.1%		4973	1.6%
Ireland	1433	0.5%		3176	1.0%
Italy	30633	11.0%		38784	12.7%
Latvia	107	0.0%		192	0.1%
Lithuania	739	0.3%		911	0.3%
Luxembourg	109	0.0%		173	0.1%
Malta	17	0.0%		17	0.0%
Netherlands	29302	10.5%		38106	12.5%
Poland	7678	2.8%		10560	3.5%
Portugal	3195	1.1%		3052	1.0%
Romania	1444	0.5%		1477	0.5%
Slovakia	1264	0.5%		975	0.3%
Slovenia	577	0.2%		674	0.2%
Spain	26817	9.6%		31173	10.2%
Sweden	4757	1.7%		4821	1.6%
United Kingdom	17863	6.4%		11571	3.8%
EU 28	*279179*	*100%*		*304965*	*100%*

Source: Own calculations and estimates based on PRODCOM statistics, literature and expert knowledge (Section 5).

3.3 Feedstock use of bio-based products

Production of bio-based products requires biomass instead of fossil fuels as feedstock. Biomass that is available for material use is processed into bio-based materials or products via converting technologies. For example, starch and sugar are converted into polymers via the 'fermentation' route: i.e. *starch and sugar => bioethanol => bioethylene => polymers*. In fact, conversion factors reflect the state of play of a technology as measured by the volume of starch and sugar used (x tonnes) to produce one tonne of polymer (in the example). The reciprocal of the conversion factor is regarded as *conversion efficiency rate*, i.e. it measures the tonnes of polymers that can be processed from one tonne of biomass feedstock. If efficiency increases, then the need for biomass feedstock declines. Table 9 shows the ten biological feedstock types used in the bio-based chemical sector as covered in BioMAT.

Table 9 - Ten biological feedstock types used in the bio-based chemical sector covered in BioMAT (Source: Authors)

Sugar	Starch	Plant oils	Sugar and starch based chemical platforms	Lignocellulose from agriculture
Lignocellulose from forestry	Animal biomass	Aquatic biomass	Plant oil based chemical platforms	Other feedstock

The relation between EU bio-based chemical production and its dependency on biomass feedstock types is established by combining economic, technological and chemical engineering expertise within the BioMonitor consortium (combined work of WP3 and WP5). During this data gathering process, firstly, the shares of feedstock type dependency per bio-based product and per bio-based application group are calculated. Those feedstock types that are dominantly used (> 25% share) within an application group are highlighted in yellow (see, Secondly, conversion factors of feedstock types per bio-based product and per bio-based product application are derived, by weighting the production volumes of the individual C20 products. High conversion factors (> 4) are highlighted in red (see Table 11). For example, the conversion factor 5 (column 3, row 2) means that 5 kg plant oils is needed to process 1 kg of solvent. The reciprocal is considered as the conversion efficiency rate, which means that 1 kg plant oil can produce 0.2 kg of solvent.

Thirdly, feedstock shares and conversion rates of bio-based products within the application groups are linked to their respective bio-based products productions (see Table 7) which provides estimates for total feedstock use per bio-based application group (Table 12). In 2018, the significant amount of 44% of EU's total biological feedstock use (55 Mton) is processed into biofuels, while another 13% goes to chemical platform products and 6% to surfactants. The rest is scattered over other application groups.
Table 10).

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Table 10 - Share of biological feedstock types per bio-based application group (ratio), EU28, in 2018

	Sugar	Starch	Plant oils	Lignoc. forestry	Lignoc. agric.	Animal biomass	Aquatic biomass	Other feedstock	Sugar platform	Oil platform
Platform chemicals	0.03	0.04	0.40	0.19	0.00	0.11	0.00	0.04	0.02	0.17
Solvents	0.14	0.73	0.00	0.08	0.02	0.00	0.00	0.01	0.03	0.00
Polymers for plastics	0.03	0.03	0.04	0.25	0.00	0.02	0.11	0.43	0.01	0.08
Paints, coat, ink	0.00	0.00	0.00	0.37	0.00	0.32	0.00	0.01	0.01	0.29
Surfactants	0.02	0.02	0.23	0.00	0.00	0.06	0.00	0.00	0.08	0.60
Cosmetics; pers. care	0.03	0.20	0.17	0.01	0.00	0.01	0.00	0.09	0.13	0.37
Adhesives	0.00	0.13	0.00	0.07	0.00	0.21	0.00	0.00	0.29	0.29
Lubricants	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.96
Man-made fibres	0.00	0.00	0.03	0.88	0.00	0.02	0.00	0.05	0.00	0.01
Biofuels	0.04	0.19	0.61	0.00	0.00	0.04	0.00	0.12	0.00	0.00
Pharmaceuticals	0.08	0.16	0.14	0.14	0.00	0.38	0.00	0.06	0.03	0.01
Food & feed	0.13	0.28	0.06	0.12	0.00	0.15	0.00	0.27	0.00	0.00
Construction	0.00	0.00	0.02	0.78	0.01	0.00	0.00	0.00	0.03	0.17
Other applications	0.00	0.00	0.59	0.16	0.00	0.07	0.00	0.15	0.01	0.02
Agrochemicals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00

Source: Own calculations based on PRODCOM statistics, literature and expert knowledge (Section 5).

Table 11 - Conversion rates of feedstock types per bio-based application group (ratio), EU28, in 2018

	Sugar	Starch	Plant oils	Lignoc. forestry	Lignoc. agric.	Animal biomass	Aquatic biomass	Other feedstock	Sugar platform	Oil platform	*Av conv rate*
Platform chemicals	3.14	2.66	1.06	0.48	1.50	1.13	0.00	8.88	1.20	1.21	*1.35*
Solvents	2.03	2.99	5.00	8.12	2.65	0.00	0.00	2.40	1.20	0.00	*0.00*
Polymers plastics	1.80	2.00	1.21	1.71	0.00	2.34	1.20	1.20	1.54	1.21	*3.21*
Paint, coat, ink	0.00	0.00	1.00	2.02	10.00	3.03	0.00	0.54	1.05	1.01	*1.40*
Surfactants	3.03	2.83	1.12	0.00	0.00	1.11	0.00	0.00	0.41	0.47	*2.02*
Cosmetics; personal care	2.03	2.41	0.78	4.76	2.71	0.77	0.00	0.92	0.67	0.74	*0.73*
Adhesives	0.00	1.00	0.00	0.60	10.00	1.10	0.00	0.00	1.00	1.00	*1.16*
Lubricants	0.00	0.00	1.20	0.00	0.00	1.20	0.00	0.00	0.00	1.00	*0.99*
Man-made fibres	0.00	0.00	1.20	2.73	0.00	3.59	0.00	0.00	2.15	1.25	*1.01*
Biofuels	2.07	3.00	1.20	2.40	2.40	1.20	0.00	1.03	1.00	1.09	*2.55*
Pharmaceu-ticals	2.33	1.75	0.51	4.33	7.51	2.67	0.00	0.97	1.19	1.29	*1.57*
Food & feed	2.75	2.32	0.43	3.16	2.40	2.49	0.00	0.98	1.20	1.33	*2.29*
Construction	0.00	0.00	1.20	3.43	10.00	0.00	0.00	0.00	1.57	1.21	*2.03*
Other applicat.	1.50	1.70	0.45	4.99	1.50	1.02	0.00	0.77	1.00	1.20	*3.01*
Agrochemicals	0.00	0.00	5.00	10.00	10.00	0.00	0.00	0.53	1.00	1.15	*1.27*

Source: Own calculations based on PRODCOM statistics, literature and expert knowledge (Section 5).

Table 12 - Total feedstock use per bio-based application group (1000 t), EU28, in 2018

	Sugar	Starch	Plant oils	Lignoc. forestry	Lignoc. agric.	Animal biomass	Aquatic biomass	Other feedstock	Sugar platform	Oil plat-form	*Total use*
Platform chemicals	431	489	2091	444	3	619	0	1778	122	985	*6962*
Solvents	118	908	0	269	21	0	0	9	14	0	*1340*
Polymers plastics	41	46	36	329	0	43	101	404	18	75	*1093*
Paint, coat, ink	0	0	3	537	1	702	0	4	7	211	*1465*
Surfactants	214	228	1222	0	0	295	0	0	155	1307	*3421*
Cosmetics; personal care	118	1055	289	80	21	18	0	179	185	598	*2542*
Adhesives	0	165	0	50	1	289	0	0	364	367	*1236*
Lubricants	0	0	9	0	0	4	0	0	0	280	*293*
Man-made fibres	0	0	23	1563	0	53	0	0	2	10	*1650*
Biofuels	1189	9094	11402	181	181	713	0	1875	1	1	*24636*
Pharmaceuticals	132	197	49	426	10	712	0	41	23	5	*1594*
Food & feed	753	1412	54	817	10	809	0	571	1	6	*4433*
Construction	0	0	4	439	12	0	0	0	8	33	*496*
Other applicat.	0	0	72	211	1	18	0	32	2	6	*343*
Agrochemicals	0	0	0	0	1	0	0	3940	1	4	*3947*
Total feedstock use	*2996*	*13595*	*15254*	*5346*	*261*	*4274*	*101*	*8832*	*903*	*3888*	*55450*

Source: Own calculations based on PRODCOM statistics, literature and expert knowledge (section 5).

Table 12 also shows that nearly 30% of the feedstock used by the bio-based application groups relies on sugar and starch as main feedstock, 28% of the products is plant oil-based, while 9% is based on woody biomass and another 7% has animal biomass as source.

More details about the building of the BioMAT database can be found in Section 5. It also takes into account the allocation of starch needs for paper pulp production in the paper industry (NACE C17).

3.4 Caveats

It is important to highlight that the BioMAT model has to deal with incomplete statistical data sources at the bio-based product level. This despite the efforts as described in Section 2.3 and Section 5 to gain better insight in the development of the bio-based chemical market in EU member states. Some of the numbers are based on estimates – literature or stakeholder interviews - and thus have a certain level of uncertainty, e.g. regarding bio-based shares of chemical products, feedstock type use of chemical products and the feedstock efficiency of chemical products and price difference between bio-based and fossil-based products within same product code.

Despite these caveats, the contribution of the BioMonitor study is valuable as it makes important steps towards deriving - in a consistent way and departing from publicly statistical sources - a set of bio-based market indicators for each EU member state level and over a time period. There is openness about the assumptions used, which can be adapted when better data and knowledge become available. Another advantage of the developed market data generating process in BioMonitor is that the procedure is repeatable, e.g. if statistics or assumptions come up with updates.

4. BioMAT modelling framework

4.1 Scope

Table 5 showed the designed product application typologies within the C20 chemical sector, while Table 9 identified the key biological feedstock types used to produce the bio-based products within the application groups. BioMAT aims to model both the markets of the bio-based product applications and the biological feedstock needed to make production a fact.

Regarding the availability of biological feedstock for material use, AGMEMOD models specifically the supply of starch from wheat, corn and potatoes, industrial sugars from sugar beets and iso-glucose, and vegetable oils from rape, soy and sun seeds. Note that BioMAT is a satellite model of AGMEMOD and is directly linked to it.

4.2 Conceptual framework

The primary objective for developing BioMAT is to make available a tool able to assess from an economic point of view the impact of changes in the policy framework or in current conditions on bio-based chemical markets. BioMAT is an econometric, dynamic, partial-equilibrium, multi-country, multi-market model for EU bio-based product markets covering the EU with a Member State detail.[5] Similar to the AGMEMOD model (Chantreuil et al., 2012; Salamon et al., 2017) it follows a bottom-up approach departing from country-level models based on common templates. The combination of the country-product models delivers the composite EU model. Next, based on a set of product-specific model templates, country-specific models are developed to capture the key elements of the EU bio-based economy at Member State level. A detailed review of each template assures analytical consistency across the country models, essential for aggregation purposes. Adherence to common model templates and a consistent modelling approach also facilitates the comparison of impacts of a policy change across different countries. To recall, herewith BioMAT follows the same approach as AGMEMOD, and it runs within the same IT system. This enables direct connections between elements of the agro-food and bio-based value chains addressed by both models.

4.2.1 Structure of country module

BioMAT provides details on the main bio-based value chains at the EU Member States level. In terms of the construction of the equations, parameters are calibrated in those cases in which estimation is not feasible or meaningful, e.g. due to data scarcity. Each country model contains the behavioural responses of economic agents (producers and consumers) to changes in prices, policy instruments, consumer preferences, technical change and macro-economic conditions (Figure 3). Bio-based product prices adjust so as to ensure the market equilibrium. Such econometrically estimated or calibrated country specific bio-based market models provides a sound basis for analysing the impacts of changes facing the EU bio-based markets in the future. In terms of the time scope, BioMAT delivers annual projections for a medium-term horizon (10 years ahead) or longer as it can run until 2050.

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[5] See also Van Leeuwen et al. (*2022*) for an overview of the structure of the model.

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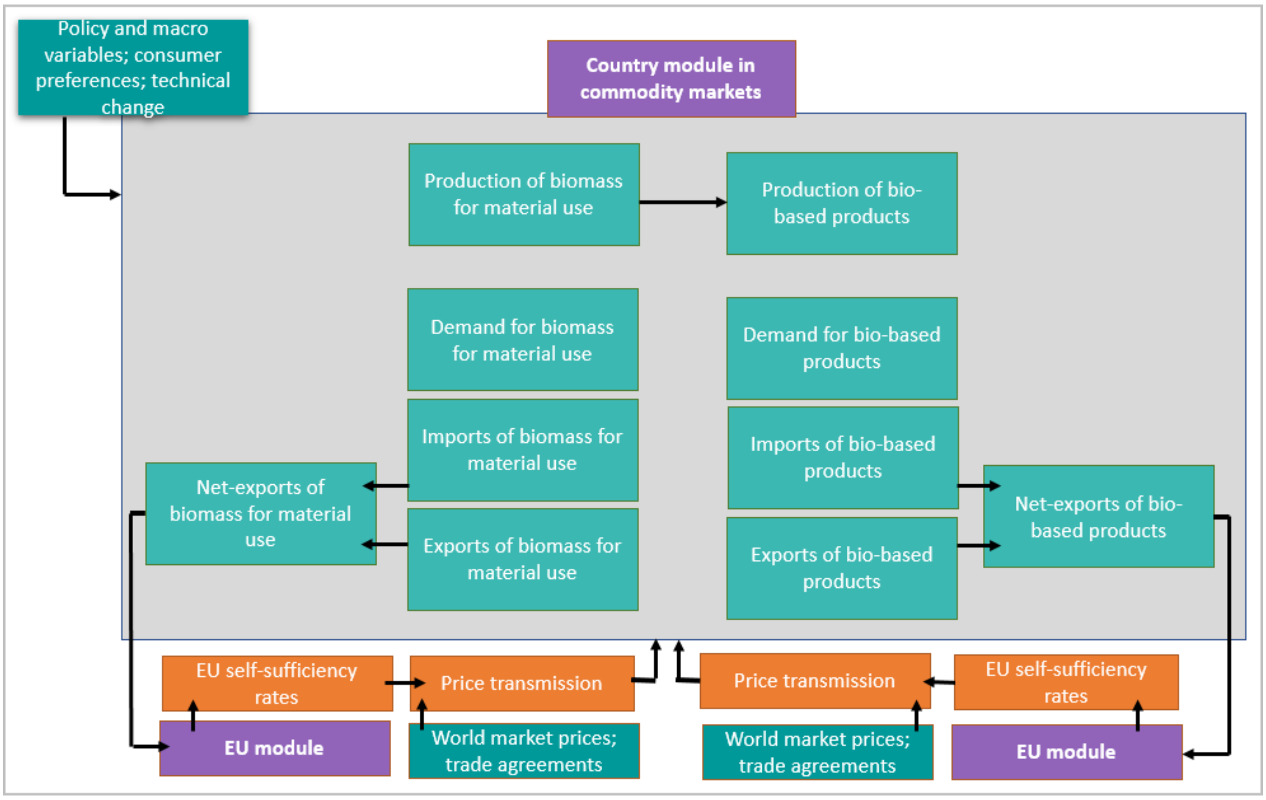

Figure 3 - Stylised market representation in BioMAT (Source: Authors)

In short, Figure 3 illustrates the general structure of a country model. Each country model in BioMAT comprises equations for bio-based product applications that represent the bio-based production in each Member State in the C20 chemical sector (see Table 6). Overall, the equations to determine endogenous variables describe the behavioural responses of agents (producer, consumer) to changes in, for example, market prices, policy instruments, macro-economic situation, consumer preferences and technical change. For each bio-based application, sets of behavioural equations describe the supply side (production and imports) and demand side (domestic use and exports) of the market. Supply and demand equations define how, in any given year, equilibrium (i.e. supply equals demand) is found within the single product application market. Further details on the equations that are included in each country model for each bio-based product application category is provided in Section 5.

4.2.2 Value chain representation

The BioMonitor consortium has brought together multi-disciplinary knowledge on how to connect traditional bioeconomy sectors (like agro-food, paper and textile) with emerging bio-based sectors (e.g., chemistry and plastics). An important outcome of this joint effort is a set of flow diagrams describing the processing routes of the bio-based value chains under consideration.

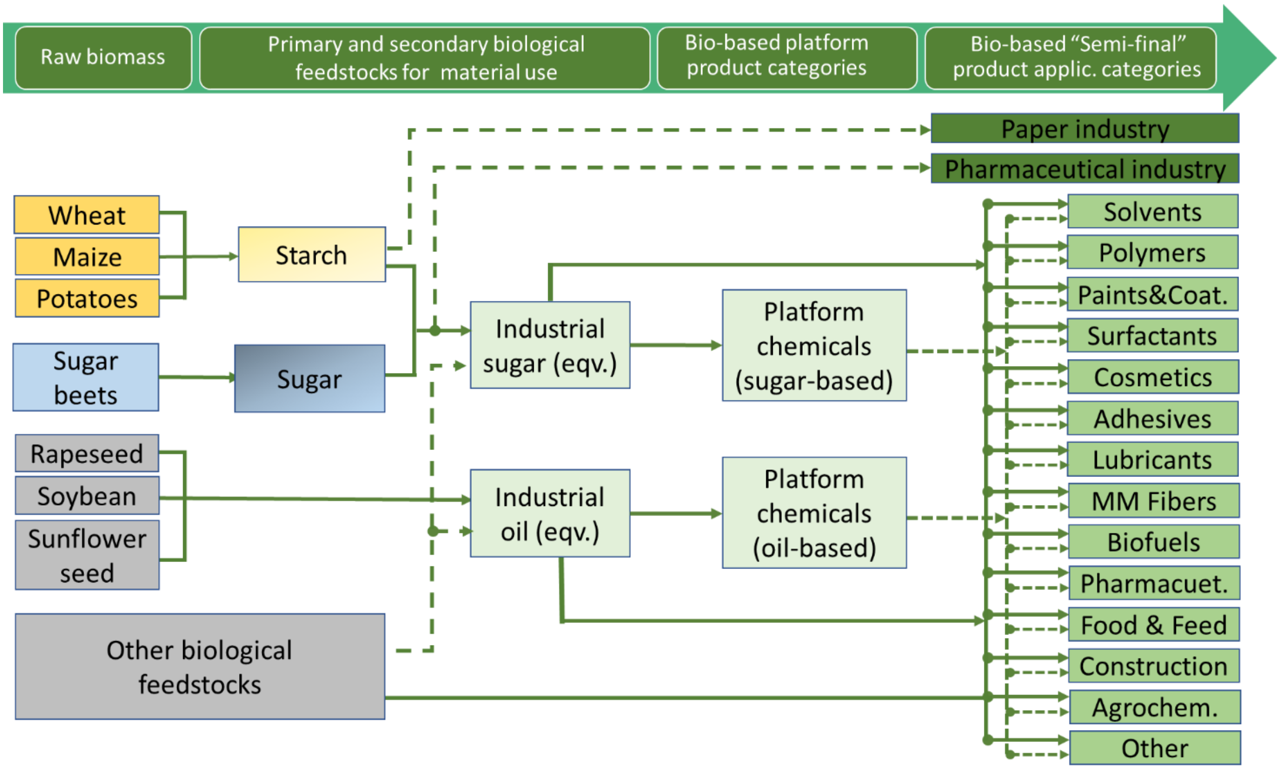

Figure 4 - Bio-based product value chains developed in the BioMonitor model toolbox (Source: Authors)

The structure of the value chains presented in Figure 4 is adopted in the partial-equilibrium models of the BioMonitor toolbox, i.e. EFI-GTM for roundwood based chemical applications (see Part II) and BioMAT for agricultural biomass based chemical applications (see Section 4).

In more detail and as a further illustration, Figure 5 shows how BioMAT links bio-based product application markets to the market of industrial sugars feedstock. A similar structure of the value chain is assumed for the market of starch and plant oil feedstock. The only difference is that depending on the type of application under consideration, like bio-based solvent, bio-based lubricants, etc., the main biological feedstock type that is used as input for the production process is different.

More specifically, emerging bio-based products are still at an early stage of its innovation process and most of them are not always competitive with its fossil-based counterparts, due to their relatively high production costs, unlevied playing field (e.g. due to the presence of tax measures that are not equally reaching all actors involved) and insufficient awareness of climate and other environmental problems on consumer and producer side. Therefore, interventions can facilitate the expansion of the bioeconomy, (i) on the supply side, through e.g. adoption of new technologies, CO_2-taxing the polluter; (ii) on the demand side, e.g. by imposing incentives to increase consumer's willingness to buy green products, regulations and certification demonstrating the sustainability aspect of using renewable resources instead of fossil-based resources. Possible driving factors to adapt, such as policy, technology, and consumer preferences, are shown in the pink balloons of Figure 5.

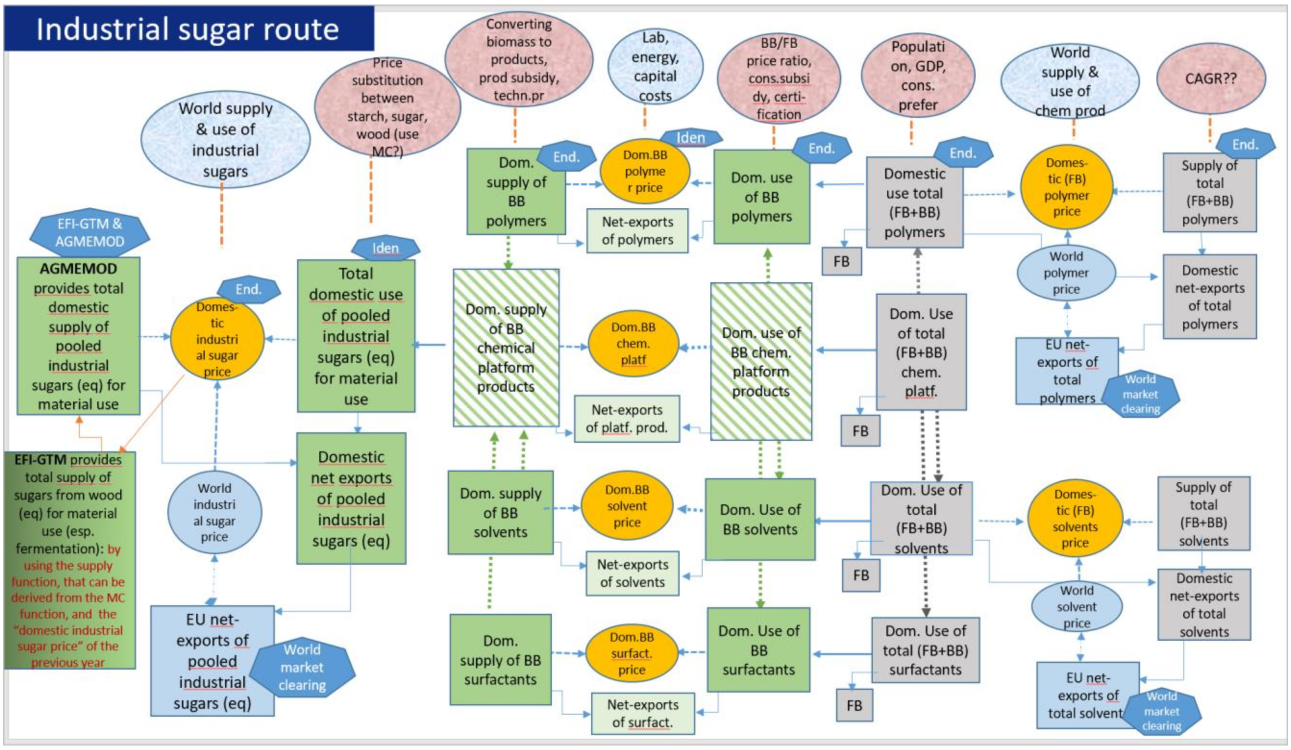

Figure 5 - Bio-based product value chains based on industrial sugar feedstock use (Source: D4.3)

Figure 5 shows that the production of bio-based product applications requires a certain amount of biomass feedstock (industrial sugars in this specific case), which is calculated from conversion factors (or conversion efficiency rates). The required feedstock volumes are then compared with the quantity of industrial sugar that is available for material use.[6] The volume of feedstock supply for material use is an outcome of AGMEMOD (for sugar, starch and plant oil biomass) and EFI-GTM (for wood biomass). The interaction of the biomass feedstock markets is visualised on the left hand side of Figure 5. The difference between supply and demand of industrial sugar for material use summed over all Member States show the EU net-trade position in the considered feedstock. The equilibrium price of industrial sugars at the global level is determined where EU net trade equals RoW net trade.

4.3 World market and price formation

The world chemical sales amounts to €3,347 billion in 2018 (Figure 6). Since 2009, China is the largest chemical producer and represents 36% of the global chemical production (Cefic, 2020). With 17%, the EU chemical industry ranks second in total sales, while US contributes with 14%. Note that China and EU both had a share of 24% in global sales in 2009, which indicates the rapid growth of China in gaining market share until 2018.

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[6] Material use is defined as feedstock needs for non-food, non-feed, non-biofuel and non-seed applications.

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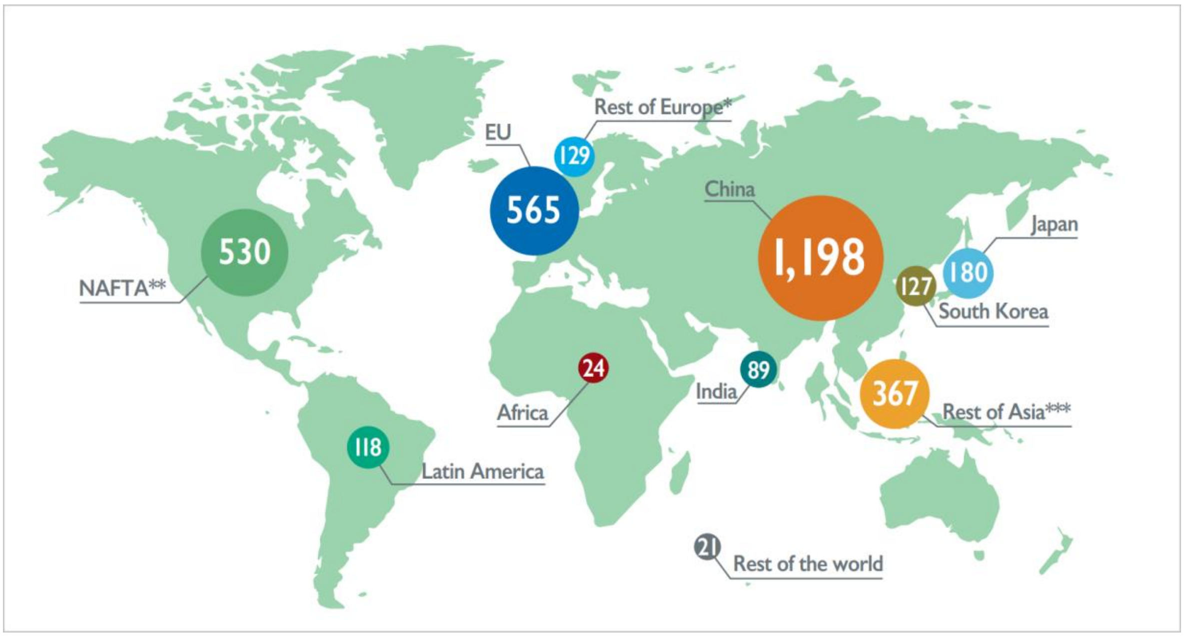

Figure 6 - World chemical sales in 2018. Source: Cefic Chemdata International 2019

When it comes to getting numbers on ‘world market prices’ for the distinguished bio-based product applications, such data are not reported in statistics. To overcome the issue, the price of a dominantly traded bio-based product within a specific application group - e.g. PLA within bio-based polymers – can be regarded as world price for the entire group, while assigning the price of the dominant producer in the world as the ‘world market’ price. For its forward-looking projections, models like BioMAT and AGMEMOD take developments of future world commodity prices as given from global models (e.g. AGLINK, MAGNET). This aspect is already organised with regard to the world price developments of biomass resources (cereals, sugars, plant oils), but obviously needs more efforts regarding world price developments of chemical products. At date, world price information used in BioMAT originates from some market reports prepared by nova-Institute[7], but on a very little scale and short projection period. This means that there is still some serious data collecting and processing work to do in this field. This is work in progress that continues after the submission of this deliverable.

Regarding the price formation in the EU, the BioMAT concept assigns a specific Member State as ‘key country’ for a specific product application. Usually, the ‘key country’ term corresponds to the most important national market for that commodity, which is mostly Germany for most chemical applications (see, Table 8). Translating these dynamics into the BioMAT modelling framework is a two-stages process. First, the key price equation is estimated by taking the world market price as main explanatory variable, and - if any - policies and trade measures, and the EU self-sufficiency rates as other explanations. Second, the national price in the other EU countries is explained by the key price and possibly a national self-sufficiency rate (Figure 7). This makes the key-price and other linked prices responsive to the EU supply and use balance of the application concerned (Chantreuil et al., 2012).

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[7] These reports are not publicly available. For further details, the reader is encouraged to contact nova-Institute.

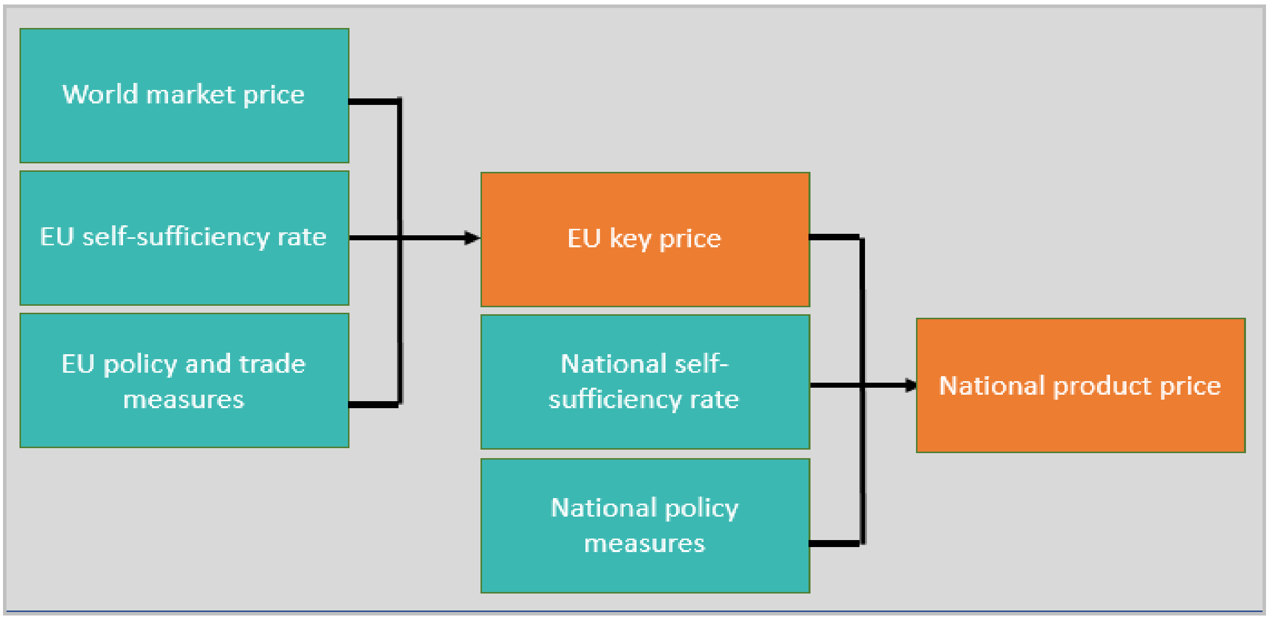

Figure 7 - Price transmission module in BioMAT

BioMAT distinguishes two markets for any envisaged chemical product application, one for the traded fossil-based chemical products within the group (the vast majority) and one for the traded bio-based chemical application products within the group. As mentioned before, world market prices are exogenously treated in BioMAT, thus requiring price projections up to 2030 for the medium run and up to 2050 for the long run. In principle, prices of fossil-based chemical products at the world market are closely related to the development of the oil price (Dammer et al., 2013). We have assumed that historical and future world prices of all fossil-based chemical applications are approximated by the oil price. The oil price development used in BioMAT is taken from AGMEMOD. Assuming an average between the OECD and IHS Markit projections, the oil price (Brent), which is bottoming out at 41 USD/bbl in 2020, is expected to rise to 83 USD/bbl in 2030 (EC agricultural outlook report, 2020). At date the Russian invasion in Ukraine has dramatically increased oil and gas prices, and Europe is searching for alternative energy sources (coal, wood). WP6 will conduct a sensitivity analysis to calculate the impacts of higher oil prices on the market of bio-based chemical applications.

Fossil-based and bio-based prices for chemical product applications at MS level are not explicitly available in statistics, but must be derived from PRODCOM data on production volumes and values. These prices are considered as unit prices due to fact that a specific application group is compiled from a variety of chemical products, each with its specific quality and price. Table 13 displays the estimated average EU prices for fossil-based chemical product applications over 2008-2018, and Table 14 does the same for bio-based applications. Similar tables are available for each member state. Table 15 shows the ratio between bio-based and fossil-based prices of the product application groups. For platform chemicals, polymers, surfactants, adhesives, lubricants, manmade fibres and construction the bio-based alternative is more expensive to produce than the average fossil-based product within this group. However, paints, coats and inks, cosmetics, pharmaceuticals, and food & feed show up with lower bio-based prices, in general due to diverging quality aspects of individual products within the respective application group. For instance, in the case of cosmetics we can distinguish expensive perfumes (mainly fossil-based) and cheap soaps (mainly bio-based). A similar story holds for pharmaceuticals. The explanation for the price differentiation within the food & feed and agrochemicals application groups needs aa deeper dive in the underlying product details. This is also work in progress that will continue after the submission of Deliverable 5.2.

Table 13 - Prices (unit values; euro/100 kg) of fossil-based product applications, EU, 2008-2018

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Platform chemicals	85	70	83	94	94	92	87	73	70	74	78
Solvents	87	88	87	105	111	103	104	107	95	86	87
Polymers for plastics	119	100	114	128	131	125	125	120	111	119	122
Paint, coat, ink, dyes	175	168	184	205	215	216	214	210	198	204	208
Surfactants	104	101	99	107	109	110	109	107	103	103	102
Cosmetic; pers. care	609	549	577	617	631	646	632	638	632	661	684
Adhesives	113	121	109	119	130	133	115	108	117	104	118
Lubricants	162	147	154	202	210	193	196	186	184	191	185
Man-made fibres	171	152	169	192	192	182	192	202	172	182	169
Biofuels	62	55	67	72	133	127	147	128	75	75	74
Pharmaceuticals	283	365	283	300	361	325	363	442	404	379	378
Food & feed	229	294	266	322	248	303	311	267	283	283	278
Construction	118	112	118	138	146	144	145	141	134	142	145
Agrochemicals	114	123	106	126	119	124	122	138	117	118	117

Source: Own calculations based on PRODCOM statistics.

Table 14 - Prices (unit values; euro/100 kg) of bio-based product applications, EU, 2008-2018

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Platform chemicals	115	105	117	140	123	129	116	114	116	121	128
Solvents	77	70	76	86	85	86	75	75	72	73	74
Polymers for plastics	201	224	251	277	277	299	259	284	244	237	261
Paint, coat, ink, dyes	103	98	105	118	126	129	126	133	126	125	136
Surfactants	83	83	98	118	128	125	127	128	128	124	116
Cosmetic; pers. care	191	171	180	188	181	192	164	169	176	183	188
Adhesives	172	164	159	180	197	208	198	187	197	192	196
Lubricants	181	173	179	192	199	193	207	191	213	208	209
Man-made fibres	231	210	219	257	256	251	250	241	242	256	256
Biofuels	60	55	65	70	85	76	65	64	65	65	63
Pharmaceuticals	104	109	109	105	122	131	110	115	125	126	149
Food & feed	201	209	222	231	231	266	246	228	281	255	269
Construction	258	256	253	265	278	267	239	249	233	239	260
Agrochemicals	13	16	15	17	14	13	13	14	13	12	12

Source: Own calculations based on PRODCOM statistics.

Table 15 - Price ratio between bio-based prices and fossil-based prices within a product application, EU, 2008-2018

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Platform chemicals	1.35	1.50	1.41	1.49	1.31	1.41	1.32	1.57	1.68	1.64	1.65
Solvents	0.88	0.80	0.88	0.82	0.76	0.84	0.72	0.70	0.76	0.85	0.84
Polymers for plastics	1.69	2.24	2.19	2.17	2.12	2.38	2.07	2.37	2.19	1.98	2.13
Paint, coat, ink, dyes	0.59	0.58	0.57	0.58	0.59	0.60	0.59	0.63	0.64	0.61	0.65
Surfactants	0.79	0.82	0.99	1.10	1.17	1.14	1.16	1.20	1.24	1.20	1.14
Cosmetic; pers. care	0.31	0.31	0.31	0.30	0.29	0.30	0.26	0.26	0.28	0.28	0.27
Adhesives	1.53	1.35	1.46	1.51	1.52	1.56	1.72	1.73	1.68	1.84	1.66
Lubricants	1.12	1.17	1.16	0.95	0.95	1.00	1.05	1.02	1.16	1.09	1.13
Man-made fibres	1.35	1.38	1.29	1.34	1.33	1.38	1.30	1.19	1.40	1.41	1.51
Biofuels	0.97	0.99	0.97	0.98	0.64	0.60	0.44	0.50	0.86	0.86	0.85
Pharmaceuticals	0.37	0.30	0.39	0.35	0.34	0.40	0.30	0.26	0.31	0.33	0.39
Food & feed	0.88	0.71	0.83	0.72	0.93	0.88	0.79	0.85	1.00	0.90	0.97
Construction	2.19	2.28	2.16	1.93	1.90	1.86	1.64	1.77	1.74	1.68	1.79
Agrochemicals	0.11	0.13	0.14	0.13	0.12	0.11	0.11	0.10	0.12	0.10	0.11

Source: Own calculations based on PRODCOM statistics.

4.4 Rest of the world

As became obvious from previous section, the EU is an open economy in terms of the supply and use of both chemical products and biological feedstock. This means that changing EU markets, for example due to trends or due to unforeseen circumstances, may affect the markets in the rest of the world (RoW) and vice versa. In current development phase of the BioMAT model, a two-ways approach is applied with regard to capturing the influence of a RoW region. First, changes in world market prices of biological feedstock types, especially starch, industrial sugar and plant oils, that arise from market changes in EU or RoW are implicitly modelled in BioMAT. This means that world market prices are endogenously modelled according to the AGMEMOD concept. Second, changes in world market prices of bio-based chemical products (polymers, solvents, etc) that arise from market changes in EU or RoW aren’t explicitly modelled in BioMAT. Potential changes on the world market and its prices are exogenously obtained from other studies or other models, or based on scenario assumptions.

Regarding the first aspect, i.e. modelling of endogenous world prices of biological feedstock, BioMAT implements a stylised feedstock market for the RoW. The RoW feedstock supply and use is just driven directly by world prices, without incorporating any wedges between world prices, producer or use prices, and without any policy measure affecting supply, use and trade. Parameters of the behavioural supply and use equations are either estimated or calibrated from literature or expert knowledge. The world market price clearing condition assumes that the RoW net-export equalizes total net-export of the EU countries. This is also work in progress that continues after the submission of Deliverable 5.2.

5. Modelling bio-based products

5.1 General considerations

Building a model for bio-based product markets and capturing the interactions between the relevant actors (suppliers and users of biomass), and between countries is new and complex. This task is a time-consuming process as an evidence-based sustainability assessment of bio-based alternatives in the EU chemicals sector is typically hampered by a paucity of available official secondary data (see Deliverable 5.3; Baldoni et al., 2021). BioMAT applies econometric and calibration methods to information reporting the past in order to understand the influence of driving factors on the behaviour of those actors participating in bio-based markets. As regular and robust data availability on bio-based product market is very poor and thus not explicitly available in public statistics, BioMonitor has made efforts to build a database for bio-based product markets at the EU Member State level (see Sections 3 and 6; in close collaboration with WP3 activities). It combined data interpolation techniques to get a complete PRODCOM database, stakeholder interaction to estimate bio-based shares and contents of chemical products and expert knowledge on technical bio-based chemical processes and feedstock conversion efficiency rates. Although the quality of the data derived must be regarded with care, the relevant point here is that data updates are feasible on a regular basis as the procedures employed take existing Eurostat statistics as a starting point. Therefore, a mixture of econometric and synthetic parameter estimation procedures is applied to this database. Literature and stakeholder expertise are used to validate estimated and calibrated parameters in supply and use behaviour equations. A comparison with the little available studies was already addressed in Section 3 with regard to bio-based shares of chemical products and conversion efficiency rates of feedstock used in chemical products. Also, the literature review in Task 5.1 of the BioMonitor project has provided some insight in potential parameter values, like the influence of prices on the demand for bio-based products or the substitution between bio-based and fossil-based products (see D5.1). Domburg et al (2006) reported the impact of two different biomass input (wheat and wood) on GHG emissions and costs of bio-refinery systems for polylactic acid (PLA) production and compared them to those of fossil-based production systems. PLA produced from bio-based feedstock generates positive environmental impact, whilst PLA produced from short-rotation wood is superior to those from wheat in terms of reducing non-renewable energy consumption, reducing GHG emissions and the overall production cost. According to literature review, the own-price elasticity of bio-based materials lies between -0.5 and -0.1; this range has been considered for calibrating the demand equation for bio-based chemical applications in the BioMAT model (see Section 5.5).

In terms of the operationalisation of the model, the conceptual framework presented in Figure 5 is the starting point for the development of market models for sugar-based bio-based products. The models entail two sets of equations:

- One representing the EU market for chemical products, e.g. for polymers (Section 5.3).
- Another representing the EU market for biomass feedstock, e.g. for industrial sugar and starch for material use (Section 5.4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

5.2 Coding and naming

Before moving onto the description of the specification of the different equations and identities comprising BioMAT, it is important to familiarise the reader with the naming conventions that were followed when bringing the data into the model. More specifically,
Table *16* lists the mnemonics (codes) of the new products represented in the BioMAT model. Note that these conventions are also used for implementing bio-based market data in the BioMonitor Data Platform.
Table *17* lists the mnemonics (codes) of the feedstock types used for material use.

Table 16 - Codes for product application groups in chemical sector

	Code for total application	Code for bio-based application	Code for fossil-based application
Platform chemicals	TCH_	BCH_	FCH_
Solvents	TSV_	BSV_	FSV_
Polymers for plastics	TPO_	BPO_	FPO_
Paint, coat, ink, dyes	TPA_	BPA_	FPA_
Surfactants	TSF_	BSF_	FSF_
Cosmetic; pers. care	TCO_	BCO_	FCO_
Adhesives	TAD_	BAD_	FAD_
Lubricants	TLU_	BLU_	FLU_
Man-made fibres	TMF_	BMF_	FMF_
Biofuels	TBF_	BBF_	FBF_
Pharmaceuticals	TPH_	BPH_	FPH_
Food & feed	TFF_	BFF_	FFF_
Construction	TBU_	BBU_	FBU_
Other applications	TRE_	BRE_	FRE_
Agrochemicals	TAC_	BAC_	FAC_

Source: Authors.

Table 17 - Codes for feedstock types used for use in chemical sector

Product	Code
Industrial plant oil feedstock use	IP
Lignocellulose from forestry feedstock use	WO
Lignocellulose from agricultural feedstock use	LG
Sugar feedstock use	SU
Starch feedstock use	SA
Animal biomass feedstock use	AF
Aquatic biomass feedstock use	AQ
Other feedstock use	OT
Sugar based chemical platform feedstock use	SCH
Oil-based chemical platform feedstock use	OCH

Source: Authors.

5.3 Equation set for bio-based product markets

When sketching the 'building blocks' of the BioMAT model, the focus is on understanding the key drivers of production, imports, exports, uses and prices of bio-based products (as well as the determinants of their fossil-based counterparts). For each of these building blocks, there are four dimensions that need to be captured: countries, product applications, biomass feedstock types, and time. The combination of these four dimensions constitutes the so-called modelling space.

Concerning the country dimension, BioMAT considers all EU27 Member States and the United Kingdom as individual regions. [8] Moreover, a RoW region is also modelled in order to close the system at the level of biological feedstock. Focusing on the product-application dimension, the following chemical applications are covered: (i) chemical platform products; (ii) solvents; (iii) polymers for plastics; (iv) paints and oils; (v) surfactants; (vi) lubricants; (vii) adhesives; (viii) cosmetics; (ix) pharmaceuticals; (x) biofuels; (xi) food and feed; (xii) building material; (xiii) agrochemicals; (xiv) manmade fibres; and (xv) other applications. In addition, the framework accounts for the following biomass feedstock types: (i) starch; (ii) industrial sugar; (iii) industrial plant oils; (iv) wood lignocellulose; (v) agricultural lignocellulose; (vi) animal biomass, (vii) aquatic biomass; and (viii) other biomass. For a proper representation of the bioeconomy, it is key to consider future developments of the total market of specific products, including also a separate representation of fossil-based and bio-based alternatives. As regards the time dimension, a period ending in 2030 is appropriate for delivering medium-term insights, although it can also be extended to 2050 for simulating long-term scenarios.

For a better understanding of general specification of the different equations, Table 18 lists the key equations and their explanatory elements in the case of polymers.

Table 18 - Template for estimation of equations for bio-based products; example for polymers (variables expressed in BioMAT codes)

Variable	Unit	Mnemonic	Specification	Type
Prices of chemical applications				
Total polymer producer price in key country *DE* (Germany)	€/100kg	TPO_PFN*DE*	TPO_PFNDE = f(FPO_PMD*EXRD, TPO_SSREU) FPO_PMD: world price (USD/tonne) of chemicals; (Brent) oil price used as proxy EXRD: exchange rate ($/€) TPO_SSR*EU*: EU self-sufficiency rate	Est
Fossil-based polymer producer price in key country *DE* (Germany)	€/100kg	FPO_PFN*DE*	FPO_PFN*DE* = TPO_PFN*DE*	Iden
Fossil-based polymer producer price in country *CC*	€/100kg	FPO_PFN*CC*	FPO_PFN*CC*=f(FPO_PFN*DE*, FPO_SSR*CC*) FPO_SSR*CC*: national self-sufficiency rate	Est
Bio-based polymer producer price in key country *DE* (Germany)	€/100kg	BPO_PFN*DE*	BPO_PFNDE = f(BPO_PMD*EXRD, BPO_SSREU) BPO_PMD: world price (USD/tonne) of bio-based polymers; PLA price used as proxy BPO_SSR*EU*: EU self-sufficiency rate	Est
Bio-based polymer producer price in country *CC*	€/100kg	BPO_PFN*CC*	BPO_PFN*CC* = f(BPO_PFN*DE*, BPO_SSR*CC*) BPO_SSR*CC*: national self-sufficiency rate	Est
Domestic use of chemical applications				
TOTAL polymer domestic use in country *CC*	1000t	TPO_UD*CCC*	TPO_UD*CCC* = f(RGDPC*CC*, TREND) RGDPC*CC*: real GDP per capita TREND: trend on consumer preferences	Est

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[8] The level of detail that each country model has is highly dependent on the availability of data in the existing statistics.

Share of bio-based polymer use in total polymer domestic use in country *CC*	Ratio (0-1)	BPO_SHUCC	BPO_SHUCC = f(BPO_PFNCC/FPO_PFNCC, TREND) BPO_PFNCC/FPO_PFNCC: price ratio between bio-based and fossil-based polymers	Cal
Share of fossil-based polymer domestic use in total polymer use in country *CC*	Ratio (0-1)	FPO_SHUCCC	FPO_SHUCC = 1 - BPO_SHUCC	Iden
Bio-based polymer domestic use in country CC	1000t	BPO_UDCCC	BPO_UDCCC = TPO_UDCCC * BPO_SHUCC	Iden
Fossil-based polymer domestic use in country *CC*	1000t	FPO_UDCCC	FPO_UDCCC = TPO_UDCCC * FPO_SHUCC	Iden
Domestic supply of chemical applications				
Total polymer domestic supply in country *CC*	1000t	TPO_SPRCC	TPO_SPRCC = f(FPO_PFNCC, TREND)	Est
Share of bio-based polymer domestic supply in total polymer supply in country *CC*	Ratio (0-1)	BPO_SHSCC	BPO_SHSCC = f(BPO_CTOTCC/FPO_CTOTCC, FAVGCC, TREND) BPO_CTOTCC/FPO_CTOTCC: production costs (dis) advantage ratio (from MAGNET) FAVGCC= average conversion rate (proxy tech change)	Cal
Production costs of bio-based polymers in country *CC*	€/100kg	BPO_CTOTCC	BPO_CTOTCC = BPO_CFECC + BPO_CENCC+ BPO_COPCC + BPO_CLACC + BPO_CAPCC CFECC: biomass feedstock costs (€/100kg) CENCC: energy costs (€/100kg) COPCC: operational costs (€/100kg) CLACC: labour costs (€/100kg) CAPCC: capital costs (€/100kg)	Iden
Share of fossil-based polymer domestic supply in total polymer supply in country *CC*	Ratio (0-1)	FPO_SHSCC	FPO_SHSCC= 1 - BPO_SHSCC	Iden
Bio-based polymer domestic supply in country *CC*	1000t	BPO_SPRCC	BPO_SPRCC = TPO_SPRCC* BPO_SHSCC	Iden
Fossil-based polymer domestic supply in country *CC*	1000t	FPO_SPRCC	FPO_SPRCC = TPO_SPRCC * FPO_SHSCC	Iden
Feedstock demand for chemical applications				
Share of feedstock types in bio-based polymer production in country *CC*	Ratio (0-1)	BPO_SFTCC	∑ BPO_SFTCC(i) = 1 BPO_SFTCC = share of feedstock type i (i = 1..10) in use of bio-based polymer product	Iden
Feedstock use per type of bio-based polymer production in country *CC*	1000t	BPO_FFTCC	BPO_FFTCC = BPO_SFTCC * BPO_XFTCC * BPO_SPRCC BPO_XFTCC: conversion ratio between feedstock type and bio-based polymer	Iden
Total feedstock use of bio-based polymer production in country *CC*	1000t	BPO_FTOTCC	BPO_FTOTCC = ∑ BPO_FFTCC(i)	Iden
Average feedstock use of bio-based polymer production in country *CC*	1000t	BPO_FAVGCC	BPO_FAVGCC= BPO_FTOTCC/ BPO_SPRCC	Iden
Closing the market				
Bio-based polymer imports in country *CC*	1000t	BPO_SMTCC	BPO_SMTCC =f(BPO_UDCCC-BPO_SPRCC)	Est
Bio-based polymer imports in country *CC*	1000t	BPO_UXTCC	BPO_UXTTCC =BPO_SPRCC+BPO_SMTCC-BPO_UDCCC	Iden

Bio-based polymer net trade in country *CC*	1000t	BPO_USN*CC*	BPO_USN*CC* = BPO_UXT*CC* – BPO_SMT*CC*	Iden
Total polymer net trade in country *CC*	1000t	TPO_USN*CC*	TPO_USN*CC* = TPO_SPR*CC* – TPO_UDC*CC*	Iden
Fossil-based polymer net trade in country *CC*	1000t	FPO_USN*CC*	FPO_USN*CC* = FPO_SPR*CC* – FPO_UDC*CC*	Iden

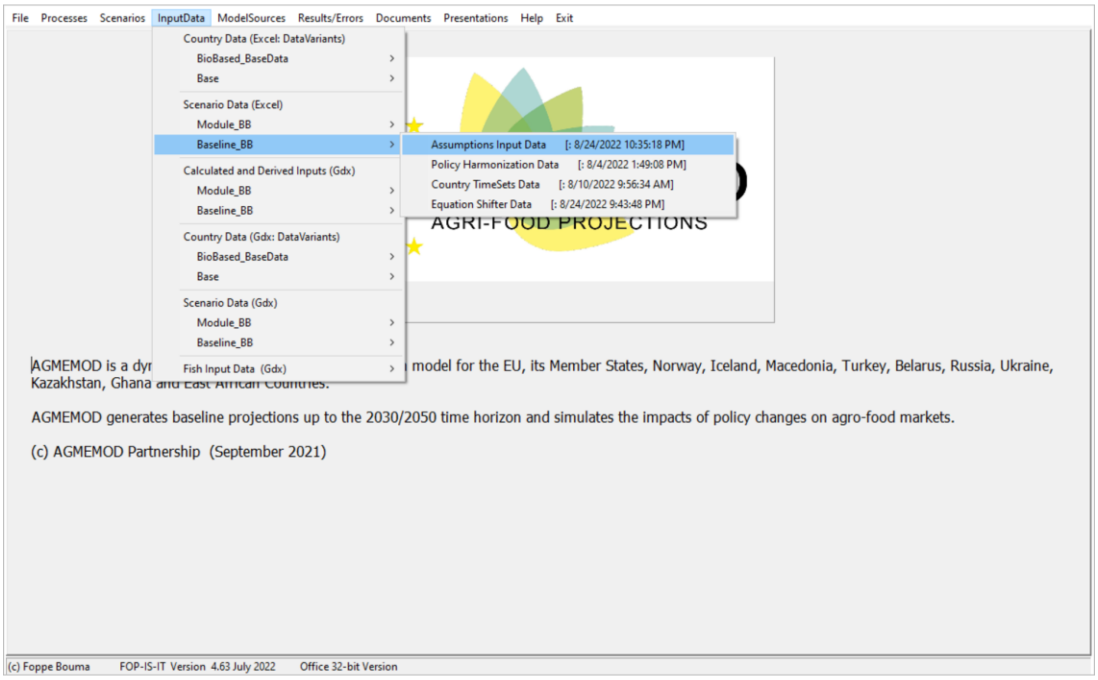
Source: Authors.

Note: *Iden* means identity; *Cal* indicates that the equation is calibrated and *Est* stands for estimated equation. *CC* stands for country; *DE* represents Germany; *EU* represents EU as a whole.

In general terms, drivers are country specific, while shifters and policy support are product specific. For specific parameter values and details on country-specific drivers the information is available in *CC-ModelEquation* and *AssumptionInput* files respectively, which are key files of the BioMAT model. Note that BioMAT is an integrated module within the AGMEMOD framework, see respectively Figure 8 and Figure 9.

The *AssumptionInput file* contains values for exogenous variables that drive the entire AGMEMOD model, including the BioMAT module, which are in particular:

- Development of world prices for agricultural products and bio-based materials until 2030/2050.
- Development of population, GDP and inflation rate in EU member states until 2030/2050.
- Values for policy instruments at both EU level (like CAP measures) and national level until 2030/2050.
-



AGMEMOD is a dyn model for the EU, its Member States, Norway, Iceland, Macedonia, Turkey, Belarus, Russia, Ukraine, Kazakhstan, Ghana and East African Countries.

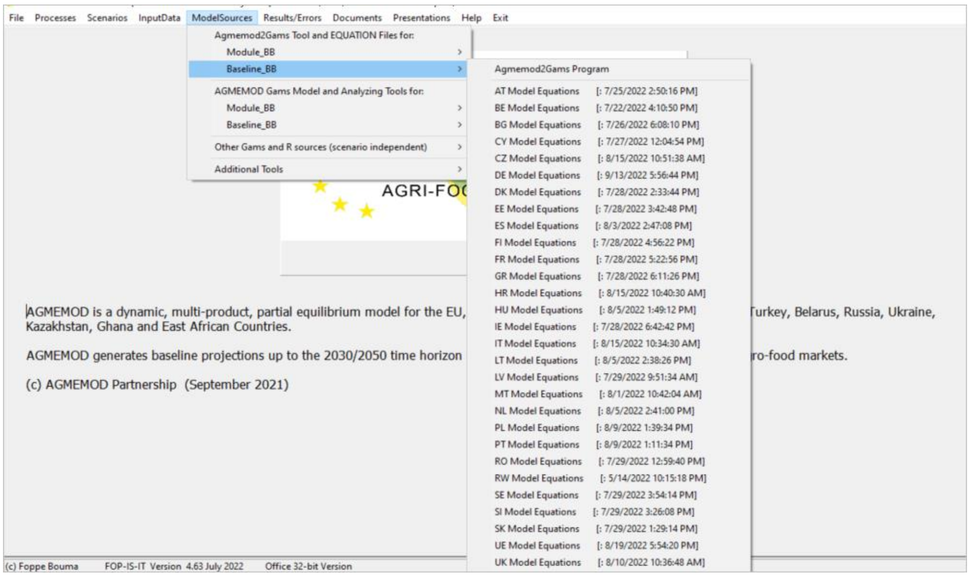
AGMEMOD generates baseline projections up to the 2030/2050 time horizon and simulates the impacts of policy changes on agro-food markets.

(c) AGMEMOD Partnership (September 2021)

(c) Foppe Bouma FOP-IS-IT Version 4.63 July 2022 Office 32-bit Version

Figure 8 - AssumptionInput file with exogenous variables used in the BioMAT model

The model equation file is country dependent and it contains all calibrated and estimated parameters for that specific EU member state level (and UK). The files are named as *AT-ModelEquation.xls* (AT=Austria), *BE-ModelEquations.xls* (BE=Belgium), BG-*ModelEquation.xls* (BG=Bulgaria), *DE-ModelEquation.xls* (DE=Germany), etc.



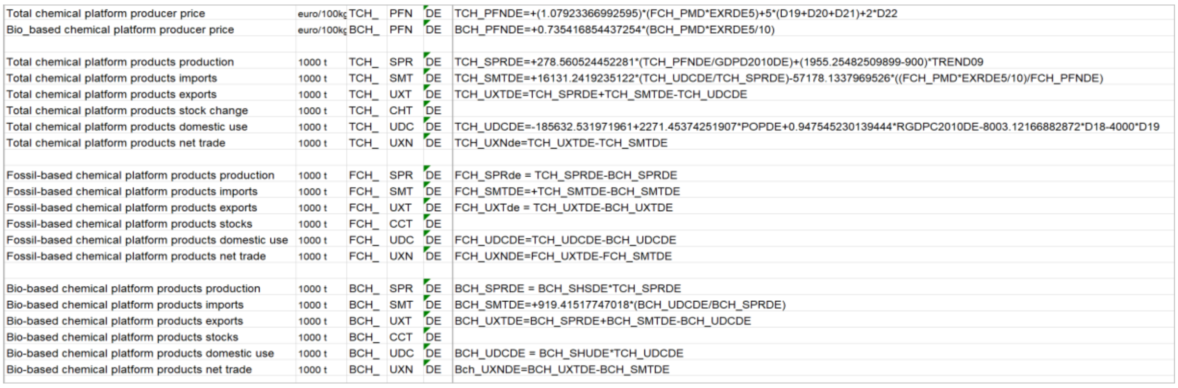
AGMEMOD is a dynamic, multi-product, partial equilibrium model for the EU, Turkey, Belarus, Russia, Ukraine, Kazakhstan, Ghana and East African Countries.

AGMEMOD generates baseline projections up to the 2030/2050 time horizon ro-food markets.

(c) AGMEMOD Partnership (September 2021)

Figure 9 - Model equation files for each EU member state (and UK) with estimated parameters

Each chemical application modelled in BioMAT encompasses around 90 equations, of which the crucial ones are econometrically estimated and calibrated (see Table 18). The remaining are either identities (derived from other equations/combination of variables) or set as a constant (fixed) value. To conclude, we emphasise that the model is country specific and the polymer template (Table 18) is identically applied to model the other chemical application markets. In total, any country based model equation file contains around 1300 equations; the complete BioMAT model encompasses around 38,000 equations[9]. Figure 10 gives an example of estimated equations for market items (production, domestic use, trade, prices) of chemical platforms in the German model equation file.



Total chemical platform producer price	euro/100kg	TCH_	PFN	DE	TCH_PFNDE=+(1.07923366992595)*(FCH_PMD*EXRDE5)+5*(D19+D20+D21)+2*D22
Bio_based chemical platform producer price	euro/100kg	BCH_	PFN	DE	BCH_PFNDE=+0.735416854437254*(BCH_PMD*EXRDE5/10)
Total chemical platform products production	1000 t	TCH_	SPR	DE	TCH_SPRDE=+278.560524452281*(TCH_PFNDE/GDPD2010DE)+(1955.25482509899-900)*TREND09
Total chemical platform products imports	1000 t	TCH_	SMT	DE	TCH_SMTDE=+16131.2419235122*(TCH_UDCDE/TCH_SPRDE)-57178.1337969526*((FCH_PMD*EXRDE5/10)/FCH_PFNDE)
Total chemical platform products exports	1000 t	TCH_	UXT	DE	TCH_UXTDE=TCH_SPRDE+TCH_SMTDE-TCH_UDCDE
Total chemical platform products stock change	1000 t	TCH_	CHT	DE	
Total chemical platform products domestic use	1000 t	TCH_	UDC	DE	TCH_UDCDE=-185632.531971961+2271.45374251907*POPDE+0.947545230139444*RGDPC2010DE-8003.1216682872*D18-4000*D19
Total chemical platform products net trade	1000 t	TCH_	UXN	DE	TCH_UXNde=TCH_UXTDE-TCH_SMTDE
Fossil-based chemical platform products production	1000 t	FCH_	SPR	DE	FCH_SPRde = TCH_SPRDE-BCH_SPRDE
Fossil-based chemical platform products imports	1000 t	FCH_	SMT	DE	FCH_SMTDE=+TCH_SMTDE-BCH_SMTDE
Fossil-based chemical platform products exports	1000 t	FCH_	UXT	DE	FCH_UXTde = TCH_UXTDE-BCH_UXTDE
Fossil-based chemical platform products stocks	1000 t	FCH_	CCT	DE	
Fossil-based chemical platform products domestic use	1000 t	FCH_	UDC	DE	FCH_UDCDE=TCH_UDCDE-BCH_UDCDE
Fossil-based chemical platform products net trade	1000 t	FCH_	UXN	DE	FCH_UXNDE=FCH_UXTDE-FCH_SMTDE
Bio-based chemical platform products production	1000 t	BCH_	SPR	DE	BCH_SPRDE = BCH_SHSDE*TCH_SPRDE
Bio-based chemical platform products imports	1000 t	BCH_	SMT	DE	BCH_SMTDE=+919.41517747018*(BCH_UDCDE/BCH_SPRDE)
Bio-based chemical platform products exports	1000 t	BCH_	UXT	DE	BCH_UXTDE=BCH_SPRDE+BCH_SMTDE-BCH_UDCDE
Bio-based chemical platform products stocks	1000 t	BCH_	CCT	DE	
Bio-based chemical platform products domestic use	1000 t	BCH_	UDC	DE	BCH_UDCDE = BCH_SHUDE*TCH_UDCDE
Bio-based chemical platform products net trade	1000 t	BCH_	UXN	DE	Bch_UXNDE=BCH_UXTDE-BCH_SMTDE

Figure 10 - Example of estimated equations for market items of chemical platform applications (fossil-based and bio-based) in the German model equation file.

5.4 Equation set for biomass feedstock markets

The second set of equations within the bio-based value chains refer to the biomass feedstock market that inter-relates with the bio-based product market (Table 19). The focus of this section is

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[9] The BioMAT model is an integrated module within the AGMEMOD framework. AGMEMOD's total size is about 4 GB. The framework is regularly updated and centrally stored and shared in a cloud environment.

on the EU market for industrial sugar (equivalents) feedstock that is processed (Figure 4 and Figure 5), including:

- starch from respectively wheat, maize and potatoes;
- sugar beet and isoglucose;
- sugar from woody biomass.

Both starch and sugar from woody biomass - though just available at a very low scale - are converted into sugars to generate a ‘pool of industrial sugar’ equivalents that is domestically available for material use in the value chain (from left side to right side in Figure 5). The process is mainly via a fermentation route (*industrial sugar -> bioethanol -> bioethylene -> bio-based chemical platform products -> bio-based application*). In this respect a unit of sugar processed from starch has the same quality and functionality as a unit of sugar processed from sugar beets. On the other hand, conversion rates and production costs to extract sugars from raw feedstock differ across the three types (see Table 11).

The technique of processing sugars from woody biomass is still in its infancy. Verkerk et al. (2017) derived marginal costs curves for wood for non-traditional products (energy and materials) under different scenarios showing how much woody biomass is available at which price. To date, especially production costs of processing wood into sugars (ethanol) is too expensive and not a common practice. However, if in future the demand for bio-based products starts growing, and the availability of starch and sugar-based feedstock might become insufficient to meet material demands, the urgency to use wood as feedstock for material production is expected to increase.

Table 19 - Template for estimation of equations for industrial sugar equivalents (starch, sugar, wood) for material use

Variable	Unit	Mnemonetic	Specification	Type
Prices of biological feedstock				
Industrial sugar price in country *CC*	€/100 kg	SS_PFNCC	SS_PFNCC = f(SU_WMP*EXRD) SU_WMP: world market price for sugar (USD/tonne)	Est
Feedstock demand for material use				
Domestic use of industrial sugar (eq.) for material use in country *CC*	1000t	SSUDC*CC*	SSUDCCC = BPO_SSXFTCC*BPO_SPRCC + BSV_SSXFTCC *BSV_SPRCC + BSF_SSXFTCC*BSF_SPRCC + ... BPO_SPR*CC*: production of bio-based polymers BPO_SSXFT*CC*: conversion rate of sugars to polymers BSV_SPR*CC*: production of bio-based solvents BSV_SSXFT*CC*: conversion rate of sugars to solvents BSF_SPR*CC*: production of bio-based surfactants BSF_SSXFT*CC*: conversion rate of sugars to surfactants	Iden
Feedstock supply for material use				
Domestic supply of industrial sugar (eq.) for material use in country *CC*	1000t	SSUMA*CC*	SSUMACC = SAUMACC*SAXTRCC + GCUMACC SAUMACC: starch for material use SAXTR*CC*: starch to industrial sugar conversion factor GCUMA*CC*: industrial sugar for material use	Iden

Domestic supply of industrial sugar (eq.) for material use in country *CC*	1000t	WOUMA*CC*	WOUMA*CC* = f(SS_PFN*CC*, WOXTR*CC*) WOXTR*CC*: wood to industrial sugar conversion factor	Eq
Total domestic supply of industrial sugar (eq.) in country *CC*	1000t	SSSPR*CC*	SSSPR*CC*=SSUMA*CC* + WOUMA*CC*	Iden
Closing the market				
Industrial sugar (eq.) net trade in country *CC*	1000t	SSUXN*CC*	SSUXN*CC* = SSSPR*CC* – SSUDC*CC*	Iden
Market clearing				
Market clearing condition for total industrial sugars (eq.) in country *CC*	1000t		∑SSUSNEU (sum over EU member states) = -∑SSUSNRW (Rest of World)	Cal

Source: Authors.

Note: Raw feedstocks variables come from AGMEMOD for the entire simulation period, ending in 2030 (and 2050 in the long run). Parameters come from literature or estimation procedures as described in Section 5.5.

5.5 Econometric approach

Further to the presentation of the equation templates, some considerations regarding the estimation procedure are due. As mentioned in Section 5.1, there was an important data challenge to overcome before operationalising the model. Since the start of the BioMonitor project, it was evident that the available data measuring different aspects of the bioeconomy was scarce and scattered across different sources and not regularly reported in the official statistics. On several occasions the available information for a certain indicator was limited to only one or two data points included in a report, or very short time series reported in the recently launched official statistics. Although the BioMonitor project has meant a considerable improvement in terms of the existing statistics, a full econometric procedure for all the equations presented above was not feasible due to the lack of long and robust time series for certain variables. More specifically, the relevant equations for the share of bio-based formulations over the total market have been calibrated by relying on the elasticities available in the existing literature as well as additional information provided by market experts. Regarding the functional form of the equations that deliver the share of bio-based formulations over the total market, a Cobb-Douglas (Cobb and Douglas, 1928) specification is used.

As an illustration, a generic example is provided below in the case of the relative share of a given bio-based application over the total market:

$$shBCH\_S = a * cdr^{b} * fcr^{c} * T^{d} \tag{1}$$

with a being the intercept; while b, c and d are the relevant elasticities for the cost ratio, cdr, efficiency ratio, fcr, and the trend variable, T.

Drawing attention to the remaining variables for which equations were econometrically estimated, e.g. prices, production, domestic use, exports, imports, etc., the reader should note that Ordinary Least Squares (OLS) was the econometric technique utilised. OLS is a usual approach for estimating the parameters in which the relationship between the endogenous variable and the explanatory ones is assumed to be linear. A generic example in the case of a supply (SPR) equation for total chemicals platform (TCH) is provided in (2):

$$TCH\_SPR = \beta + \pi * (TCH\_PFN/GDPD) + \mu * T + \varepsilon \qquad (2)$$

in which β, π and μ are the estimated coefficients, *TCH_PFN* is the unitary price of total chemical platforms, *GDPD* stands for the GDP deflator, *T* accounts for a trend, and ε *is the random error with expectation 0 and variance* σ^2*.*

The OLS routine was implemented by means of the R built-in interface included in the AGMEMOD-BioMAT user interface. However, any other econometric software, e.g. STATA, can be used for the estimation of the relevant equations.

Nevertheless, it is important to emphasise that the data collection of bio-based indicators should be maintained over time, delivering then longer time series that allow for the econometric estimate of the parameters (b, c and d) in the future. At the same time it will permit the future re-estimation and update of the coefficients calculated in the modelling exercise carried out in 2022 when they get outdated in the course of time. To sum up, Table 20 presents the assumed elasticities values used to calibrate bio-based share functions of chemical application in EU member states. Elasticities applied fall in general within range as identified from literature review in D5.1.

Table 20 - Ranges of elasticity values to calibrate bio-based share functions of chemical applications in EU MS

	Bio-based share in total supplied chemicals (BioMAT)	Bio-based share in total used chemicals (BioMAT)	Other studies
Bio-based/fossil-based price	--	-0.5 to -2	-0.5 to -1 (bio-based plastics in EU); Domberg et al. (2006)
Fossil-based/bio-based production costs	2	--	3 (bio-based vs fossil-based plastics); Nowikci et al. (2010
Biomass feedstock conversion efficiency rate	2 to 5	--	Conv. efficiency 1 (starch to polymers); 0.8 (glucose to acids); Iffland et al. (2015)

Source: Authors.

6. BioMAT database

6.1 Objective and structure

The BioMAT database is a comprehensive consistent database for EU member states, EU27 and UK that has been developed to fulfil two objectives:

- First, to enable an assessment of developments on the markets for bio-based materials, in particular bio-based chemicals. Furthermore, to track the associated demand for bio-based resources used as production inputs and to calculate a set of related sustainability indicators for the past and current state.
- Second, to provide essential information for the BioMAT model, an econometric partial-equilibrium model, which aims to provide projections for markets of bio-based materials (in particular bio-based chemicals). And to consider a connection to the markets for biomass (i.e. markets for crops) under different scenarios, with a primary focus on the bio-based chemicals for EU Member States and EU27 to 2030/2050.

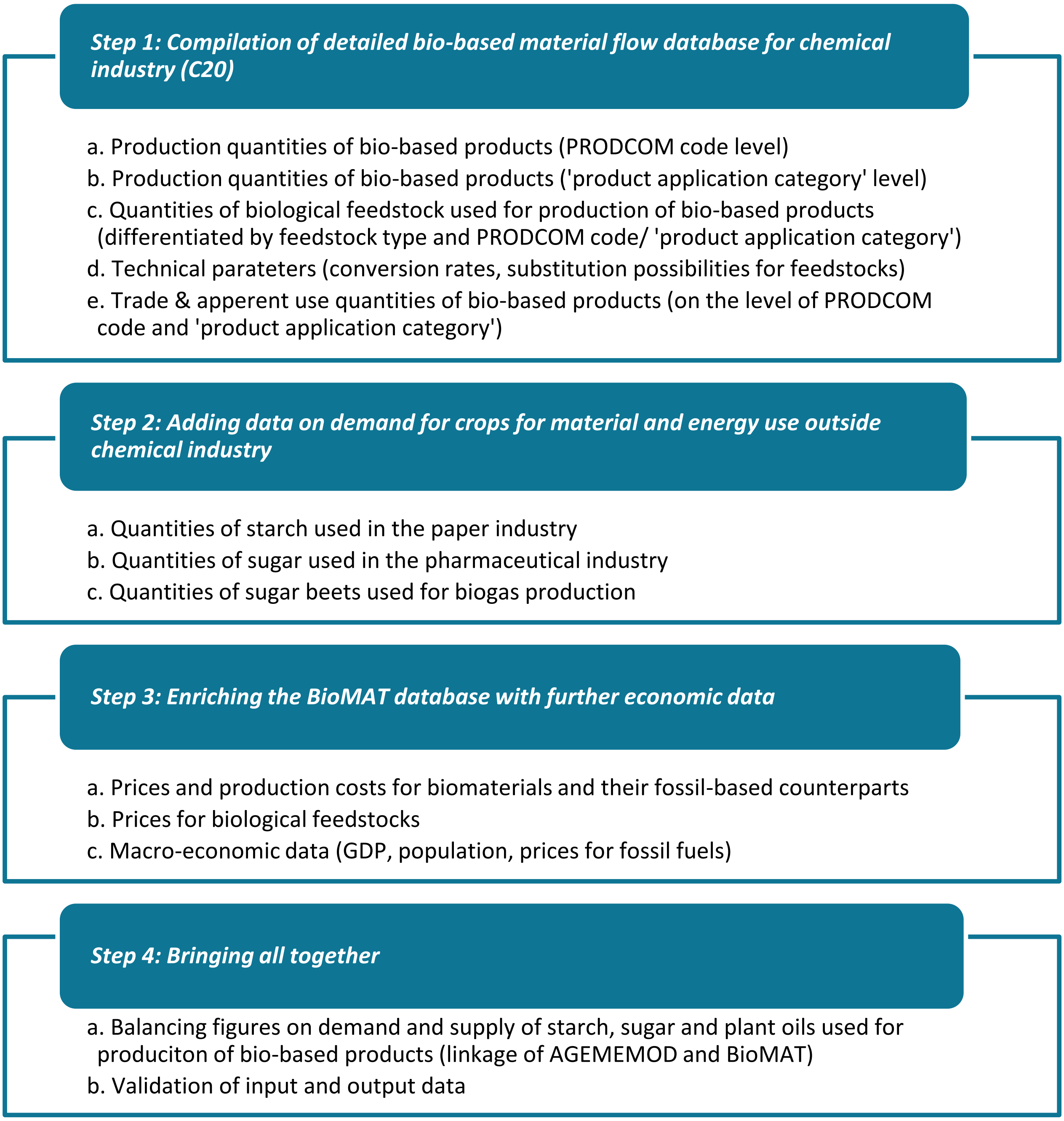
BioMAT is a multi-dimensional database. For most of the variables following dimensions are applied: time (year), region (country), products application category and biological feedstock type. Some variables have only one dimension (for example, exchange rate or world market prices) or two dimensions (for example, GDP and population developments in different countries over time). The BioMAT database is designed to provide information on an annual basis; current version covers annual data for 2008-2018. *Table 21* shows the disaggregation of the dimensions.

Table 21 - Dimensions of BioMAT database

Countries (c)	Chemical application categories (k)	Biological feedstock types (j)
Austria, Belgium-Luxembourg, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Maltha, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden, United Kingdom	1. Platform chemicals 2. Solvents 3. Polymers for plastics 4. Paints, coatings, inks and dyes 5. Surfactants 6. Cosmetics; personal care products 7. Adhesives 8. Lubricants 9. Man-made (MM) fibres 10. Biofuels 11. Pharmaceuticals 12. Food & feed 13. Construction 14. Agrochemicals 15. Other applications	1. Sugar 2. Starch 3. Plant oils 4. Lignocellulosic from forestry 5. Lignocellulosic from agriculture 6. Animal biomass 7. Aquacultures 8. Other primary biological resources 9. Sugar/Starch-based platform chemicals 10. Oil-based platform chemicals 11. Bio-naphtha

6.2 Step-by-Step construction of the database

Unfortunately, there are no sources providing the needed information in a consistent way. So, building the BioMAT database required not only the collecting of data from various sources (official statistics, literature review, expert knowledge) but also the processing of original data. The BioMAT data compilation procedure is organised in the four steps described in Figure 11.



Step 1: Compilation of detailed bio-based material flow database for chemical industry (C20)

a. Production quantities of bio-based products (PRODCOM code level)
b. Production quantities of bio-based products ('product application category' level)
c. Quantities of biological feedstock used for production of bio-based products (differentiated by feedstock type and PRODCOM code/ 'product application category')
d. Technical parateters (conversion rates, substitution possibilities for feedstocks)
e. Trade & apperent use quantities of bio-based products (on the level of PRODCOM code and 'product application category')

Step 2: Adding data on demand for crops for material and energy use outside chemical industry

a. Quantities of starch used in the paper industry
b. Quantities of sugar used in the pharmaceutical industry
c. Quantities of sugar beets used for biogas production

Step 3: Enriching the BioMAT database with further economic data

a. Prices and production costs for biomaterials and their fossil-based counterparts
b. Prices for biological feedstocks
c. Macro-economic data (GDP, population, prices for fossil fuels)

Step 4: Bringing all together

a. Balancing figures on demand and supply of starch, sugar and plant oils used for produciton of bio-based products (linkage of AGEMEMOD and BioMAT)
b. Validation of input and output data

Figure 11 - Steps for BioMAT data compilation procedure

6.3 Step 1: Compilation of bio-based material flows for chemical industry

6.3.1 Framing the scope

The newly compiled detailed database on bio-based material flows for the chemical industry is at the heart of the BioMAT database. This database provides information in terms of physical quantities on:

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

This information is also useful for the creation of material flow diagrams (Sankey diagrams) and for calculation of a set of bioeconomy indicators (e.g. average feedstock conversion rate, bio-based share in production/ 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 must serve as a starting and a focal point to enable the continuation and updating of the database as well as to safeguard the consistency;
- it must 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 of manufactured goods (PRODCOM) together with related external trade data (based on COMEXT) 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.

Information on production of manufactured goods (PRODCOM) is provided at the 8-digit level used in the PRODCOM list which are linked to the 4-digit NACE[10] list (from 2008 onwards NACE Rev. 2). In NACE Rev. 2 section ‘C’ covers *Manufacturing* and division ‘C20’ 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 on 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 such gaps, data from official production and trade statistics for the C20 PRODCOM codes were first subjected to data imputation techniques (e.g. outlier detection, regional and product harmonisation procedures, RAS balancing methods) before being used for the data generation.

The second requirement addresses the issue of direct use of the database on bio-based material flows for the chemical industry in the BioMAT model. The most relevant aspect in this content is the harmonisation of dimensions. Temporal (year) and regional (country) dimensions are aligned. The dimension for feedstock is not prescribed by data core sources and can be freely chosen. Therefore, by building the bio-based material flow database for the chemical industry we use the same categories of feedstock as defined in the BioMAT concept. More challenging was to get a database

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[10] Statistical classification of economic activities in the European Community (NACE)

with a "product" dimension aligned with one of BioMAT. BioMAT needs data at the level of product application category whereas the PRODCOM statistic, which is the main source for data, provides information at the level of PRODCOM product code (much more dis-aggregated level, however, with another grouping concept). To resolve this mismatch a mapping technique has been applied within the database generation procedure (see Section 6.3.2).

6.3.2 Database generation procedure

As already mentioned, the official statistics on production of manufactured goods (PRODCOM) together with related external trade data (based on COMEXT) are the primary data sources. However, these sources do not provide enough information to generate the bio-based material flow database. Therefore, further information is incorporated to enable the construction of the bio-based material flow database. Thus, before moving onto the description of the technical side of the database generation procedure, the need for integration of additional data and how these are obtained are explained.

Information on bio-based shares at the level of PRODCOM codes. Information on bio-based production, trade and apparent use in most cases cannot be directly extracted from PRODCOM statistic. There are two reasons for this. First, some bio-based products produced exclusively from bio-based raw materials (e.g. starch blends for polymers, polyethylene glycol) do not have own dedicated PRODCOM codes and are captured under PRODCOM codes that cover a number of different products (Sturm et al. 2021, 2022; van Leeuwen et al. 2022). Second, some products are produced from bio-based as well as from fossil-based feedstocks (for example, PLA, lactic acid), but are reported under the same PRODCOM codes as the structure of PRODCOM statistics does not foresee the distinction of products with respect to the type of feedstock use. To overcome this problem we incorporate information on bio-based shares for C20 compiled by nova-Institute. Based on market monitoring, literature review and interviews with industry stakeholders, quantities of bio-based production are estimated and then translated into bio-based shares for PRODCOM codes. Such procedure helps to overcome confidentiality issues to some extent, but not all. Thus, this database is not freely available and is subject to confidentiality in its full extend. The datasets on bio-based shares are available for 2008-2018. Additionally, some outlooks are provided for future periods based on market trends and expectations.

Mapping matrix of PRODCOM codes to BioMAT application categories. Chemical products produced under PRODCOM codes can be used whether for semi-final uses or as intermediates. The last 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 enables the elimination of double counting, which is especially important for the calculation of the demand for bio-based feedstock by chemical industry. In the BioMAT database two product groups are classified as intermediates ("Sugar/Starch-based platform chemicals" and "Oil-based platform chemicals") and the rest are considered as semi-final use product groups/ application categories (Table 21). Based on literature review, expert knowledge and assumptions made, a mapping matrix was compiled providing information to which product group(s) or application category(-ies) the output of each PRODCOM code are to assign.

Mapping matrix of bio-based feedstock to PRODCOM codes with respective conversion rates. The bio-based material flow database aims to show which quantities of different bio-based feedstocks are used for production of bio-based chemical products. There is no source providing such information for the EU countries whether on the level of application categories or PRODCOM code level. Therefore, such a database was compiled based on literature review, expert knowledge and assumptions made (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). The mapping matrix indicates the importance of different bio-based feedstocks for each PRODCOM code; respective conversion rates specify which quantity of feedstock (in tons) is required for production of one ton of a PRODCOM product output. Combined, these figures are used to calculate the demand for different types of bio-based feedstocks.

Figure 12 explains the step-by-step procedure applied to generate the bio-based material flow data. The steps are applied to each EU Member State, point of time and each PRODCOM's dimension (production, import and export). As statistics don't directly report on domestic uses this variable is considered to be a variable that closes the market at the country, product group and year levels. It is calculated in the additional fourth step via *Apparent use = Output + Import – Export*.

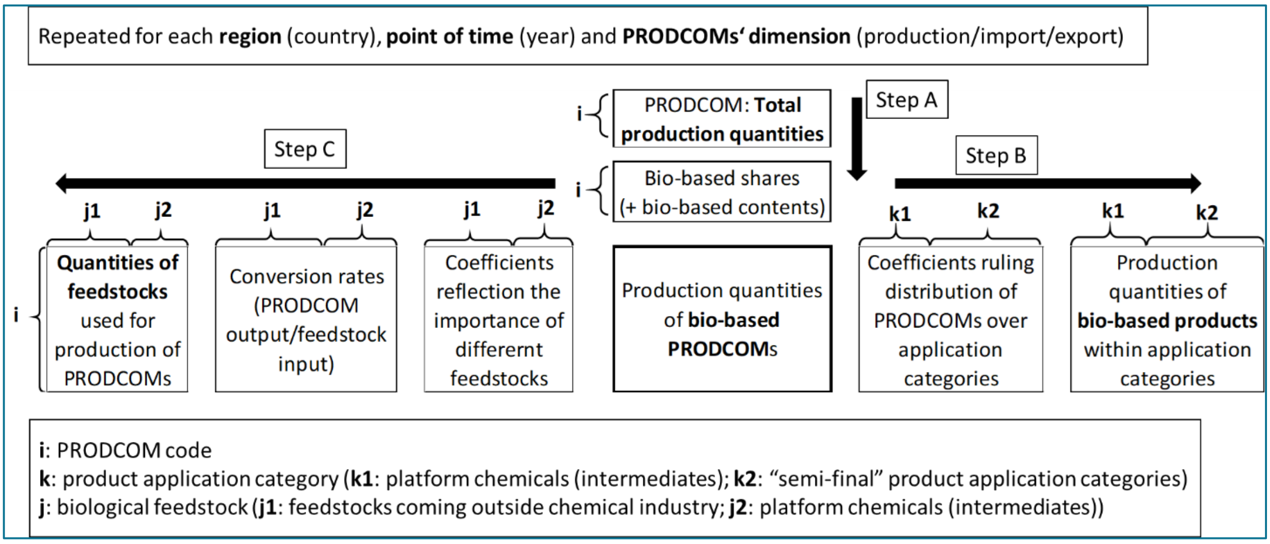

Figure 12 - Database generation procedure for bio-based material based on PRODCOM statistic

Step A combines PRODCOM statistics on production (and import and export) quantities with the information on bio-based shares at the level of PRODCOM codes to calculate bio-based production (and bio-based import and export) quantities for each PRODCOM code.

Step B distributes the bio-based production (import/export) quantities from individual PRODCOM codes 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. 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 (import/export) for each application category associated with production activities covered by individual PRODCOM codes. Summing up these quantities over all PRODCOM codes quantifies the total bio-based production (import/export) within each individual application category.

Step C calculates the quantities of different bio-based feedstocks used for bio-based production within each individual PRODCOM code. A mapping matrix of bio-based 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 bio-based 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 code. 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 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).

Step D (not shown in Figure 12) calculates the quantities of apparent domestic use as *Apparent use = Output + Import – Export*. Figures on apparent use are available for each PRODCOM code as well as for each application category.

6.4 Step 2: Adding data on feedstock used outside chemical industry

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). This Step 2 focuses on the main uses of agricultural biomass, more precisely the use of agricultural crops, outside C20. This is needed to establish the linkage between the demand for agricultural crops for energy and material use and their availability on the supply side provided by AGMEMOD (see Step 4 below).

The **material use of agricultural crops** in construction, production of polymers or man-made textiles occurs not directly, but through intermediate use of bio-based materials that is processed in the chemical industry (C20). We assume that the only material uses that require additional demand for agricultural crops that are not captured by C20, are restricted to the use of starch in the paper industry and the use of sugar in the pharmaceutical industry.

Use of starch in the paper industry (C17). 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 chemical industry, C20) and, 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 the C20 industry.

There are no official statistics on the direct starch use by the paper industry in EU countries. We have analysed different sources providing information about the use of starch by the paper industry on national and EU level, i.e. information from associations, industry reports and other publications. Unfortunately, figures vary greatly depending on the source. Comparing figures provided by associations we observed that figures reported by associations which represent the starch industry (e.g., Starch Europe[11] for the EU, VGMS[12] for Germany) are considerable higher then figures reported by associations which represent the paper industry (e.g., Cepi[13], VDP[14] or DIE PAPIERINDUSTRIE e. V.[15] in Germany) (Figure 13). For example, Starch Europe reports that 31% of 10.9 million tonnes of starch (2.85 million tonnes of starch) was used for “Corrugating & Paper” application in the EU28 in 2020. The European association representing the paper industry (Cepi) on the other hand reports that it’s members (17 EU28 member countries plus Norway) that cover 98,3% of the total paper and board production in the EU28 plus Norway used only 1.69 million tonnes of starch for production of paper and boards in 2020 (CEPI 2021). Similar, for Germany in 2020, VGMS reports the use of 0.808 million tonnes of starch in paper industry whereas VDP reports only the use of 0.482 million tonnes of starch. Figures available from other reports and publications (LMC 2021; BIO-TIC team) are closer to figures reported by associations which represent the paper industry than those reported by associations which represent the starch industry. While Cepi and VDP report figures on the quantities of starch used as a raw material for paper production, Starch Europe and VGMS do not specify what is included in their figures. A possible explanation could be, that figures provided by Cepi and VDP cover only the direct use of starch by the paper industry, whereas figures provided by Starch Europe and VGMS also cover the indirect use of starch in form of starch-based inputs/products (e.g., glues and coating materials). As already mentioned, the demand for starch for the production of starch-based chemicals (e.g., glues and coating materials) was calculated separately in the demand for starch by the chemical industry (C20) in “Step 1”. Therefore, we conclude that the figures provided by paper industry associations (e.g., Cepi, VDP) on the use of starch for the paper production are more suitable for our purpose. In Figure 13, we have calculated a "Starch in Paper coefficient (SPc)" that reflects the relation between the total production quantities of pulp and paper and the quantity of starch directly used by the paper industry:

SPc = Starch use in Paper Industry / Production of Pulp and Paper

Based on data from the paper industry associations (VDP and Cepi) on starch use in the paper industry, the value of the SPc for Germany is 0.0215-0.0231 and for Cepi-members it is 0.0166-0.0198 (for “Cepi – Germany”: 0.0147-0.0189). We have additionally evaluated these figures with experts. The figures for Germany based on the VDP data are in line with the experts' estimates, while the figures for the rest of Europe are considered by the experts to be somewhat low. So, in BioMAT we use the figures on quantities of starch used directly by the paper industry for Germany from VDP, whereas for the rest of countries we calculate these quantities using the SPc of 0.020-0.022 (linear increase over 2015-2020, in line with a calculated value for SPc based on different sources).

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[11] The European Starch Industry Association (Starch Europe), https://starch.eu/

[12] Verband der Getreide-, Mühlen- und Stärkewirtschaft VGMS e.V., https://www.vgms.de/

[13] Confederation of European Paper Industries (Cepi), https://www.cepi.org/

[14] Verband Deutscher Papierfabriken e. V. (VDP)

[15] DIE PAPIERINDUSTRIE e. V., https://www.papierindustrie.de/

	2014	2015	2016	2017	2018	2019	2020
Production of Pulp and Paper (in 1,000 tonnes)[a]							
Germany	22,540	22,601	22,629	22,925	22,682	22,080	21,339
EU28	91,883	91,505	91,342	92,664	92,586	89,937	85,329
Norway	1,023	979	1,099	1,097	1,134	1,155	933
Cepi[b] (18 EU countries + Norway)[c]	91,093	90,951	90,903	92,299	92,233	89,578	84,797
Starch use in paper industry (in 1,000 tonnes) based on…							
VGMS for Germany [d]	634	656	686	706	713	713	808
VDP for Germany [e]	484	493	504	527	524	489	482
StarchEurope for EU28 [d], [f]	n.a.	n.a.	2,697	n.a.	2,790	2,852	2,912
Cepi[b] (18 EU countries + Norway)[c]	1,761	1,521	1,506	1,567	1,542	1,639	1,682
"Starch in Paper coefficient (SPc)"							
VGMS for Germany	0.0281	0.0290	0.0303	0.0308	0.0314	0.0323	0.0379
VDP for Germany	0.0215	0.0218	0.0223	0.0230	0.0231	0.0222	0.0226
StarchEurope for EU28	n.a.	n.a.	0.0295	n.a.	0.0301	0.0317	0.0341
Cepi[b] (18 EU countries + Norway)	0.0193	0.0167	0.0166	0.0170	0.0167	0.0183	0.0198
"Cepi - Germany"	0.0186	0.0150	0.0147	0.0150	0.0146	0.0170	0.0189

[a] *FAO, forest statistics, https://www.fao.org/faostat/en/#data/FO*

[b] *The National Associations of the 18 following countries are Cepi members: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom*

[c] *Cepi; https://www.cepi.org/statistics/*

[d] *VGMS, https://www.vgms.de/staerkeindustrie/presse-service/daten-fakten/*

[e] *VDP, 2021*

[f] *https://starch.eu/the-european-starch-industry/*

Figure 13 - Use of starch by paper industry in Germany and the EU

Use of sugar in the pharmaceutical industry (C21). As official statistics on quantities of sugar used in the pharmaceutical industry are missing, we estimate these figures based on 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 under PRODCOM code 21.10.40. We assume that figures on the production of chemically pure sugar is equivalent to the demand for sugar by this production activity. Table 22 provides figures on EU27 production, apparent use and trade of chemically pure sugar produced by the pharmaceutical industry. It is interesting to note that export makes up a significant share of the production of chemically pure sugar. Apparent use increases over the years in line with domestic production, while import increases to a much lesser extent.

Table 22 - EU27 Production, use and trade of chemically pure sugar (PRODCOM code 21.10.40), in 1000 tons

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	90.00	116.84	114.04	99.94	117.59	99.95	127.27	132.09	146.71	180.00	145.47
Import	14.10	11.77	13.84	15.51	18.39	19.11	17.46	19.16	18.41	19.35	21.44
Export	89.89	90.36	86.30	92.03	88.49	83.19	82.94	84.37	83.23	84.08	78.74
Apparent use	14.21	38.24	41.58	23.42	47.50	35.86	61.79	66.88	81.89	115.27	88.17

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, for example, for the production of such amino acids as lysine (mainly feed-grade) and glutamic acid. Both products have dedicated PRODCOM codes (21.10.20.10 for "Lysine and its esters, and salts thereof" and 21.10.20.20 for "Glutamic acid and its salts") and official statistics provide some figures on these products, although significant gaps exist because of confidentiality issues (figures only for EU27 with a wide uncertainty range can be extracted). Currently, the production of feed-grade lysine in the EU27 takes place only in France. The plant capacity for amino acids production in France is approximately 80,000-100,000 tons/year, which in case of lysine results in a sugar demand of ca. 145,000-180,000 tons (Sturm et al. 2022, 2021). Table 23 shows the production quantities of lysine and glutamic acids (PRODCOM statistics) and the estimated demand for sugar in the EU. As already mentioned, these figures should be treated with caution, as they are calculated based on production data, which are subject to a wide range of uncertainty.

Table 23 - Production of glutamic acid and lysine and estimated dedicated demand for sugar, in 1000 tons, EU27

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production (in 1000 tons)											
Glutamic acid and its salts	2	1	1	20	210	200	120	200	210	200	140
Lysine and its esters, and salts thereof	120	50	40	120	180	70	60	103	100	50	60
Conversion efficiency rate (glucose->amino acid)											
Glutamic acid and its salts	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Lysine and its esters, and salts thereof	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Demand for sugar/glucose (in 1000 tons)											
Glutamic acid and its salts	3	1	2	29	300	286	171	286	300	286	200
Lysine and its esters, and salts thereof	218	91	73	218	327	127	109	187	182	91	109
SUM of demand for sugar	*221*	*92*	*75*	*247*	*627*	*413*	*281*	*472*	*482*	*377*	*309*

Assuming that no chemically pure sugar is used as input in the production of glutamic acid and lysine, we calculate the total demand for sugar needed for the production of these three products (It ranges between 400,000 and 750,000 tons in the EU27 since 2014, the year of the significant increase in glutamic acid production).

There are many more pharmaceutical products produced using sugar as a feedstock (e.g., vitamins, antibiotics, other drugs etc.). However, the estimation of the associated additional demand for sugar requires a collection of detailed information and their processing, similar as we have done for the chemical industry. Since this goes beyond the scope of this study, we use the estimated figures on the demand for sugar needed for the production of chemically pure sugar, lysine and glutamic acid as a proxy for the total sugar demand from the pharmaceutical industry. At the same time, we acknowledge that these figures reflect the lower bound of the total use of sugar in the pharmaceutical industry.

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 reported in "Section D – Electricity, Gas, Steam and Air Conditioning supply" under code "35.21: Manufacture of gas", 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 (IEA 2020). Unfortunately, there are no statistical surveys on the use of sugar crops in biogas production, but estimates indicate that in Germany sugar beets from approximately 25,000 ha are used for biogas production (BLE 2022).

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 (Table 21). From the description of PRODCOM statistics it is not obvious whether the production of bio-naphtha is reported at all and if yes, 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 in the detailed bio-based material flow database for chemical industry. Currently, the BioMAT concept foresees that the respective demand for biomass is calculated separately based on figures on production quantities of bio-naphtha, which should be obtained from different sources (as official statistics don't provide figures on the production of bio-naphtha). At present, the production of bio-naphtha is estimated to be almost equal to zero, though some companies express 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 to around 100 000 t. Therefore, the importance of bio-naphtha can increase significantly over time with the corresponding increase in demand for biomass needed for its production. For the production of bio-naphtha various biomass types (including crops and products thereof) can be used. Although the production and the use of bio-naphtha is currently considered in BioMAT in a very stylised way, the groundwork has been laid for its inclusion as soon as more data becomes available.

To summarise, currently, the total demand for crops for material and energy use outside the chemical industry (C20) is: (i) approximately 1,800-2,000 thousand tons of starch for the paper industry, (ii) at least 400-750 thousand tons of sugar (including starch-based sugar) for the pharmaceutical industry; and (iii) about 280 thousand tons sugar (correspondence to 25,000 ha of sugar beets) for biogas production.

6.5 Step 3: Enriching database with further economic data

Besides information on production, trade and use quantities of bio-based products and on quantities of 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 bio-based feedstocks;
- macroeconomic data (GDP development, inflation rates, population development, oil price development).

6.5.1 Market data for chemicals

Prices and production costs are important indicators and drivers of product markets. We enrich the BioMAT database with this information for bio-based chemicals and their fossil-based counterparts. This information is provided at the level of product application category.

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. To generate these figures, we proceed as follows. Firstly, we take information on production values (in euros) from PRODCOM statistics and calculated the respective values of bio-based chemicals using the same procedure as for calculation figures on physical quantities (based on bio-based shares for each PRODCOM code). Figures on the production values are calculated for both for each PRODCOM code and each application category (see Step 1 and Step 2). Secondly, dividing the values of bio-based chemicals by the respective physical quantities we estimate 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, meaning that the figures on the bio-based shares for physical volumes are also applied for the production values. In doing so, we assume that prices of bio-based and fossil-based products covered under the same PRODCOM code are the same. Such assumption is not a problem if products covered by a PRODCOM code have roughly the same price and are predominantly bio-based. But it is getting more problematic if a PRODCOM code covers a mixture of products that differ considerably in prices, bio-based products make only a small share and prices of bio-based and fossil-based products differ substantially from each other. However, it seems that unit prices of bio-based and fossil-based chemicals within 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 none for bio-based chemicals within the same application category (and vice versa).

Production costs. Even if 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 situation, BioMAT obtains information on production costs from external studies (Spekreijse et al. 2019; Spekreijse et al. 2021; Philippidis et al. 2022; Baldoni et al. 2021). Production costs consist of costs for biomass, energy, capital, labour and other materials, and have been calculated for the average chemical, plastic and pharmaceutical sectors - both for the bio-based and fossil-based product version - in the average EU.

6.5.2 Prices for bio-based feedstocks

Prices on agricultural crops and products thereof used as feedstocks for production of bio-based products are taken from AGMEMOD. We focus on developments of prices for wheat, corn, potatoes, sugar and oilseeds and oils which are used as feedstocks for production of bio-based materials.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

6.5.3 Macro-economic data

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

6.6 Step 4: Bringing all together

On the one hand, in BioMAT, in Step 1 and Step 2, we estimate 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. On the other hand, through access to the AGMEMOD database we have figures on the availability of specific agricultural crops and products thereof 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 material use. Combining information from both databases (and models) enables the tracking of common feedstocks along the entire chain - 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 points. 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 14 illustrates the general idea.

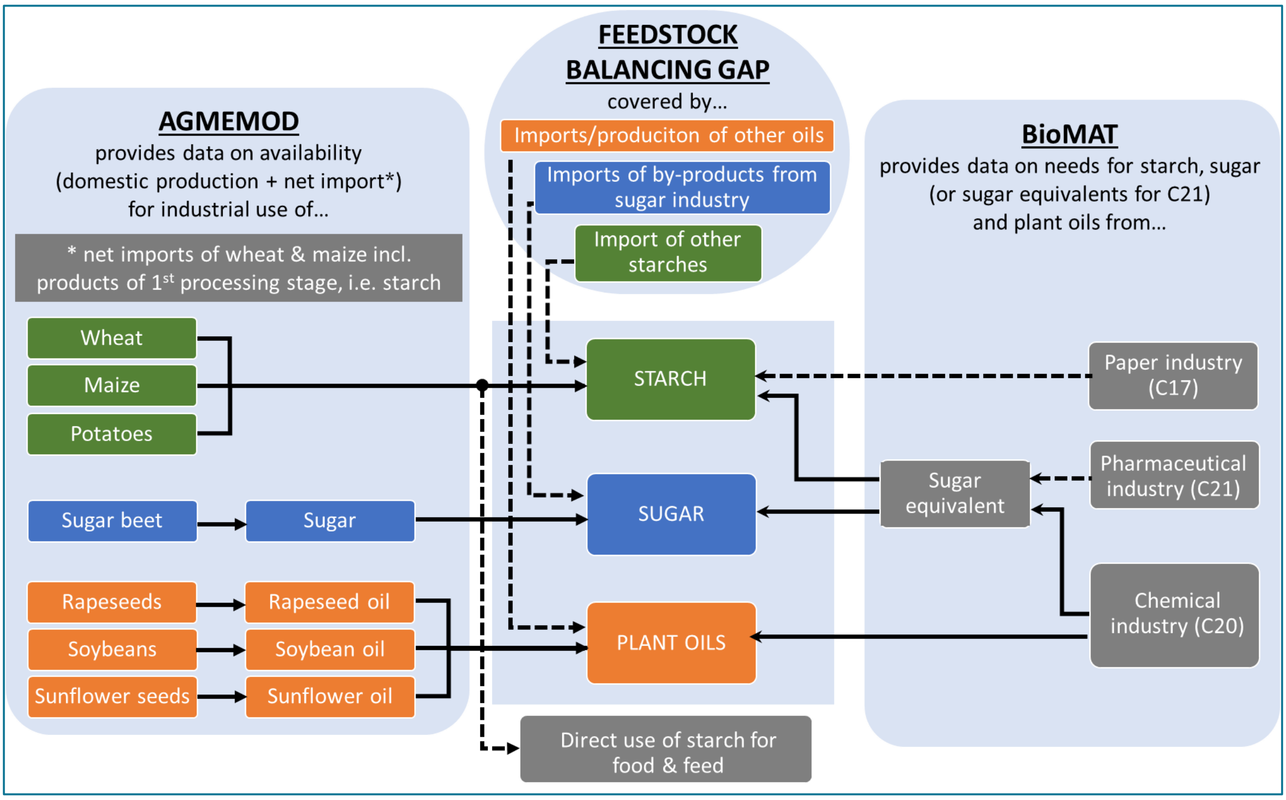

Figure 14 - Calculation of supply, demand and ‘balancing gap’ for starch, sugar and plant oils

In the middle of Figure 14, three types of bio-based 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 availability/ supply for industrial use of related bio-based resources is provided by AGMEMOD. The right side shows how demand on these bio-based resources for different applications comes off within BioMAT. Possible discrepancies between the BioMAT and AGMEMOD figures on respectively demand and supply 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 just covers the main crops (and products thereof) harvested in the EU, though not crops harvested in the EU but 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.

Starch. AGMEMOD provides figures on quantities of wheat, corn and potatoes available for processing, material and energy use. To be in line with the defined processing routes we use these figures to calculate the total quantity of starch produced from the respective feedstocks. According to Starch Europe[16] approximately 60% of the total starch available in the EU is allocated to food and feed. Therefore, we assume that circa 40% of available starch calculated based on AGMEMOD figures is used as a feedstock for the applications covered by BioMAT. The processing routes defined in BioMAT foresee that starch is used whether directly (mainly by paper industry) or as a starch-based sugar (in particular glucose) obtained by hydrolysis of starch. The total demand for starch calculated in BioMAT exceeds the supply of starch calculated based on figures 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 crops 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, maize) is not captured. Therefore, the "feedstock balancing gap" estimated for starch is attributed to the imports of starch-based sugar, in particular glucose, and starch produced from other raw materials (peas, rice, cassava etc.) that is available for material and energy use.

Sugar. AGMEMOD provides figures on quantities of sugar available for industrial/ material use (attributed to sugar from sugar beets). The total demand for sugar calculated in BioMAT and the total supply of sugar for industrial/ material use from AGMEMOD are mostly balanced. From the 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. molasse) not explicitly covered by AGMEMOD.

Plant oils. AGMEMOD provides figures 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 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 used cooked oil

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[16] The European Starch Industry Association (Starch Europe), https://starch.eu/

(UCO) and tall oil from the wood industry are 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 be closed via imports of these oils for industrial use.

Besides the conceptual aspects mentioned above, the occurrence of "balancing gaps" can partly be attributed to uncertainties in both models. AGMEMOD is an established model that undergoes regularly validations with industrial and policy stakeholders. BioMAT, on the contrary, is a newly developed database (and model) and builds mainly on processed data. Processed data, although in essence based on official statistics, usually depend a lot on expert knowledge and are thus subject to uncertainties. Following information in BioMAT is subject to uncertainties and can be adjusted if better knowledge and data becomes available:

Information related to data for the chemical industry, such as:

- bio-based shares;
- coefficients in mapping individual PRODCOM codes to application categories;
- coefficients in mapping bio-based feedstock types to PRODCOM codes;
- conversion rates (relation between feedstock use and bio-based material output).

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 production;
- other (potential) material uses of crops.

To date, several validation rounds of the created database have already been conducted. Not only via specific knowledge on the agricultural and chemical sectors provided by project partners, but also via feedback provided by the industry. Reviews are used to improve the BioMAT database and model.

All data series for market items of the chemical applications are country-specific and available in *CC-Datagmemod* files, which are the key data files of the BioMAT model. To remind, BioMAT is an integrated module within the AGMEMOD framework, see Figure 15. Data files are named as *AT-Datagmemod.xls* (AT=Austria), *BE-Datagmemod.xls* (BE=Belgium), *DE-Datagmemod.xls* (DE=Germany), etc.. In total, any country based data file contains series for around 1300 variables; the complete BioMAT data set encompasses around 38,000 series[17]. Some of the data that have been derived and reported in the CC-Datagmemod files have already been shown in Section 3. For example, see Table 7 for production volumes of total and bio-based C20 applications in EU28 in 2018; Table 8 for production volume of C20 applications in EU member states in 2010 and 2018; Table 11Secondly, conversion factors of feedstock types per bio-based product and per bio-based product application are derived, by weighting the production volumes of the individual C20 products. High conversion factors (> 4) are highlighted in red (see Table 11). For example, the conversion factor 5 (column 3, row 2) means that 5 kg plant oils is needed to process 1 kg of solvent.

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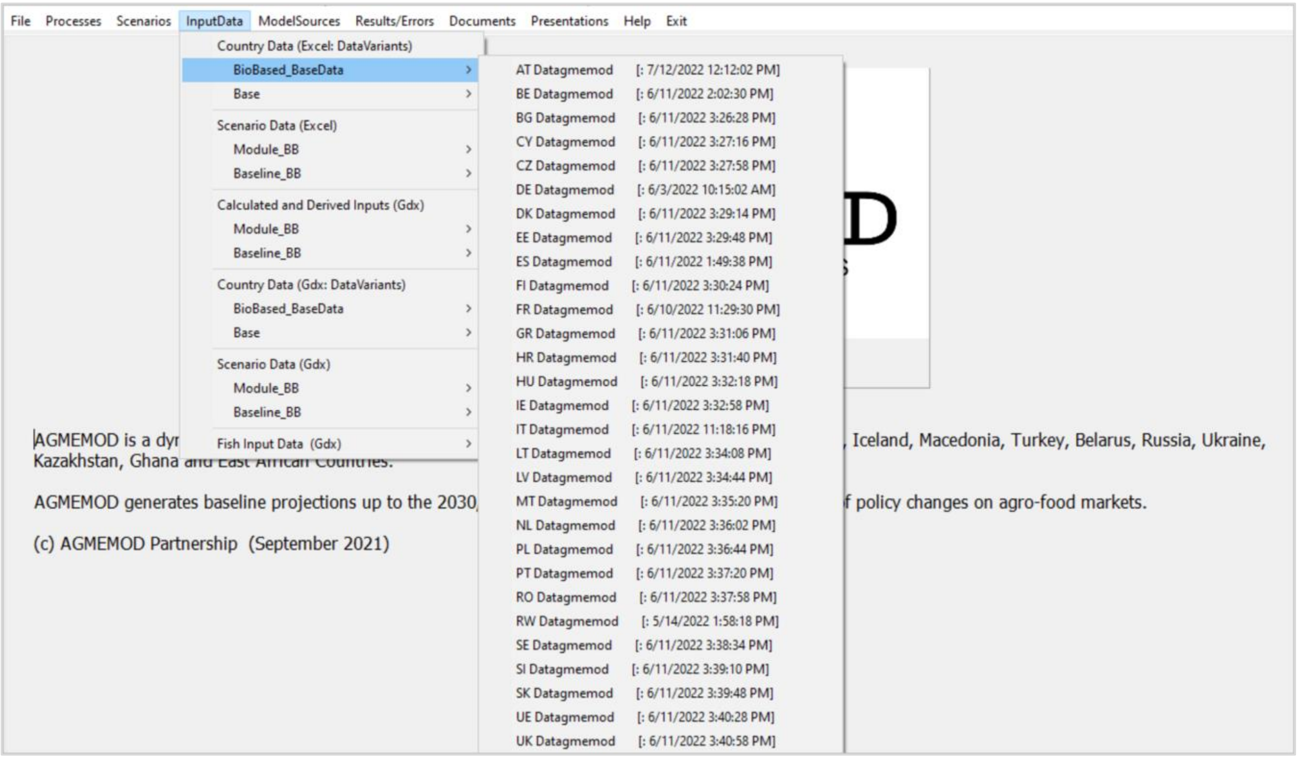
[17] The BioMAT model is an integrated module within the AGMEMOD framework. Its total size is about 4 GB. The AGMEMOD framework is regularly updated and centrally stored and shared in the cloud.

The reciprocal is considered as the conversion efficiency rate, which means that 1 kg plant oil can produce 0.2 kg of solvent.

Thirdly, feedstock shares and conversion rates of bio-based products within the application groups are linked to their respective bio-based products productions (see Table 7) which provides estimates for total feedstock use per bio-based application group (Table 12). In 2018, the significant amount of 44% of EU's total biological feedstock use (55 Mton) is processed into biofuels, while another 13% goes to chemical platform products and 6% to surfactants. The rest is scattered over other application groups.
Table 10 for conversion efficiency rates of feedstock use per application in EU28 in 2018.



AGMEMOD is a dyı , Iceland, Macedonia, Turkey, Belarus, Russia, Ukraine, Kazakhstan, Ghana

AGMEMOD generates baseline projections up to the 2030, f policy changes on agro-food markets.

(c) AGMEMOD Partnership (September 2021)

Figure 15 - Data files for each EU member state (and UK) with data series for market variables of chemical applications

7. Trends and outlook

7.1 Reference

Contributing to the policy-making process regarding the bioeconomy is complex (Figure 16) in the sense that bio-based value chains are influenced by policies, macro-economic situation, organisation of value chains, demographic factors and consumer preferences, situation on the world market, financial funds available for innovation, and so on. More specifically, it is not always clear if the bio-based value chain will be positively or negatively influenced through the combination of policies and trends, and there might be unforeseen trade-offs. Note that the factors shown in Figure

16 coincide with the drivers considered in the BioMonitor conceptual framework presented in D1.1 (Kardung et al., 2020).

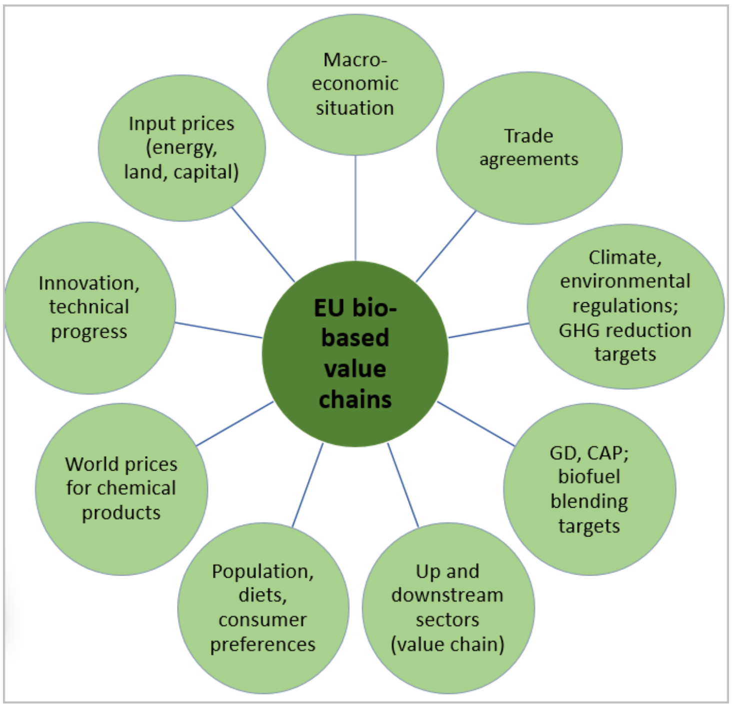


Figure 16 - Factors influencing EU bio-based value chains (Source: Authors)

The reference scenario will take on board – as much as possible - current knowledge on the factors mentioned above and assume that current policies and trends are extended until 2030 (for medium-term projections) and 2050 (for long-term projections). For a better understanding of the general picture presented in the BioMAT reference scenario more details regarding assumptions about macroeconomic developments, population growth, world market prices, consumer preferences, as well as policies implemented is provided in the remainder of this section.

To begin with, we refer to the general macroeconomic picture which is presented in the reference scenario. As regards energy prices, the crude oil price is assumed to recover to the pre-covid level and steadily increasing until reaching a level of around 77 USD/barrel. The exchange rate EUR/USD is expected to fluctuate in the range of 0.83-0.87, following a declining trend in the coming decade. Another important macroeconomic element to describe is GDP. Table 24 reports on the average annual GDP rates of growth assumed for 2020 and 2030.

Table 24 - GDP developments - annual average growth rates (%)

	2010-14	2015-19	2020-24	2025-30
Belgium	3.07	3.40	2.59	3.13
Denmark	2.83	3.31	2.59	2.83
Germany	3.67	3.33	2.75	3.02
Greece	-5.64	0.68	1.65	3.01
Spain	-0.69	3.82	1.93	3.21
France	2.12	2.45	2.20	2.81
Ireland	2.87	13.28	6.41	2.91
Italy	0.64	1.93	1.78	2.21
Luxembourg	6.17	4.98	4.46	4.30
The Netherlands	1.45	3.83	2.66	3.18
Austria	2.96	3.60	2.52	2.75
Portugal	-0.24	4.34	2.06	3.23
Finland	2.64	3.04	2.88	3.60
Sweden	3.65	4.71	2.51	2.87
United Kingdom	3.77	3.52	1.62	3.71
Bulgaria	2.81	7.39	4.73	3.16
Czech Republic	1.92	5.76	3.52	3.69
Estonia	7.31	6.88	4.08	4.39
Hungary	4.38	7.76	6.25	4.57
Latvia	4.80	5.21	3.95	4.72
Lithuania	6.38	5.97	4.34	4.09
Poland	4.54	6.04	5.45	4.04
Romania	3.82	8.16	5.44	5.84
Slovakia	3.55	4.26	4.24	4.59
Slovenia	0.77	5.17	3.31	5.22
Malta	6.97	9.24	3.45	4.24
Cyprus	-1.29	5.05	3.01	4.28
Croatia	0.04	3.96	3.53	4.36

Source: AGMEMOD-BioMAT.

In terms of the demographic developments underlying the BioMAT reference (Figure 17), negative prospects has been assumed for both the EU15 and the New Member State (NMS) region. More specifically, for the total EU27 and the former EU15 region (including the UK) population growth is expected to slow down over time reflecting the ageing of the EU population and low fertility rates. Eventually these two factors will result on a declining trend over the coming decade. In the case of the NMS region, prospects are even more negative with an average annual negative rate of growth of around -0.03% over the period 2021-2030.

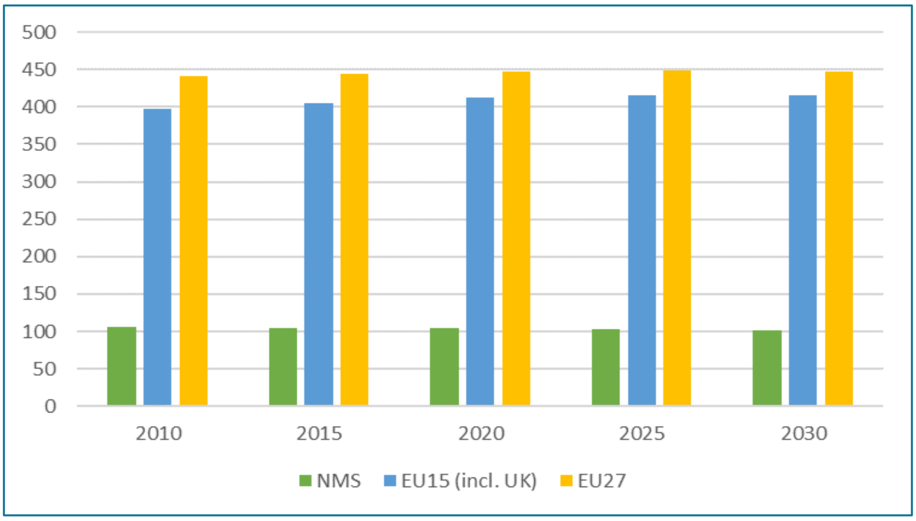


Figure 17 - Population developments (million heads) (Source: AGMEMOD-BioMAT)

Focusing on the expected developments for world market prices and given the little information received, Figure 18 reports on the prices for chemical platforms and polymers for plastics for both bio-based and fossil-based formulations. In sum, bio-based prices for both are expected to remain at the current level for the projection period. However, while bio-based chemical platforms are expected to be higher than in the past, PLA prices could be lower than at the beginning of the period. Looking at their fossil-based counterparts, prices has been declining over time, although they are expected to increase reflecting the societal fight against climate change and the impacts of the Russian invasion in Ukraine.

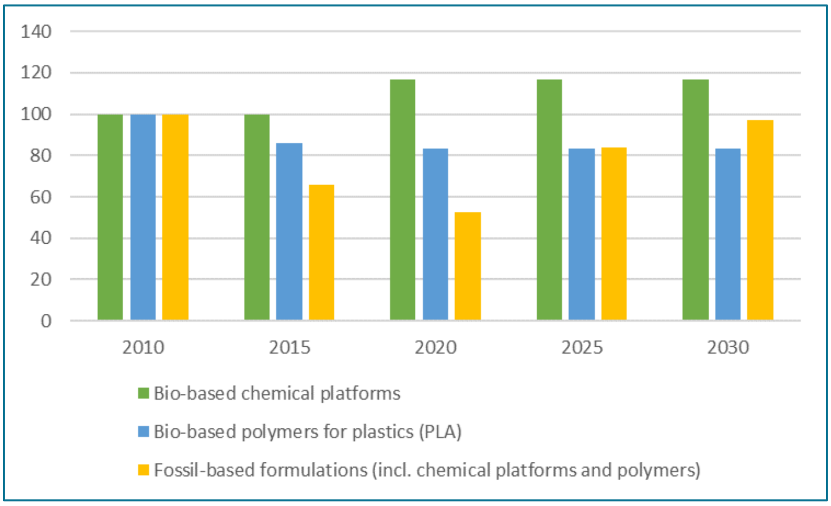


Figure 18 - Price developments - chemical platform and polymers (2010=100) (Source: AGMEMOD-BioMAT)

Drawing attention to the prices of the raw feedstocks required as the basis for bio-based production, Figure 19 shows the evolution of prices of selected commodities at the global market level for the period 2010-30. Overall, the reference figures indicate a moderate price increase in the coming decade. For the second part of the projection period (2026-30), global prices for these selected commodities are expected to show average annual price increases of around 1.4-1.9%.

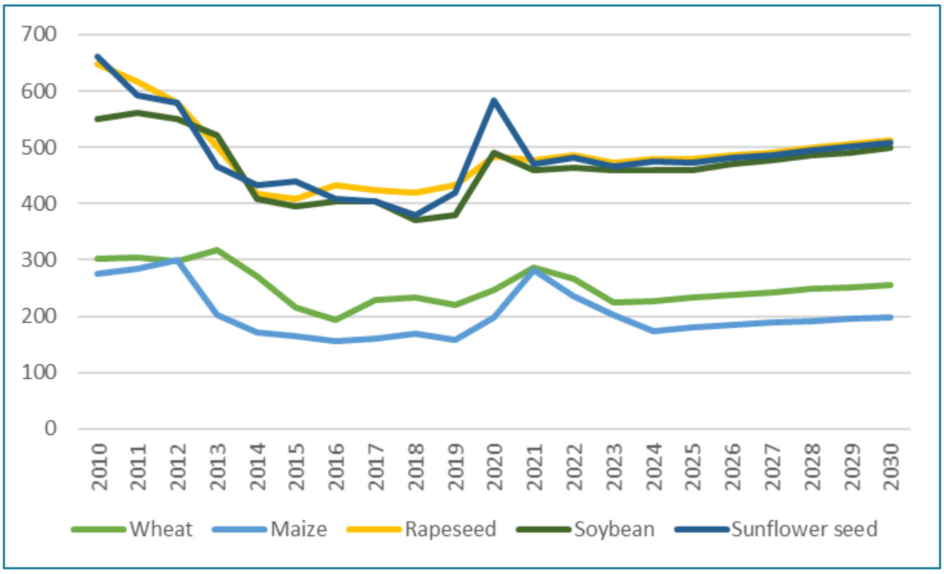


Figure 19 - Raw feedstock price developments on world market (USD/t) (Source: AGMEMOD)

Other important elements of the reference are the expected developments of consumer preferences. For a better illustration of the reference trends in this respect, Figure 20 concentrates on the EU and presents per capita (apparent) consumption levels of the key feedstock types that are employed for human consumption. In general terms, per capita consumption has been increasing in the past decade. This trend is expected to continue in the coming years although some stabilisation is expected over the period 2025-30 for all commodities, with the exception of maize whose consumption is expected to continue growing over the entire period.

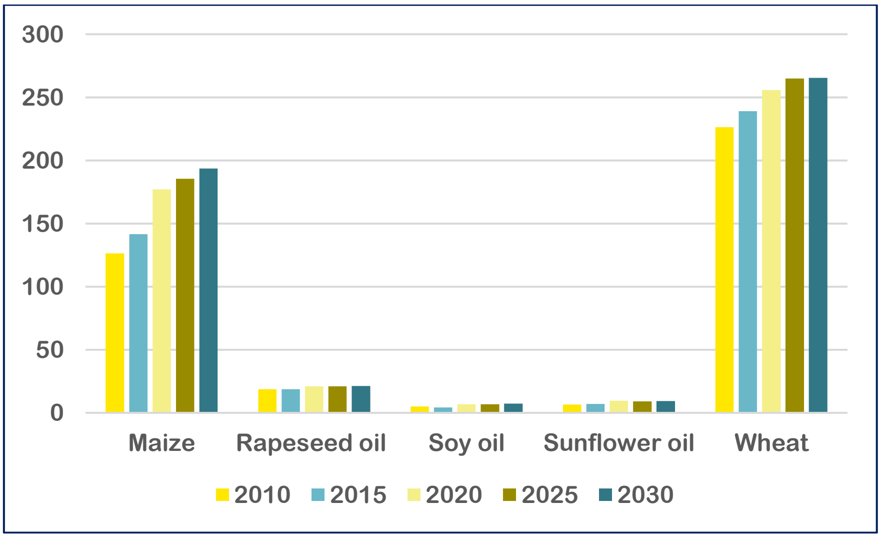


Figure 20 - (Apparent) food consumption per capita in EU (kg/head/year)

Focusing on products downstream the value chain, Figure 21 reports on the produciton (red line) and domestic use (green line) of total C20 chemical products, while Figure 22 reports on the production (red line) and use (green line) of the C20 bio-based products. The domestic use is driven by the development of the real income per capita in a country. As shown in the figures, the increases in total consumption of both total chemicals and bio-based chemicals have been reported over the period 2010-18 (historical period) and these developments are also expected to continue in the coming decade. The growth rate of consumption of bio-based chemicals from 2018 to 2030 is with 3.5% almost three times higher than the 1.2% growth rate for total chemical consumption. This is mainly due to a bio-based/fossil-based price ratio that develops in favour of bio-based products (see dotted lines) and a general trend development. In terms of production volumes, the EU continues to be a net-importer of chemical product applications in the medium term.

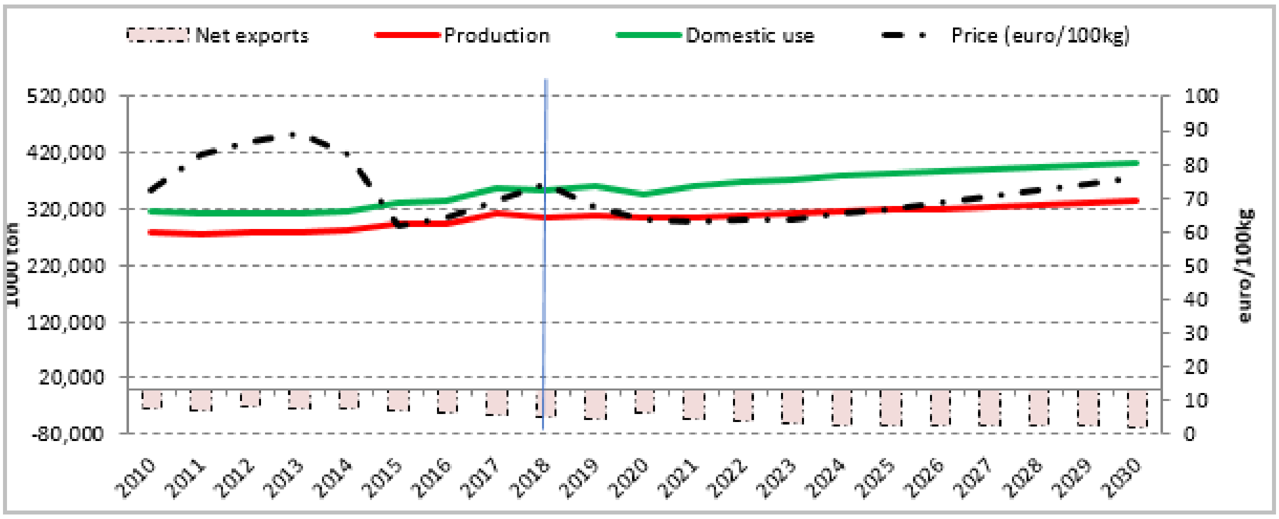


Figure 21 - Development of supply and use of C20 chemical products in EU 28, in 2010-2030

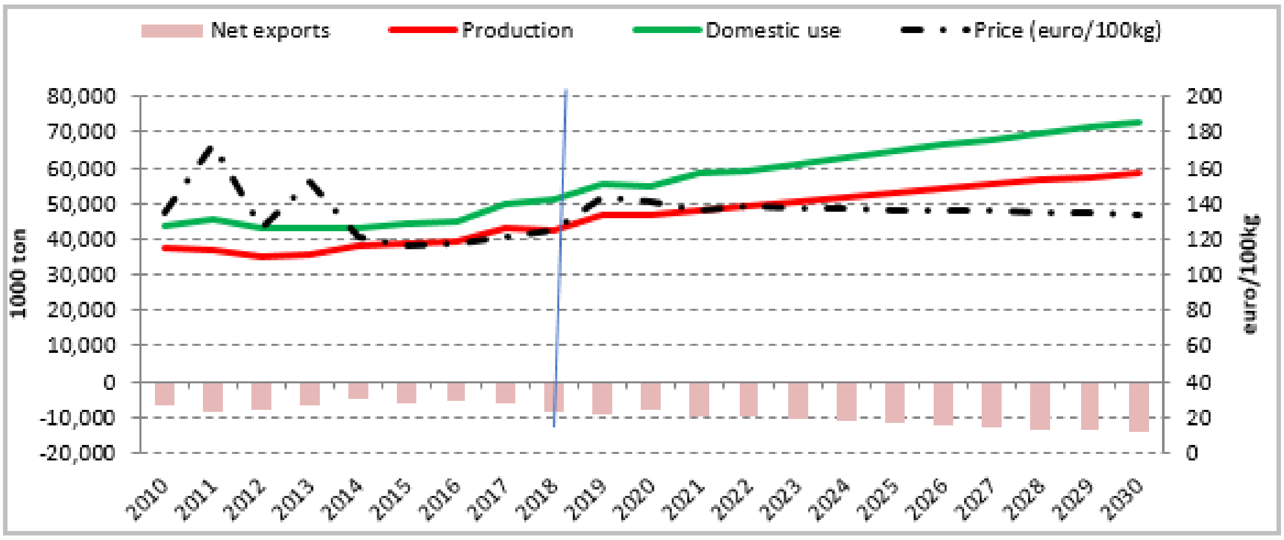


Figure 22 - Development of supply and use of C20 bio-based chemical products in EU 28, in 2010-2030

Table 25 shows the domestic use development of a selected number of chemical applications. In most cases the bio-based consumptions growth faster than the fossil-based consumption for each application due to changing relative prices. Table 26 presents the domestic supply development of the same selected chemical applications.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 773297.

Table 25 - Domestic use (1000t, %-share) and its growth rates of total and bio-based applications in EU, 2030 vs average 2016-2018

	Average 2016-18*	2030*	Annual growth rate
Chemical platform (bio-based)	8481 (6.5%)	15906 (10.4%)	5.4%
Chemical platform (total)	130109	153522	1.4%
Polymers (bio-based)	830 (0.1%)	2259 (2.4%)	8.7%
Polymers (total)	785674	92744	0.7%
Solvents (bio-based)	564 (7.8%)	1039 (12.1%)	5.2%
Solvents (total)	7246	8578	1.4%
Cosmetics (bio-based)	2378 (37%)	3750 (47.2%)	3.9%
Cosmetics (total)	6422	7953	1.8%
Paints (bio-based)	1254 (6.6%)	2240 (9.6%)	5.0%
Paints (total)	19055	23308	1.7%
Lubricants (bio-based)	241 (5.8%)	407 (8.3%)	4.5%
Lubricants (total)	4181	4881	1.3%
Adhesives (bio-based)	1299 (24%)	2158 (34.9%)	4.3%
Adhesives (total)	5417	6181	1.1%
Pharma (bio-based)	990 (30.4%)	1367 (40.3%)	2.7%
Pharma (total)	3252	3388	0.3%
All chemicals (bio-based)	*48460 (13.9%)*	*70904 (17.6%)*	*3.2%*
All chemicals (total)	*349177*	*402539*	*1.2%*

Source: AGMEMOD-BioMAT. * In brackets the share of the bio-based application in the total application

Table 26 - Domestic supply (1000t and growth rates) of total and bio-based applications in EU, 2030 vs 2016-2018

	Average 2016-18*	2030*	Annual growth rate
Chemical platform (bio-based)	4829 (4.7%)	8338 (7%)	4.7%
Chemical platform (total)	101942	118988	1.3%
Polymers (bio-based)	771 (1%)	1745 (2.1%)	7.0%
Polymers (total)	78530	83112	0.5%
Solvents (bio-based)	418 (7.4%)	619 (9.4%)	3.3%
Solvents (total)	5656	6578	1.1%
Cosmetics (bio-based)	2266 (33.4%)	3481 (45.2%)	3.6%
Cosmetics (total)	6786	7695	1.1%
Paints (bio-based)	758 (3.7%)	1354 (6.7%)	5.0%
Paints (total)	20424	20107	-0.1%
Lubricants (bio-based)	281 (6.2%)	488 (8.1)	4.7%
Lubricants (total)	4507	5988	2.4%
Adhesives (bio-based)	1234 (22.4%)	1690 (27.6%)	2.7%
Adhesives (total)	5500	6115	0.9%
Pharma (bio-based)	732 (27.2%)	935 (33.8%)	2.1%
Pharma (total)	2688	2764	0.2%
All chemicals (bio-based)	*41700 (13.7%)*	*57514 (17.5%)*	*2.7%*
All chemicals (total)	*303869*	*329005*	*0.7%*

Source: AGMEMOD-BioMAT. * In brackets the share of the bio-based application in the total application

Figure 23 shows the projected biomass needs, per type, for the total production of bio-based C20 applications in EU in 2030. About one third regards industrial plant oil, followed by starch (21%), wood lignocellulosic (13%), animal biomass (10%) and sugars (6%).

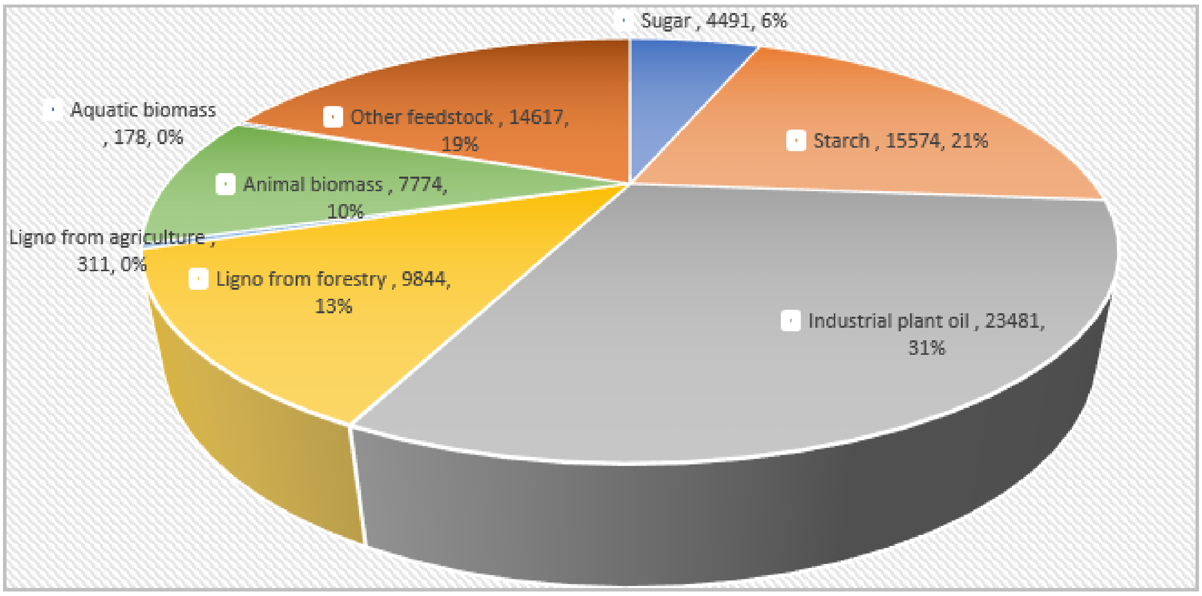


Figure 23 - Biological biomass types required by bio-based chemical applications in EU in 2030, 1000t

Figure 24, Figure 25 and Figure 26 show the development up to 2030 of the EU markets of industrial sugars, starch and industrial plant oil respectively that is available for the EU bio-based chemical industry (red lines) and required by the EU bio-based chemical industry (green lines). The EU is a net importer for each of the three biomass types, but there are clear differences. The sugar market is quite balanced, net-imports of starch will increase from 1,4 million ton in 2020 to 2,9 million ton in 2030, and net-imports of industrial plant oils are expected to grow from 10,1 million ton in 2020 to 15,6 million ton in 2030. As industrial plant oils form the dominant biomass input in the bio-based chemical sector (Figure 23), and given that its vast majority originate from non-EU regions, the attention for sustainable sourcing of (traded) biomass is key.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

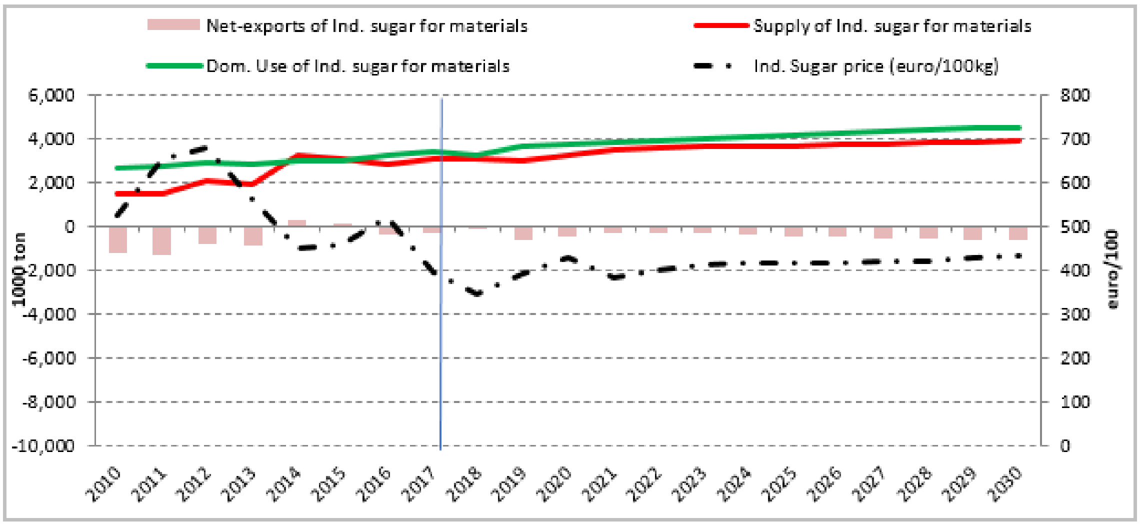


Figure 24 - EU industrial sugar market for material use in C20 bio-based applications

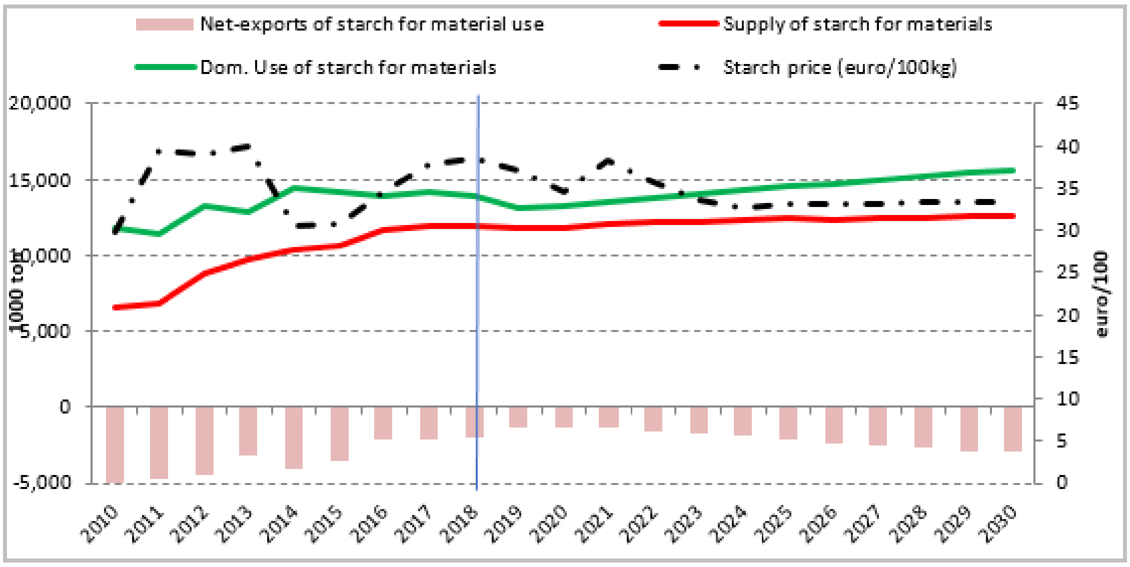


Figure 25 - EU starch market for material use in C20 bio-based applications

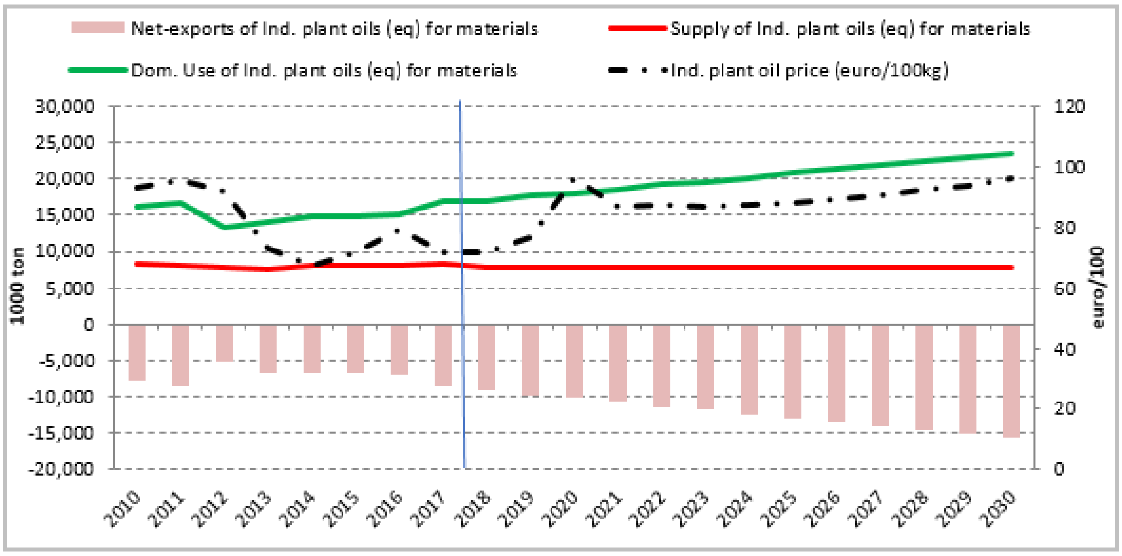


Figure 26 - EU plant oil market for material use in C20 bio-based applications

7.2 Alternative options

The modelling of forward-looking alternative scenarios is the focus of WP6, including their definition, actual simulation and calculating impacts on indicators compared to the reference. At this stage, a few preliminary considerations regarding the scenarios that will be modelled in the context of the BioMonitor project are provided. More specifically, the following drivers might be explored when designing scenario options:

- more efficient technologies/conversion factors;
- lower production costs, cheaper inputs;
- higher oil prices compared to biomass feedstock prices;
- substitution of biomass resources for energy and material uses;
- incentives to reduce the use of fossil-based inputs (CO_2 price, CO_2 tax at the border);
- public support for bio-based materials (support subsidies or fossil taxes);
- food waste reduction.

When thinking about the potential size of the impacts on these drivers, the main challenge is to estimate the size of a specific supply shock (due to e.g. CO_2 tax or technical progress) or of a specific demand shock (e.g. due to imposing consumer incentives, or growing awareness for sustainability in society) on the behaviour of market actors. Expert knowledge, literature review, and case studies carried out in the BioMonitor project and some statistical analyses are expected to help to identify plausible and relevant shocks for each scenario.

Part II: EFI-GTM model improvements

8. Wood-based product markets

8.1 Introduction

The forest sector is an important sector in the bioeconomy. The sector has been long manufacturing conventional forest products, such as houses, furniture, the numerous types of paper products, as well as less well-known materials, such as chemicals and cellulose-based fillers (Hassegawa *et al.*, 2021, 2022). During the manufacturing process of many of the conventional products, residues are produced, which are often used to generate energy for the industry. However, some of the residues and by-products have functional properties and can be used as feedstock in the production of (new) value-added products. In addition, there is an increasing interest from the population to have access to products that have a lower negative impact to the environment and that represent solutions to problems caused by the extensive use of non-renewable materials and the dependence on fossil sources (Hurmekoski *et al.*, 2018; Hassegawa *et al.*, 2021, 2022).

The EFI-GTM (European Forest Institute Global Trade Model) is a multi-regional and multi-periodic partial equilibrium model of the global forest sector (Kallio *et al.*, 2004). It depicts the system consisting of wood supply, forest industries (sawmilling, wood-based panels, pulp and paper industries) and production of wood-based energy and biofuels, demand for forest industry products and woody biomass for energy, and international trade in wood and forest products. The model has a detailed representation of European countries and considers other countries in global regions; in total there are 57 countries and regions covering the world. The model includes about 30 forest industry and energy sector products, five roundwood categories, three categories for forest chips, four recycled paper grades, and the main by-products of the forest industries, such as sawmill chips, sawdust and black liquor.

Within BioMonitor, EFI-GTM has been updated for the modelling of traditional forest products and has been extended to include new wood-based products. Figure 27 maps the traditional (i.e., already existing) and new products covered by EFI-GTM.

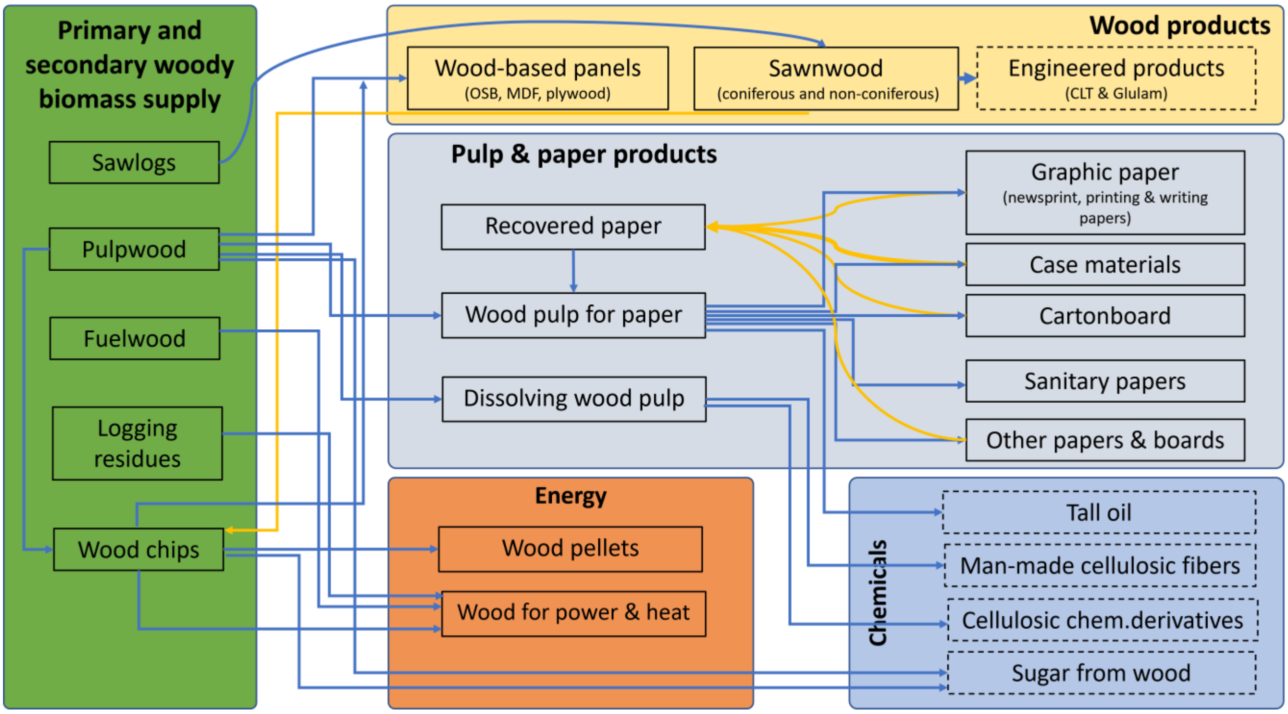


Figure 27 - Overview of main EFI-GTM products and material flows (Source: D4.3).

To prepare an outlook for wood-based product markets, new econometric analyses have been conducted for some products categories (carton board, case materials, graphic papers, man-made cellulosic fibres) to estimate income and price elasticities for demand, which currently do not exist in the scientific literature. For other product categories (sawnwood, other paper & paperboard, cellulosic chemical derivatives) income and price elasticities have been updated based on the recent scientific literature, as identified in Deliverable 5.1. For the intermediate products (mainly chemical pulp) the demand has been calculated based on the final products demands. For some of final products (sugar, tall oil) the demand is driven by scenario assumptions and are only considered in the alternative scenarios that will be reported in Deliverable 6.2.

8.2 Traditional wood products

Solid wood products, paper and paperboard and energy have been traditionally the main product categories. Especially for several paper products long used relationships between increasing graphic paper production and consumption and consumers' income growth appear no longer valid, as at high enough income levels, further income growth is now associated with decreasing graphic paper consumption (Chiba et al., 2017; Hurmekoski and Hetemäki, 2013), often explained by the adoption of Internet and electronic media (Latta et al. 2016; Johnston 2016).

Most econometric studies that estimated income and price elasticities of paper and paperboards consider three major paper categories: newsprint, printing & writing papers, and other papers and paperboards. Production, import and trade statistics for these three paper grades are available from FAOSTAT (FAO) for >200 countries as yearly volumes in metric tonnes since 1961. These statistics could be disaggregated in more detailed product categories such as *sanitary papers*, *wrapping*, *packaging paper* and *paperboard*, *other paper and paperboard n.e.s.* (n.e.s: not elsewhere specified). Moreover, *packaging paper and paperboard* has been further subdivided into *Carton* *board*, *Case materials*, *Other papers mainly for packaging* and *Wrapping papers*. For all these more disaggregated paper grades data are available from FAOSTAT from 1998 onwards.

Despite the availability of these disaggregated statistics, most econometric studies nevertheless consider only one aggregated paper grade besides newsprint and printing & writing paper. However, there are important differences in trends between paper grades. *Case materials* is the main paper & paperboard grade among other paper and paperboards grades in terms of volume and growth rate. *Carton board* is another important grade in terms of volume and equally important with case materials in terms of economic value. Sanitary paper is of less importance in terms of volume, nevertheless sanitary papers shows stable growth rates. Other paper grades among *other paper and paperboard* shows very low or no growth and their importance in terms of volume is of relatively low importance. To differentiate between these paper and paperboard, we tried to estimate new functions for case material and carton board.

8.2.1 Case materials and carbon board

To prepare a future outlook for case materials and carton board, we estimated new demand equations for both case materials and carton board as a function of income (GDP) and price.

To estimate the demand, we collected annual data for production, import and export starting from 1998 from FAOSTAT for some two hundred countries. From these statistics, we estimated the apparent consumption (or annual demand) as production plus import minus export. In this way, the annual case materials and carton board countries' demand is estimated in metric tonnes (total per product grade and per year for the period 1998 – 2020). To make the data comparable between countries, we expressed demand per capita. We collected population statistics from the World Bank (WB databank). Countries with a very low or negative demand for case materials and / or carton board were dropped from the analysis.

For the independent variables, we collected GDP (2010 US$ constant) data from the World Bank (WB databank) for the period 1998-2020. However, GDP data for 2020 were not complete (many missing data), therefore time period was cut to 1998-2019 (22 annual data points for each country). Furthermore, we estimated price for case materials and carton board obtained from FAOSTAT in constant 2010 US$ values using a US deflator 2010 base (WB databank).

After all processing, our panel data consisted of 22 annual observations for 90 countries (i.e., 1980 observations in total) for case materials and for carton board. We considered three approaches for dealing with panel data: pooled OLS method (all observations are pooled together without countries' data distinction), Fixed Effect (FE) method (with country considered as constant factor), and Random Effect (RE) method (with country effect considered as random factor). The decision which method / model to use was based on F-tests (Pooled OLS versus FE model) and Hausman tests (FE versus RE models). We used the Gretl econometric software (GNU Regression, Econometrics and Time-Series) for our econometric analyses.

For the case materials and carton board, we used a quadratic function so that we would consider saturation effects with higher GDP per capita:

$$DemCap = aGDP_{cap} + bGDP_{cap}^{2} + cRealPrice$$

Regression results showed that real price variable was not statistically significant (p=0.66) and it was therefore dropped from the final equations (Table 27). According to the F-test and Hausman test FE model deemed to be preferable.

Table 27 - Regressing results for case materials and carbon board

Product category	a	b	c
Case material	0.0026***	- 0.0000000254***	NS
Carton board	0.00066***	- 0.00000001053***	NS

p < 0.05; ** p< 0.01; *** p< 0.005; ^{NS} Not Significant

Figure 28 shows the historic (2000-2020; FAOSTAT) and projected demand for carton board and case materials by the EU27 and the entire world. According to these results, the global demand would increase by 78% between 2020 and in 2050. The EU27 demand is projected to increase only modestly by about 14%. These projected developments reflect historic trends according to which the global demand grew the same 78% over the last 20 years, while the demand in EU27 grew only 38%.

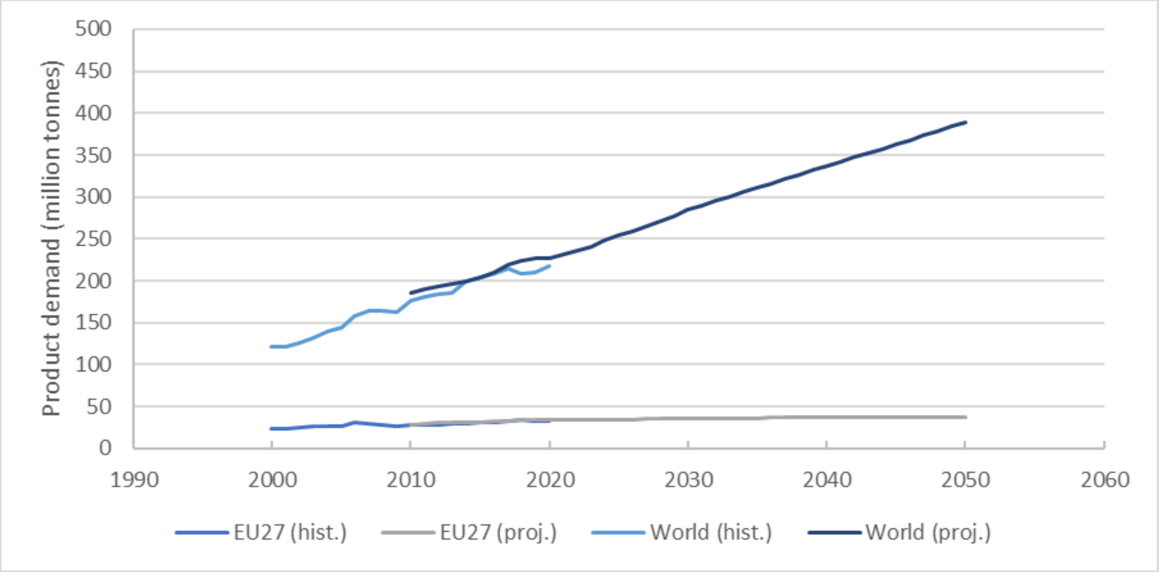


Figure 28 - Historic and projected global and EU27 case materials and carton board demand (unit: million tonnes). The historical development is based on FAOSTAT and the projected development by EFI-GTM.

8.2.2 Newsprint and graphic paper

To prepare a market outlook for case materials and carton board, we estimated new demand equations for newsprint and graphic papers. For graphic papers, we estimated separate functions for Uncoated Wood-Free paper (UWF), Uncoated Wood-Containing (UWC) and Coated paper grades. We used a similar approach as for carton board and Case materials in terms of the collecting panel data on demands per capita, income (GDP per capita) and price. However, an important difference is our attempt to capture the ongoing declining trend in consumption of newsprint and graphic papers in most countries and which became visible in EU region especially after 2007 – 2010 with the economic recession. To capture the declining trend, we used the internet adoption share (IntShare) as an additional variable (see also Latta, 2016; Johnston, 2016). The internet adoption share expresses the share of the total population in the country with internet access (obtained from WB databank) and aims to reflect the use of digital media over paper products.

Similar as for case materials and carboard, we consider a quadratic function for newsprint and graphic papers with the following functional form:

$$DemCap = aGDP_{cap} + bGDP_{cap}^2 + cRealPrice + dIntShare + eIntShare*GDP_{cap}$$

Real price variable deemed to be statistically not significant and dropped from the final equations (Table 28). According to the F-test and Hausman test, the FE model deemed to be preferable.

Table 28 - Regression results for newsprint and graphic paper

Paper grades	a	b	c	d	e
Newsprint	0.000286**	- 0.000000002898**	NS	NS	– 0.00000582***
Uncoated Wood-Free paper	0.000328**	-0.00000000358***	NS	NS	– 0.00000232*
Uncoated Wood-Containing	0.000205**	NS	NS	NS	– 0.00000494***
Coated paper	0.000225**	NS	NS	0.0488695***	– 0.00000625***

p < 0.05; ** p< 0.01; *** p< 0.005; ^{NS} Not Significant

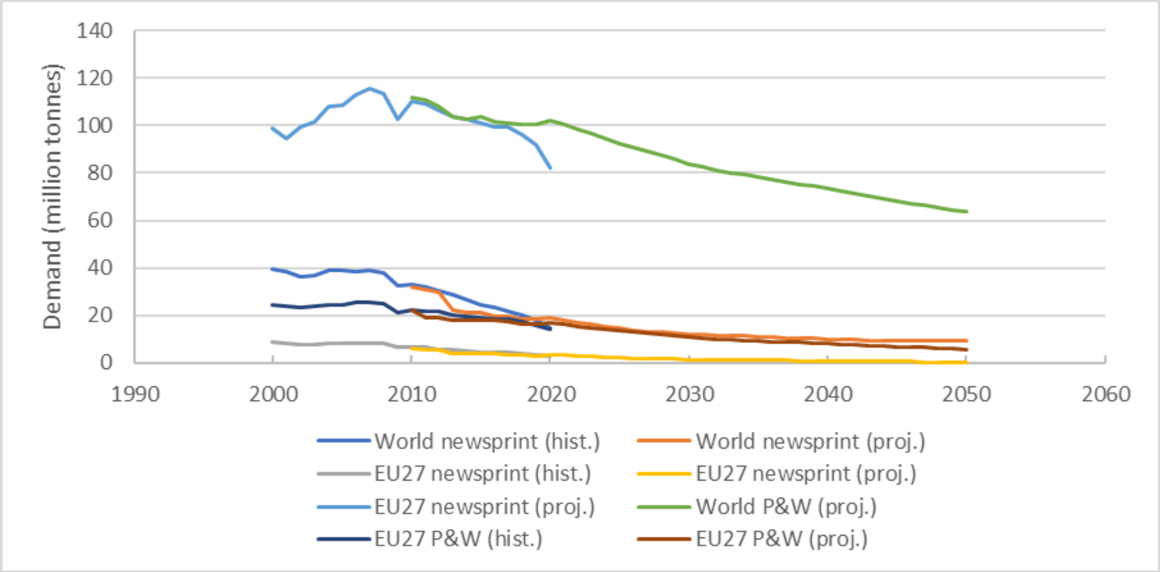


Figure 29 - Historic and projected global and EU27 demand for newsprint and for printing and writing papers (unit: million tonnes). The historical development is based on FAOSTAT and the projected development by EFI-GTM.

Figure 29 shows historic (2000-2020) and projected Global and EU27 graphic papers demand for the EU27 and the entire world. Global printing & writing paper demand is projected to decline by almost two times compared to its maximum in 2007, while EU27 printing & writing paper consumption is projected to decline by more than 4 times since 2007 (more than two times from 2020 level).

8.2.3 Solid wood products

Besides pulp and paper products, the forest sector produces a wide range of solid products such as sawnwood, panels and boards. There are few econometric studies that estimated income and price elasticities at the global and EU level (Table 29) and we used these studies to update the forest products demand estimates by EFI-GTM.

Table 29 - Overview of income elasticities for forest products estimate in literature

Product category	Buongiorno 2015 (period: 1992-2013)	Buongiorno 2015 (period: 2004-2013)	Morland et al. 2018	Rougieux & Damette, 2018	This study
Sawnwood	0.24	0.42-0.55	0.19		-
Sawnwood coniferous			0.44	0.214-0.356	0.44
Sawnwood non-coniferous			0.22		0.22
Plywood	0.62	0.72	0.6		0.6
Particleboard	0.59	0.55-0.67	0.75	0.73-0.99	0.75
OSB					1
Fiberboard	0.93	0.79-0.94	1.07	0.32-0.39	
MDF					1.07
Hardboard & Insulation Board					0.2

In this project, we adopted income elasticities for solid wood products based mainly on Morland et al. (2018), which are more or less in line with the two other studies reported in Table 29. However, EFI-GTM considers a more disaggregated product classification than used in other studies and models. For these more disaggregated products (Oriented Strand Board (OSB), Medium Density Fibreboard (MDF) and Hardboard & Insulation boards) there are no specific income elasticities reported in the literature. We therefore applied the following approach and assumptions:

- MDF is a major part of the fibreboard market representing 88% of the global fibreboard market, while hardboard and insulation boards represent 7% each. MDF shows the fastest annual growth rate of 9.8% globally over the last 25 years (FAOSTAT data on the disaggregated products are available for 1995 - 2020), while Hardboard & Insulation boards grew only 0.6% per year globally. Therefore, we used the highest Fibreboard's income elasticity (1.07) estimated by Morland et al. (2018) as income elasticity for MDF.
- OSB demonstrated 3.5% annual growth globally over last 25 years, while Particleboard (other than OSB) grew only 2.5% per year globally. Therefore, we used the highest Particleboard's income elasticity estimate (0.99 by Rougieux) as income elasticity for OSB and we used the average Particleboard's elasticity estimate (0.75) as income elasticity for Particleboard (other than OSB).
- Hardboard & Insulation boards showed only limited growth and we estimated the elasticity as 0.2 (based on a 0.6% growth in annual hardboard and a 3% annual Global GDP growth over the last 25 years).

Based on these income elasticities, Figure 30 shows the global projected sawnwood and wood-based panels demand development. Global sawnwood demand is projected to develop more or less in parallel to the historic linear trend projection. However, the starting point (2010) for the projection is somewhat below the long-term trend due to the very low historic consumption of sawnwood during the economic downturn in the years 2008 and 2009. The global wood-based panel demand is estimated to exceed sawnwood consumption after 2025 and the projected demand development is roughly within the historic long-term trend. In the EU27 region, a similar sawnwood and wood-based panels demand development is projected (Figure 31). However, wood-based panels demand is not expected to exceed sawnwood demand by 2050.

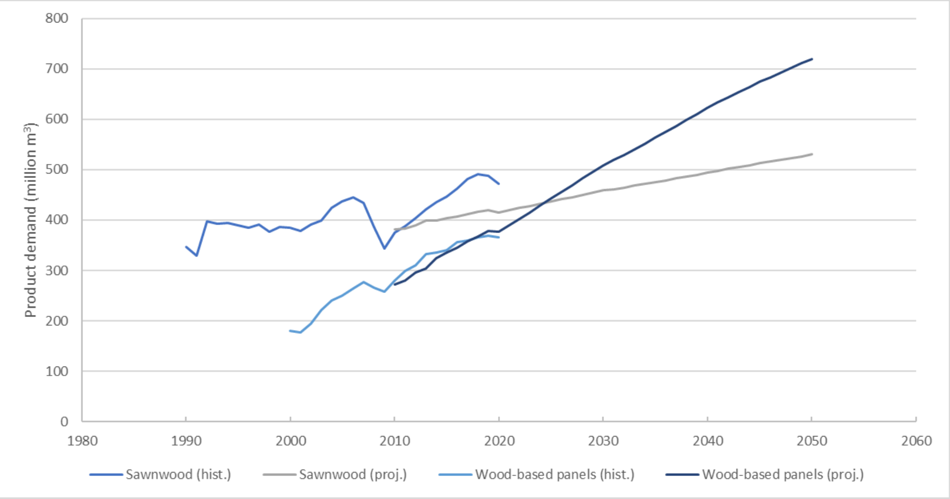


Figure 30 - Historic and projected global sawnwood and wood-based panels demand (unit: million m^3). The historical development is based on FAOSTAT and the projected development by EFI-GTM.

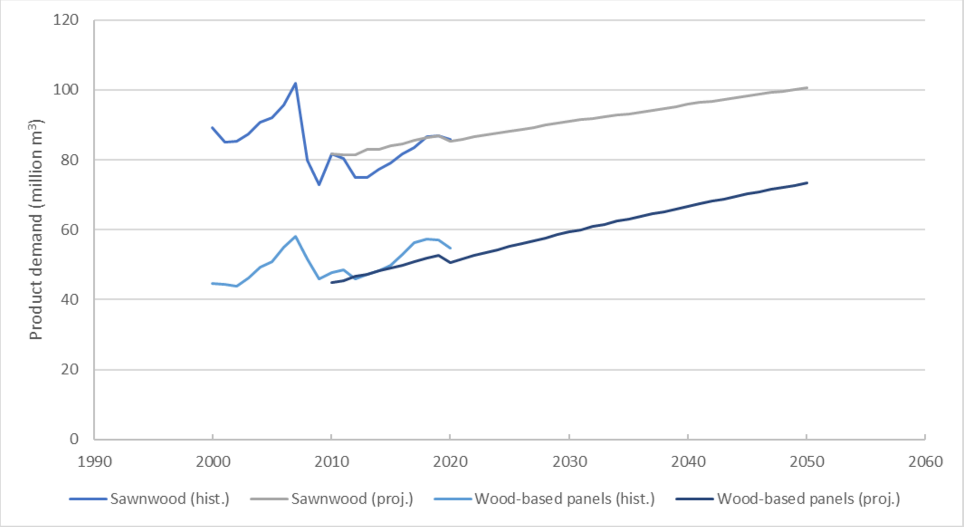


Figure 31 - Historic and projected EU27 sawnwood and wood-based panels demand (unit: million m^3). The historical development is based on FAOSTAT and the projected development by EFI-GTM.

8.3 Emerging wood products

The development of new products with potential for substitution of fossil-based or GHG-intensive materials is one of the elements in the circular bioeconomy. The forest sector has been active in trying to find alternative products that are not simply technical substitutes for traditional materials, but that also help solve some of the problems related to increases in GHG emissions, depletion of natural resources, and generation of residues and waste (Hurmekoski *et al.*, 2018; Hassegawa *et al.*, 2021, 2022). Hassegawa *et al.* (2021, 2022) identified emerging wood-based products in the EU that could be economically produced in Europe from lignocellulosic biomass from forests in the near to medium future. They also analysed the requirements for biomass quality and quantity and the extent to which these products are compatible with existing value chains. The analysis by Hassegawa *et al.* (2021) has been used as a basis for extending EFI-GTM with new wood-based products, which focused on including Man-Made Cellulosic Fibres (MMCF) as well as other cellulosic chemical derivatives that are produced from dissolving pulp.

8.3.1 Man-Made Cellulosic Fibres

Most wood-based textiles that are on the market are categorized as MMCF, which include viscose, acetate and lyocell, among others. Viscose has already been produced for over 100 years, whereas Lyocell is a newer fibre. Lyocell is produced with a more environmentally friendly production method, especially compared to viscose whose production generate toxic chemical waste. The production process of MMCF is usually based on dissolving wood pulp and wet spinning.

The existing MMCF (viscose and lyocell) are produced from dissolving pulp produced from pulp logs, which can be converted to different grades of MMCF, as well as for cellulosic chemical derivatives. The conversion efficiency from dissolving pulp to MMCF is about one to one (i.e., one ton of dissolving pulp per ton of MMCF; Hassegawa et al., 2022). There are also newer wood-based fibres that follow another value chain and do not rely on dissolving pulp (see Hasegawa et al. 2021). These newer fibres will not be considered in EFI-GTM as they are not yet commercially produced and production efficiencies are not known. Dissolving pulp is already included in EFI-GTM but its modelling has been revised in BioMonitor by including MMCF, as well as for cellulosic chemical derivatives in the model (Figure 32). Consequently, the demand and supply of dissolving pulp has been calculated by EFI-GTM as derived, i.e., based on the demand for final products taking into account conversion efficiencies.

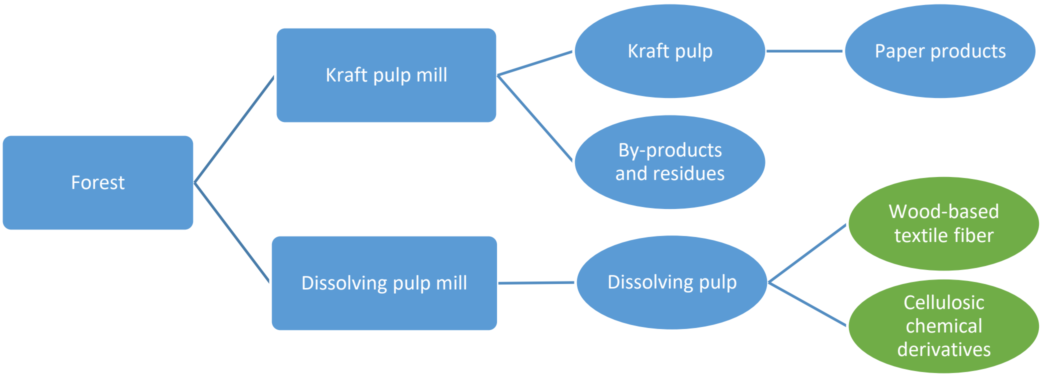


Figure 32 - Value chain for woo-based fibres and cellulosic chemical derivatives in EFI-GTM (new developments indicated in green). Source: Hassegawa et al. (2021)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

Data compilation

Similar as for the products described in section 8.2, the demand for MMCFs and cellulosic chemical derivatives and has been estimated from available production data and import / export statistics. Data on the production of MMCF are available from the European Man-Made Fibres Association (CIRFS, 2019), while global trade statistics are available from international datasets (e.g., United Nation's COMTRADE database[18] and derived databases such as BACI international trade database[19] and the Forest Products Trade Flow database[20]). CIFRS provides annual reports that contain annual production data of MMCFs for the period from 2005 to 2017. In addition to MMCF other Man-Made Artificial or synthetic Fibres (MMAFs such as polyamide, polyester, acrylic, polypropylene, elastan, PVA/PVC, aramid) are reported. As MMCFs may substitute for MMAFs as well as cotton, we collected cotton fibres production from FAOSTAT for the same time period 2005 – 2017. Import & export statistics for MMCF, MMAF and cotton were collected from the BACI trade database.

Figure 33 shows the demand (apparent consumption) development for cotton and man-made fibres for Europe, China (the largest global consumer) and the rest of the world. While the global demand for cotton was relatively stagnant at the level around 25 million tonnes annually, MMAF grew by 67% and MMCF by 96% within 2005 – 2017 period. The main region where this growth occurred was China with the MMAF growth of 135% and MMCF growth of 229% over the 2005 – 2017 period. The demand for MMCF grew at a significantly lower rate over the same period with 40% in Europe and 32% in the rest of the World. Globally, MMCF fibre increased its relative share globally only marginally – from 4.4% to 6.5% (see Figure 30). The increase in the share of MMCF is mainly observed in China, while in most other regions this share was more or less stagnant, especially for the last 10 years. However, according to CIFRS (2019), the share of MMCF in global fibre consumption was in the range of 12-18% during 1950 – 1980, then it declined to 5.2% in 2000. In the long run there is still high uncertainty regarding potential growth of MMCF share. Nevertheless, since the share of MMCF was changing globally and in different regions over time, accounting for this variable would allow to get a better fit for the historic data and better prediction of the future wood-based textile demand.

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[18] https://comtrade.un.org/

[19] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37

[20] https://efi.int/knowledge/databases/fptf

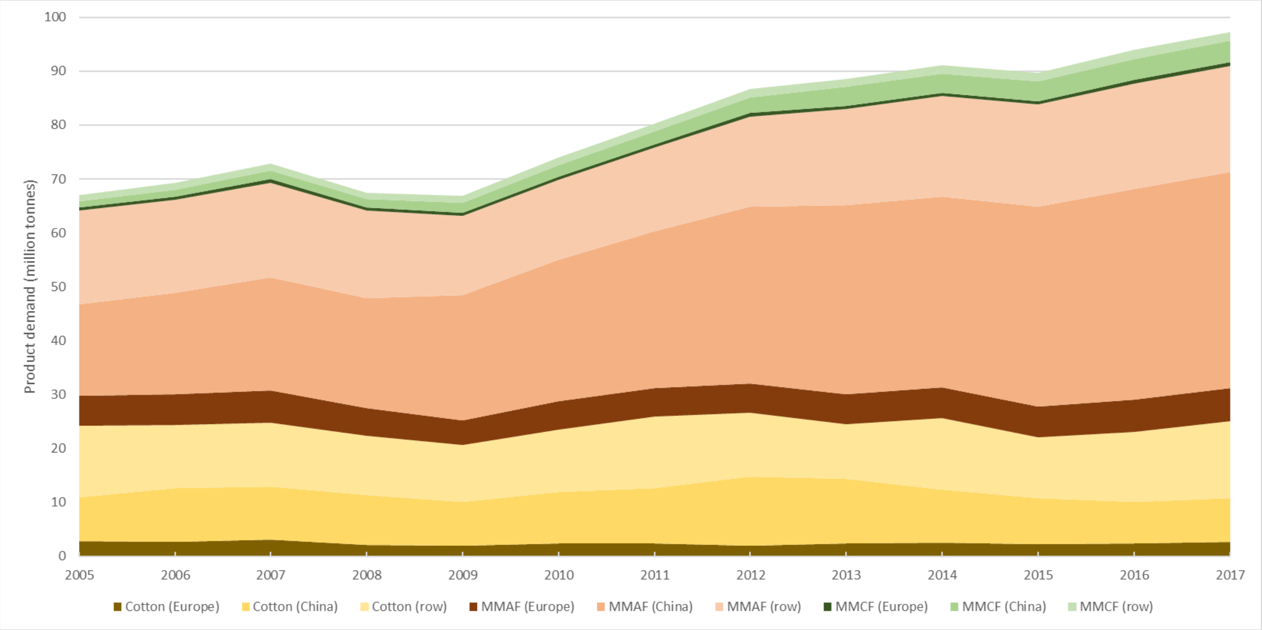

Figure 33 - Apparent consumption of cotton and man-made fibres in China, Europe (EU27 plus other European countries) and the rest of the world (row). Source: BACI database for import & export, CIRFS for the production of MMCF & MMAF and FAOSTAT for the cotton production.

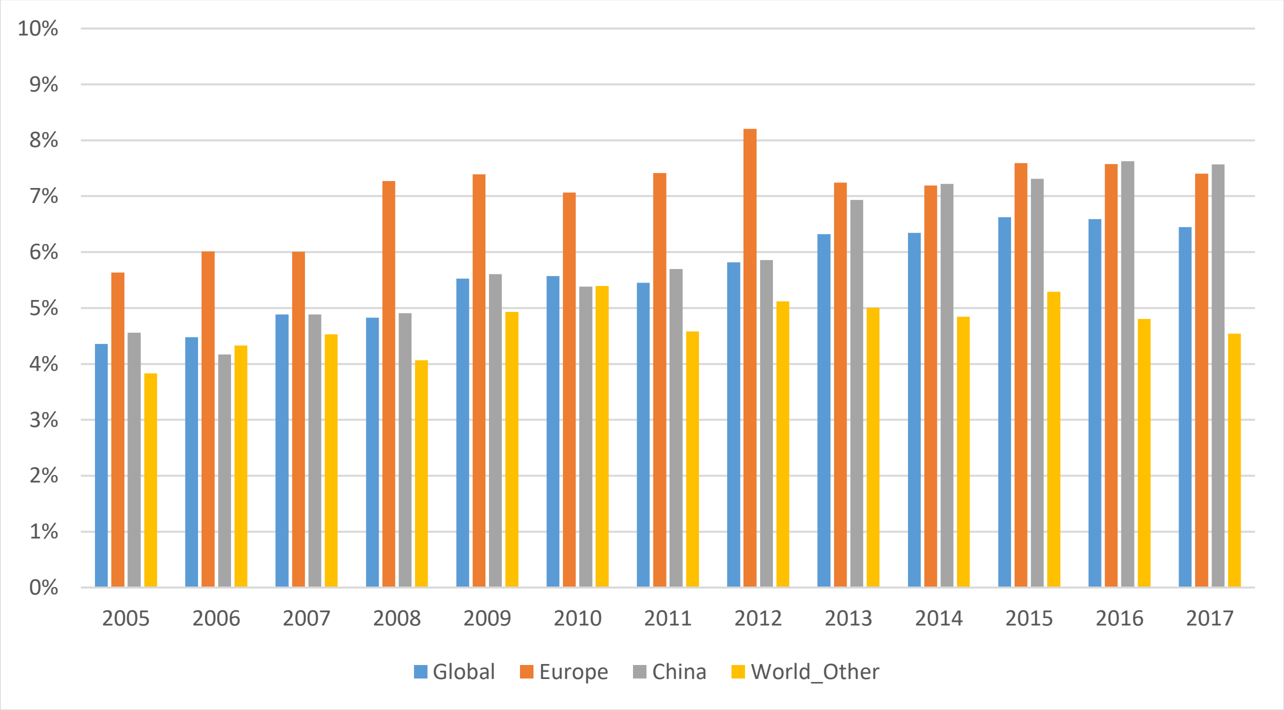

Figure 34 - Relative share of MMCF in total fiber production (MMCF + MMAF + cotton) in China, Europe and the rest of world. Source: own estimation

Econometric estimations

To estimate econometric functions, we applied a similar approach as for the econometric function estimated in Section 7.2. Hence, we used the apparent consumption of MMCF per capita (kg/capita per annum) as dependent variable, and GDP per capita, real Price of MMCF, and in addition MMCF relative share (shareMMCF) as independent variables.

We tested three functional forms of the equations. Firstly, we considered a quadratic function:

$$DemCap = aGDP_{cap} + bGDP_{cap}^{2} + cRealPrice + dShareMMCF \tag{1}$$

Secondly, we applied a logarithmic scale to all variables excluding GDP_{cap}^{2} variable from the equation:

$$Log\_DemCap = aLog\_GDPcap + cLog\_RealPrice + dLog\_ShareMMCF \tag{2}$$

Thirdly, we considered one more simplified version of the logarithmic scale equation by excluding the ShareMMCF variable:

$$Log\_DemCap = aLog\_GDPcap + cLog\_RealPrice \tag{3}$$

The third equation was considered to compare our results against those by Schier et al. (2021), who also estimated wood-based textile fibre demand.

For each of these equations, we considered three approaches for dealing with panel data: pooled OLS method, Fixed Effect (FE), and Random Effect (RE) method. According to the F-test and Hausman test, the FE model deemed to be preferable in all three variants of equations. The regressions results for the FE models are presented in (Table 30).

Table 30 Regression results for MMCF demand

Equation	a	b	c	d
(1) DemCap	0.000251422***	−3.26168e-09***	−8.17484e-05***	1.48564***
(2) Log_DemCap2	0.718481***	-	−0.124174**	0.789058***
(3) Log_DemCap3	1.28284***	-	−0.322049***	-

p < 0.05; ** p< 0.01; *** p< 0.005; ^{NS} Not Significant

For all models, all coefficients were significant and had the expected signs. For equations 2 and 3, the coefficients *a*, *c* and *d* can be interpreted as elasticities. In equation 1 both income and MMCF share are captured, but these parameters cannot be interpreted as elasticities. When applying equation 3, we estimated an income elasticity of 1.28, which would imply that each percent of future GDP growth will increase demand by 1.28%. This income elasticity is quite similar to the results of Schier et al. (2021) who reported an income elasticity of 1.17. However, when considering the MMCF share as an additional variable (in equation 2), the income elasticity dropped to 0.72. This would imply that for each percent of future GDP growth, the demand for MMCF would increase by 0.72% only. However, MMCF share increase by 1% will cause 0.79% increase in consumption in equation 2.

Figure 31 shows the historic (2005 – 2017) and projected MMCF demand outlook based on using equations 1-3. In *Demand1*, *Demand2* and *Demand3*, the demand for MMCF is driven by the assumed reference scenario GDP changes (see D4.4), whereas we assumed no changes in MMCF share when applying equations 1 and 2 (i.e., the MMCF share was assumed to be fixed at 2017 levels). Applying equations 1 (*Demand1* in Figure 31) and 2 (*Demand2*) yields rather similar results for the future demand for MMCF. However, applying equation 3 (*Demand3*) results in a projected demand for MMCF by 2050 that is nearly twice the demand obtained when applying equation 2. According to some tests we conducted, applying equation 2 would yield similar results as equation 3 when the share of MMCF would increase from its current level to 15% globally. These results indicate that a change in the MMCF share globally could affect the future demand dramatically. However, the uncertainty in this parameter is very high.

To decide on the equation to be used, we compared our estimates from Figure 35 with estimates by TextileExchange (2021), which estimate a global production (or demand) of MMCF about 10 million tonnes by 2030. This estimate is similar to our estimates when using equations 1 and 2 (Demand1 and Demand2 in Figure 35) and when assuming no change in the share of MMCF in total global fibre production. Based on this comparison, we focused on equations 1 and 2. Finally, we used equation 2 for this project, since it can be scaled according to MMCF share changes very well, while MMCF share would change demand in equation 1 only marginally regardless on the assumption for the increasing MMCF shares. In the final version of the reference scenario, we used a conservative option assuming that future MMCF share will stay fixed at its current (2017) level under reference scenario (i.e., 6.5%). The alternative future changes in MMCF shares in different regions will be explored under alternative scenarios.

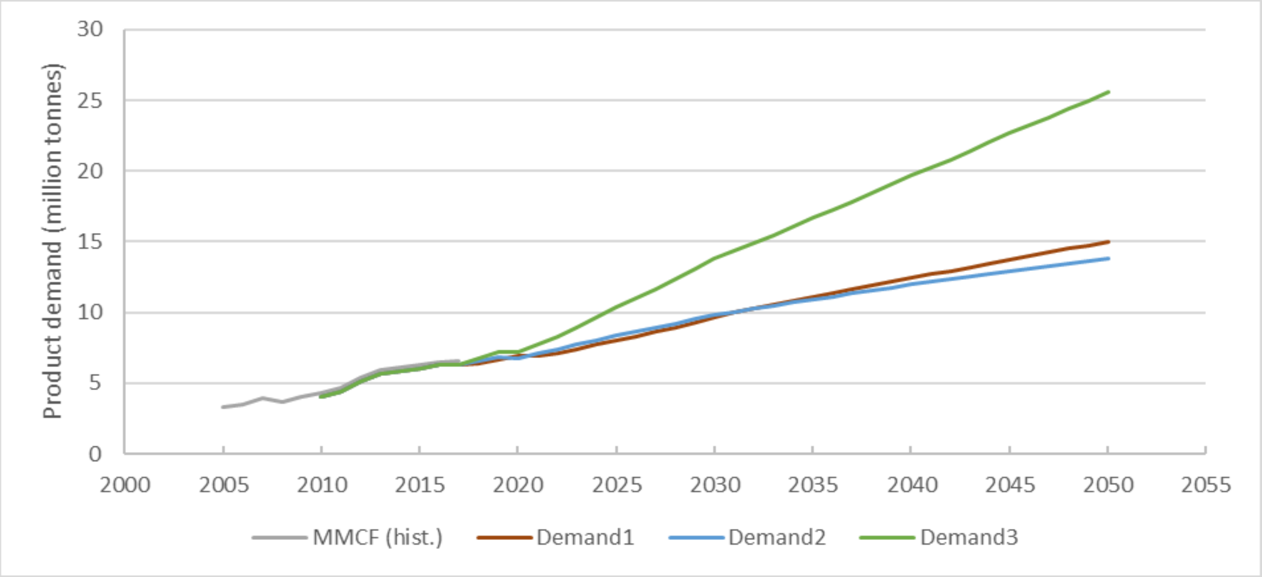

Figure 35 - Historic and projected global demand for wood-based textile fibre (MMCF) demand (unit: Million tons). Projected development by EFI-GTM based on equations 1-3: Demand1 – equation 1, Demand2 – equation 2 (MMCF share fixed at 2017 level), Demand2_China – equation 2 (MMCF share fixed at 2017 level and increasing in China from 7.5% to 15% in 2050), Demand3 – equation 3. Source: own estimation

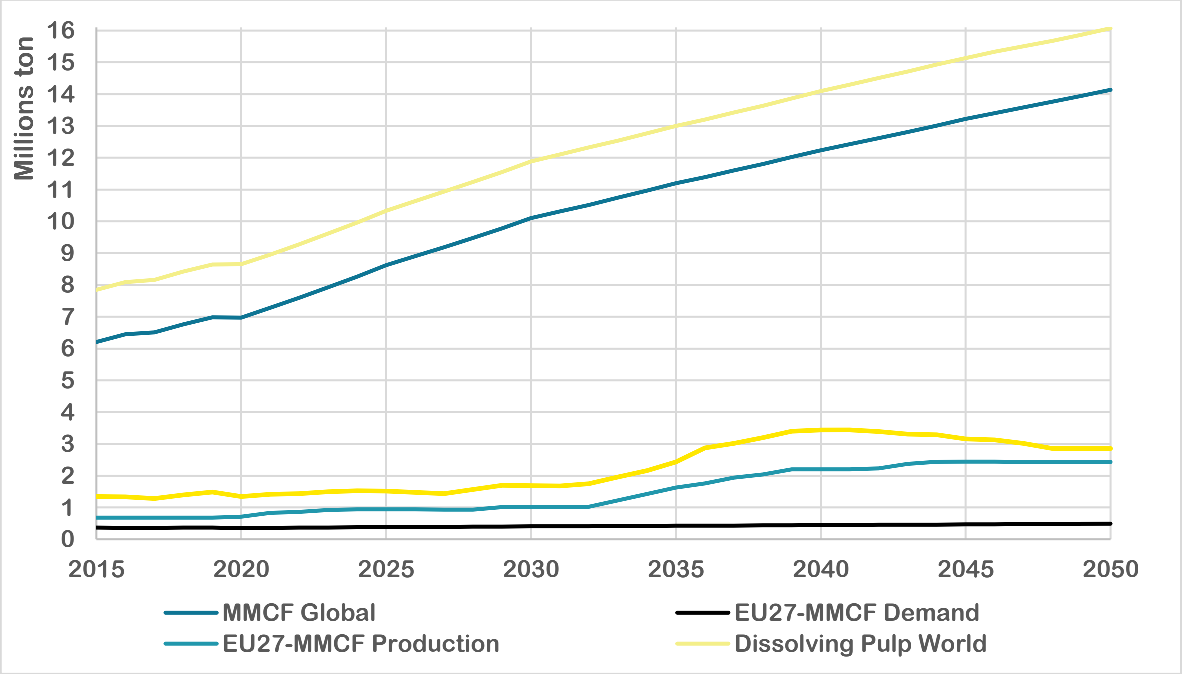

Figure 36 - Projected (EFI-GTM) MMCF global and EU27 demand & production and dissolving pulp production.

Implementation in EFI-GTM

To implement MMCF in EFI-GTM, we needed to estimate MMCF fibre production and demand at Member State level. Data at Member State level were not available from CIFRS due to confidentiality issues. To be able to initialise EFI-GTM at EU Member State level, we therefore tried to infer MMCF fibre production from all statistics available. To start, we checked from EUROSTAT in which Member States MMCF production is taking place. EUROSTAT confirms that production is taking place in five countries (Austria, Belgium, Czech, Germany and Poland), but does not provide any quantitative information due to confidentiality. Then, we obtained statistics on production (FAOSTAT) and trade (BACII and COMEXT) of dissolving pulp (see Table 31). From production and trade, we estimated total dissolving pulp use (or consumption) for these five countries. Then, we also obtained data on the production of other chemical derivatives from dissolving pulp. According to the data, production in these five countries is only taking place in Germany. Finally, we subtracted the dissolving pulp for other chemical derivatives from total dissolving pulp consumption to estimate remaining dissolving pulp available for MMCF production. Hereby, we estimated that 661 thousand metric tonnes of dissolving pulp is available for MMCF production in EU27.

Table 31 - Estimated production (metric tonnes) of MMCF in EU27 in in 2017.

EU member state	Dissolving Pulp Net Import	Dissolving Pulp Production	Dissolving Pulp Use	Chemical Derivatives Production	Dissolving pulp for MMCF
Austria	-96,500	458,710	362,210	0	362,210
Belgium	26,353	0	26,353	0	26,353
Czech	-231,795	255,000	23,205		23,205
Germany	400,000	0	400,000	220,000	180,000
Poland	8,876	60,000	68,876	0	68,876
Total	106,934	773,710	880,644	220,000	660,644

8.3.2 Cellulosic chemical derivatives

MMCF is the main product determining dissolving pulp production, but dissolving pulp is also used to produce cellulosic chemical derivatives. Cellulosic chemical derivatives are used to produce cellulose esters (e.g., acetates and nitrates), cellulose ethers (e.g., carboxymethyl- and ethyl-celluloses) and other cellulose-based products (nano- and micro-crystalline celluloses) (Chen et al. 2016). Chemical derivatives are a heterogenous group of products with varying production efficiencies regarding the use of dissolving pulp. On average it takes less than ton of dissolving pulp for one ton of chemical derivatives.

Data on the production and consumption of cellulosic chemical derivatives are limited. At the global level, about 20% of global dissolving pulp is consumed by chemical derivatives, which translates to aproximately 1.7 million ton of dissolving pulp used for chemical derivatives. Figure 37 shows production, net trade and use of dissolving pulp for MMCF production and other chemical derivatives. Source of the data is mainly BACI trade data, complemented by COMEXT Eurostat data for selected EU countries. Dissolving pulp production data are based on FAOSTAT complemented / corrected with RISI dissolving pulp production capacities data (https://www.risiinfo.com/product/asset-database/). Use of dissolving pulp for MMCF production was estimated with MMCF production data from CIRFS (2019), complemented for EU total MMCF production, reported by EUROSTAT.

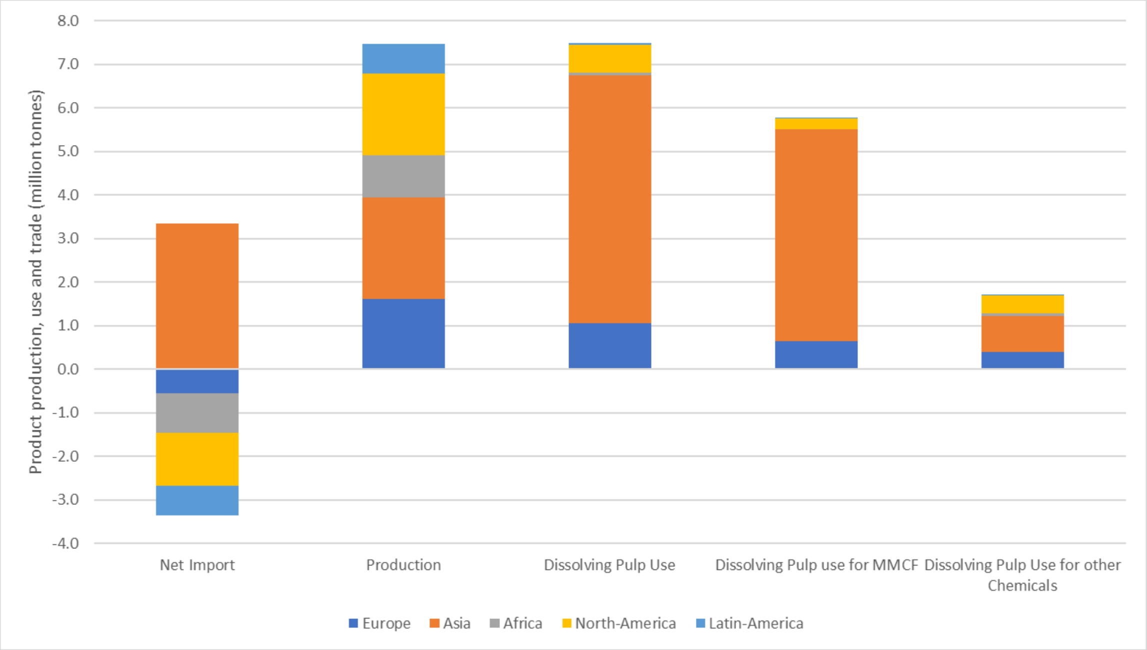

Figure 37 -Dissolving pulp production, net trade and use globally in 2017. Source: own estimation

Figure 37 shows statistics at the global level but regional production and consumption of cellulosic chemical derivatives are not available from available sources (with the exception of trade data). Therefore, we don't attemp to model production & consumption of chemical derivatives as we do for MMCF and other wood-based products. Instead, we model dissolving pulp demand for chemical derivatives with the initial demand defined as volume of dissolving pulp remaining unsued after allocation of dissolving pulp for MMCF production in 2017. The initial demands for other dissolving

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

pulp (intended for other chemical derivatives) is assumed to be growing with 1% annual rate under the reference scenario assumptions.

To estimate the dissolving pulp needed for producing other chemical derivatives in EFI-GTM, we tried to infer production from all statistics available. Similarly, as for MMCF, we checked from EUROSTAT in which member states production of other chemical derivatives is recently taking place (in 2015 or later). EUROSTAT reports production statistics (in addition to Germany) in France (approx. 15,000 tonnes/yr), Italy (approx. 20,000 tonnes/yr) and Netherlands (approx. 27,000 tonnes/yr). From EUROSTAT export statistics, inferred that approx. 50,000 tonnes/yr in produced in Finland and 30,000 tones/yr in Ireland and approx. 20,000 tonnes/yr in Sweden.

Figure 36 shows the global and EU27 development of MMCF and dissolving pulp production and demand for MMCF and other dissolving pulp intended for other chemical derivatives. Despite a slow EU27's MMCF demand growth, EU is estimated to remain a net exporter of MMCF with high production growth, especially after 2030.

8.4 Synthesis: wood and wood fibre production development

8.4.1 Outlook for wood-based product markets

The future demand for wood-based products drives the demand for wood and wood-based fibres (e.g., wood pulp, including chemical pulp and dissolving pulp). Figure 38 summarizes the historical and projected development of paper & board production globally and in the EU27 region. Despite that graphic papers demand is expected to decline dramatically (see Figure 29), and case & carton board paper grades are expected to substantially increase globally (see Figure 28) the whole paper & paperboard is projected to grow by 40% globally compared to its present level.

Recycled fibre is already a main fibre for paper making globally and in Europe. The global paper recycling rate is about 57% (based on FAOSTAT data, FAO, 2022), and it is assumed that in the reference scenario this will gradually increase to 74-75% on average in 2050, which would allow for greater use of recycled fibre in papermaking. However, recycled fibres can be used for printing and writing papers only to a limited extent. Due to increasing global paper & paperboard consumption, the increasing paper recycling rate would lead to 48% growth in the global supply of recycled paper for papermaking (see **Error! Reference source not found.**). This development is also supported by increasing share of other paper & paperboard in the total paper consumption (from 76% in 2020 up to 87% in 2050). Due to increasing use of recycled paper in papermaking, the global supply of chemical pulp for paper is expected to stagnate during 2020 – 2030 and to decline after 2030.

In the EU27 region, the production of paper & paperboard is expected to slowly decline until 2050 (see Figure 40) due to a dramatic decline in graphic paper demand and slow increase of other paper & paperboard consumption. As a result of declining paper & paperboard production in the EU27, the use of recycled and chemical, semichemical & mechanical pulp fibres will slowly decline (see Figure 41).

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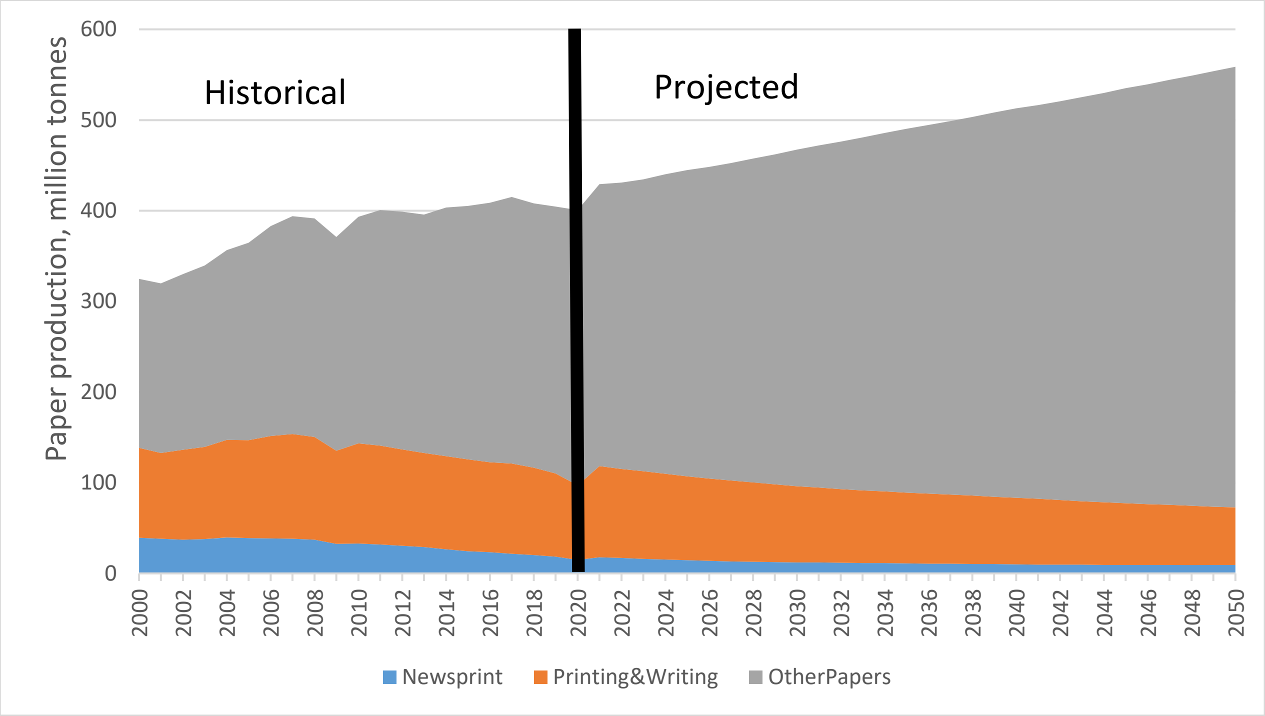

Figure 38 - Historic (FAOSTAT) and projected (EFI-GTM) production of newsprint, printing & writing and other paper & paperboard globally.

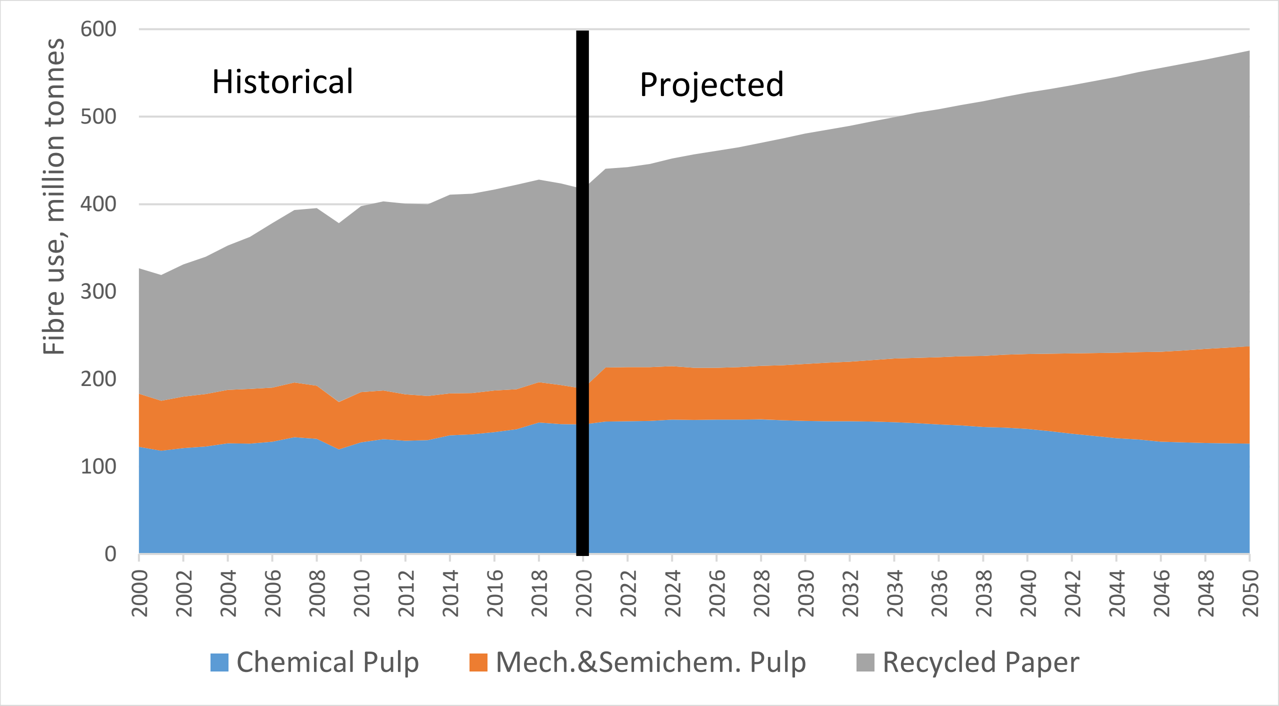

Figure 39 - Historic (FAOSTAT) and projected (EFI-GTM) use of recycled and virgin (chemical, semichemical & mechanical) fires for papermaking globally.

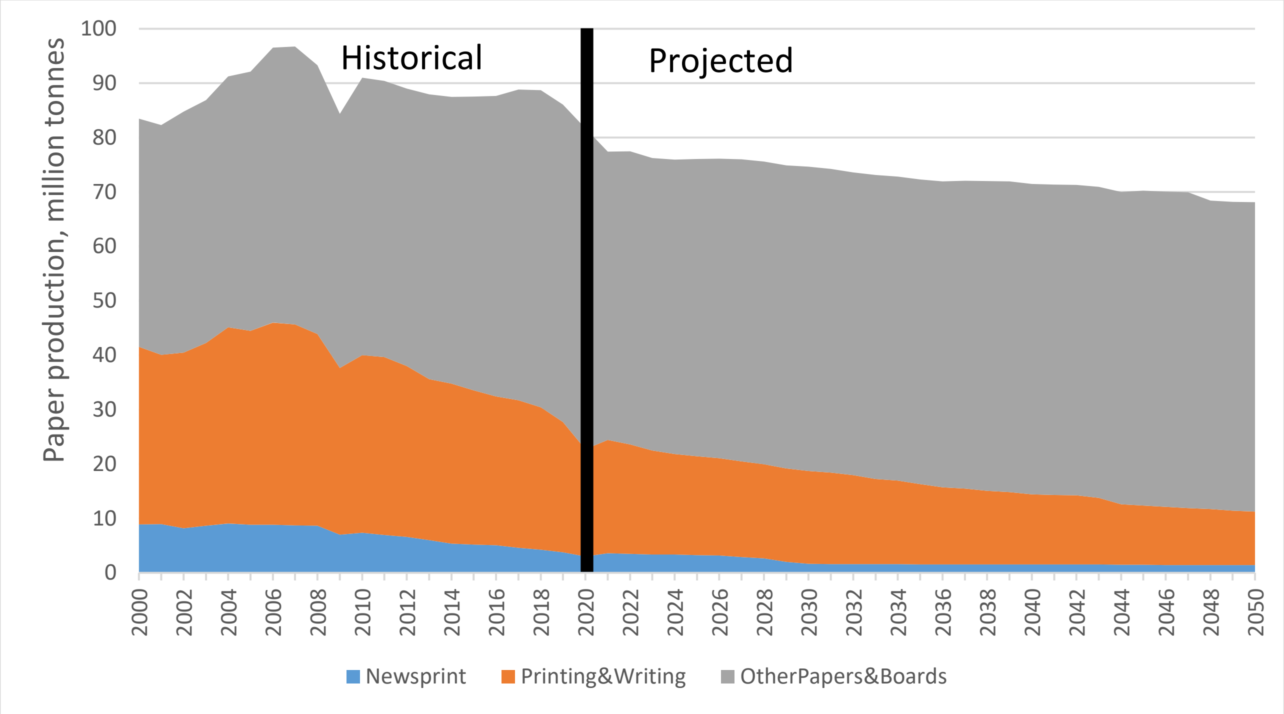

Figure 40 - Historic (FAOSTAT) and projected (EFI-GTM) production of newsprint, printing & writing and other paper & paperboard in the EU27.

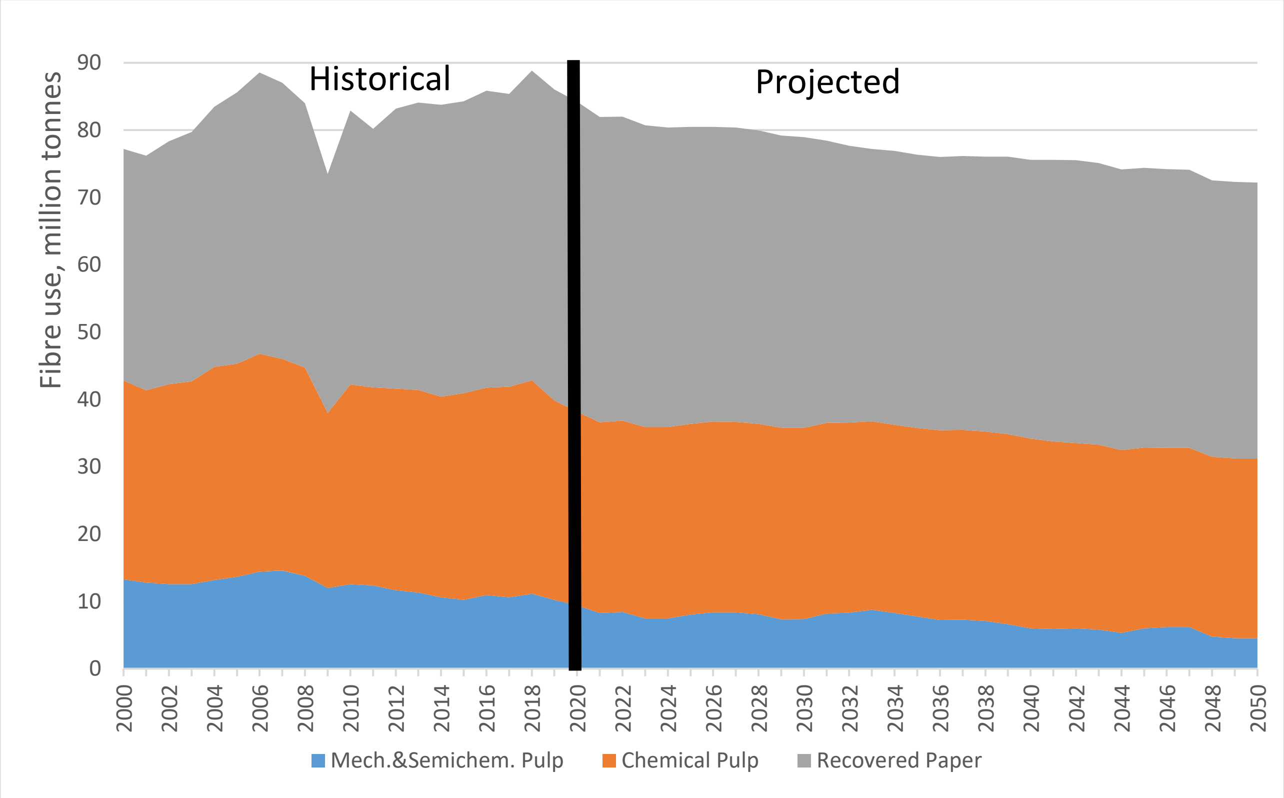

Figure 41 - Historic (FAOSTAT) and projected (EFI-GTM) use of recycled and virgin (chemical, semichemical & mechanical) fires for papermaking in the EU27.

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Figure 42 shows the historic and projected sawnwood and wood-based panels production development in the EU27 region. EU27 is a net exporter of sawnwood products, and is expected to remain exporter of sawnwood, although the volume of net export of sawnwood will slowly decrease from its present levels. Although the EU27 demand (consumption) of sawnwood is expected to moderatly increase, the production of sawnwood in the EU is expected to stagnate over the period between 2020 and 2050 due to increasing prices for sawlogs. The EU27 demand for wood based-panels is projected to grow continuously (and more substantially than sawnwood) until 2050. However, panels production will stagnate and EU27 is projected to change froma net exporter to become a net importer of wood based panels after 2040. The latter could be explained because of the increased competition for pulpwood with growing dissolving pulp production.

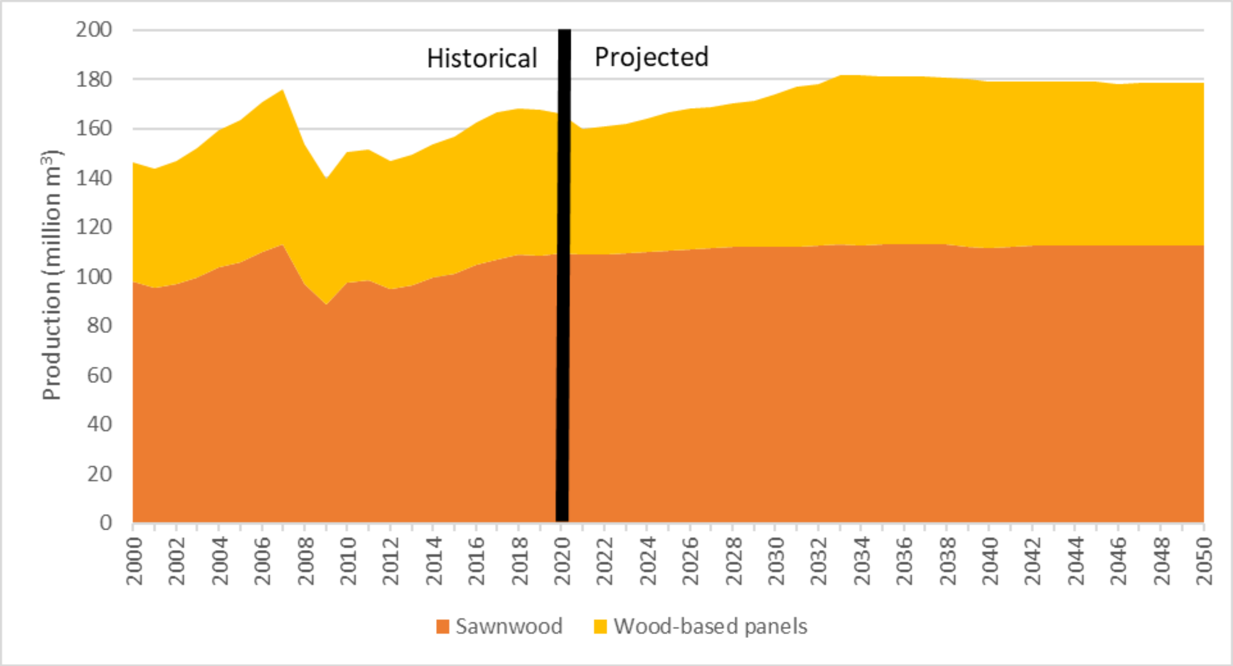

Figure 42 - Historic (FAOSTAT) and projected (EFI-GTM) sawnwood and wood-based panels production in the EU27.

Table 32 summarizes the outlook for demand (consumption), production, and net trade of wood-based products for the period 2020, 2030, 2040 and 2050 as projected by EFI-GTM.

Table 32 Historical (FAOSTAT) and future (EFI-GTM) EU27 demand, production, and net trade of wood-based products (sawnwood, plywood, particle board & OSB, and fibreboard: million m3 under bark; newsprint, printing & writing paper, packaging paper, household & sanitary paper, chemical pulp, MMCF and dissolving pulp: million metric tons).

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Table 33 - Historical (FAOSTAT) and future (EFI-GTM) EU27 demand, production, and net trade of wood-based products (sawnwood, plywood, particle board & OSB, and fibreboard: million m3 under bark; newsprint, printing & writing paper, packaging paper, household & sanitary paper, chemical pulp, MMCF and dissolving pulp: million metric tons).

Product category	Demand				Production				Net Trade			
	2020	2030	2040	2050	2020	2030	2040	2050	2020	2030	2040	2050
Sawnwood Conif.	76,551	83,327	88,015	92,673	99,947	102,179	100,641	101,528	-23,396	-18,852	-12,626	-8,855
Sawnwood Non-conif.	9,257	10,672	10,844	11,119	9,286	10,027	11,268	11,259	-29	645	-424	-140
Sawnwood	**85,808**	**93,999**	**98,859**	**103,792**	**109,233**	**112,205**	**111,909**	**112,787**	**-23,425**	**-18,207**	**-13,050**	**-8,995**
Plywood	6,368	6,364	6,914	7,553	4,550	12,972	12,651	12,144	1,818	-6,608	-5,738	-4,591
OSB	5,933	5,153	5,936	6,697	6,774	6,081	7,260	8,260	-841	-927	-1,324	-1,563
Particleboard	26,284	35,938	40,179	44,097	28,084	29,956	33,845	31,707	-1,801	5,981	6,333	12,390
Particleboard & OSB	32,217	41,091	46,115	50,794	34,858	36,037	41,106	39,968	-2,641	5,054	5,009	10,827
MDF	12,193	9,235	11,094	12,498	14,498	12,664	13,638	13,807	-2,305	-3,429	-2,544	-1,309
Other Fiberboard	2,691	4,045	4,092	4,135	2,611	531	469	464	80	3,514	3,623	3,671
Fiberboard	14,884	13,280	15,186	16,633	17,109	13,195	14,107	14,271	-2,225	85	1,078	2,362
Wood-based panels	**53,469**	**60,735**	**68,214**	**74,981**	**56,518**	**62,204**	**67,864**	**66,383**	**-3,049**	**-1,469**	**350**	**8,598**
Newsprint	2,818	1,634	973	424	2,986	1,696	1,550	1,425	-168	-62	-578	-1,001
Coated Printing&Writing	5,725	3,866	2,382	1,387	8,848	9,679	7,868	6,012	-3,123	-5,812	-5,486	-4,624
Uncoated wood free UWF	4,888	4,572	3,845	2,855	6,647	5,618	3,758	3,019	-1,759	-1,046	88	-164
Uncoated mechanical UWC	3,373	2,666	2,094	1,662	4,219	1,753	1,517	820	-847	913	577	842
Printing&Writing papers	13,985	11,105	8,321	5,904	19,714	17,050	13,142	9,851	-5,728	-5,945	-4,822	-3,947
Cartonboard	6,602	7,269	7,044	6,361	11,060	11,999	11,606	10,277	-4,457	-4,731	-4,562	-3,915
Case materials	26,342	29,778	31,322	32,338	29,165	28,013	29,769	31,344	-2,823	1,766	1,553	994
Other papers (mainly packaging)	10,847	10,216	10,090	9,941	12,114	10,295	10,124	9,998	-1,267	-80	-34	-57
Packaging paper & paperboard	43,791	47,262	48,456	48,640	52,338	50,307	51,499	51,618	-8,548	-3,045	-3,043	-2,979
Sanitary papers	6,481	6,708	6,915	7,279	6,662	6,534	6,538	6,433	-181	174	376	847
Paper & paperboard	**67,076**	**66,709**	**64,663**	**62,247**	**81,701**	**75,587**	**72,730**	**69,327**	**-14,625**	**-8,878**	**-8,066**	**-7,080**
Chemical pulp	**28,764**	**25,157**	**22,420**	**19,343**	**26,827**	**28,446**	**28,156**	**26,693**	**1,937**	**-3,289**	**-5,736**	**-7,350**
MMCF*	354	406	448	492	710	1,014	2,198	2,436	-356	-608	-1,750	-1,943
Dissolving pulp for other chemical der**	474	523	568	623	na	na	na	na	na	na	na	na
Dissolving pulp	**1,267**	**1,536**	**2,766**	**3,059**	**1,893**	**1,687**	**3,437**	**2,854**	**-626**	**-151**	**-671**	**205**

8.4.2 Outlook for industrial roundwood production

The projected trends and devlopments in the consumption, production and trade of wood-based products results in rather stable industrial roundwood demand projection in the EU27. In contrast, industrial roundwood production and consumption is projected to increase globally by 28% between 2020 and 2050 (0.83% annual growth). This growth is mainly driven by substential growth of wood-based panels and to lesser degree by global sawnwood consumption growth (see Figure 30). Figure 43 shows the historic and projected industrial roundwood production in the five largest industrial roundwood producers within the EU27 bloc (i.e., Sweden, Finland, Germany, Poland and France).

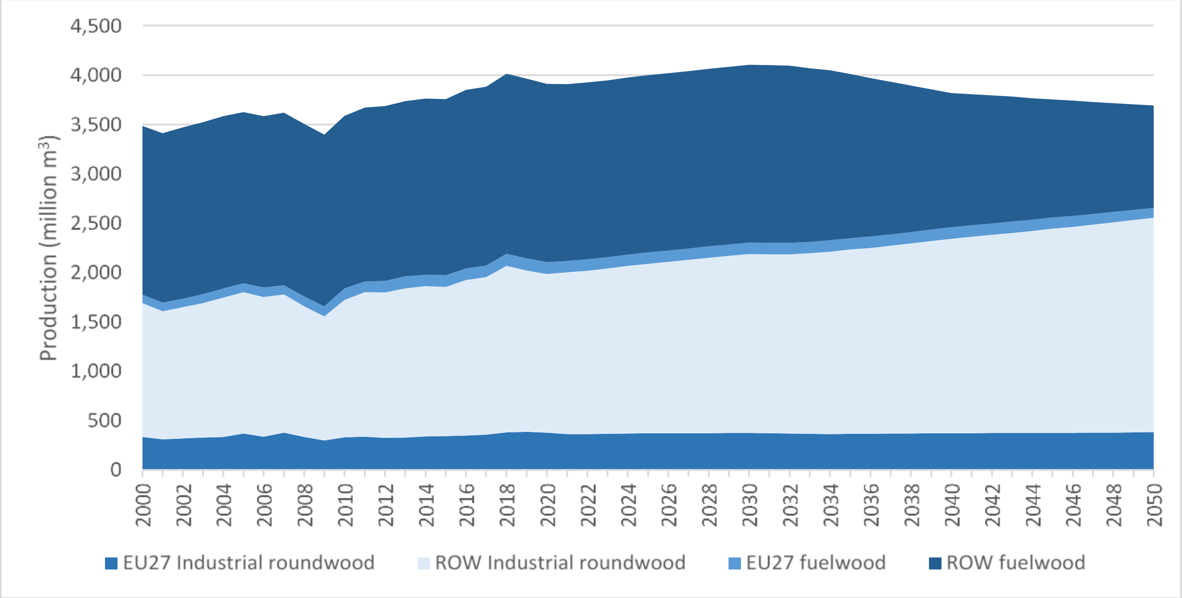

Figure 43 - Historic (FAOSTAT) and projected (EFI-GTM) industrial roundwood and fuelwood production in the EU27 and the rest of the world (row).

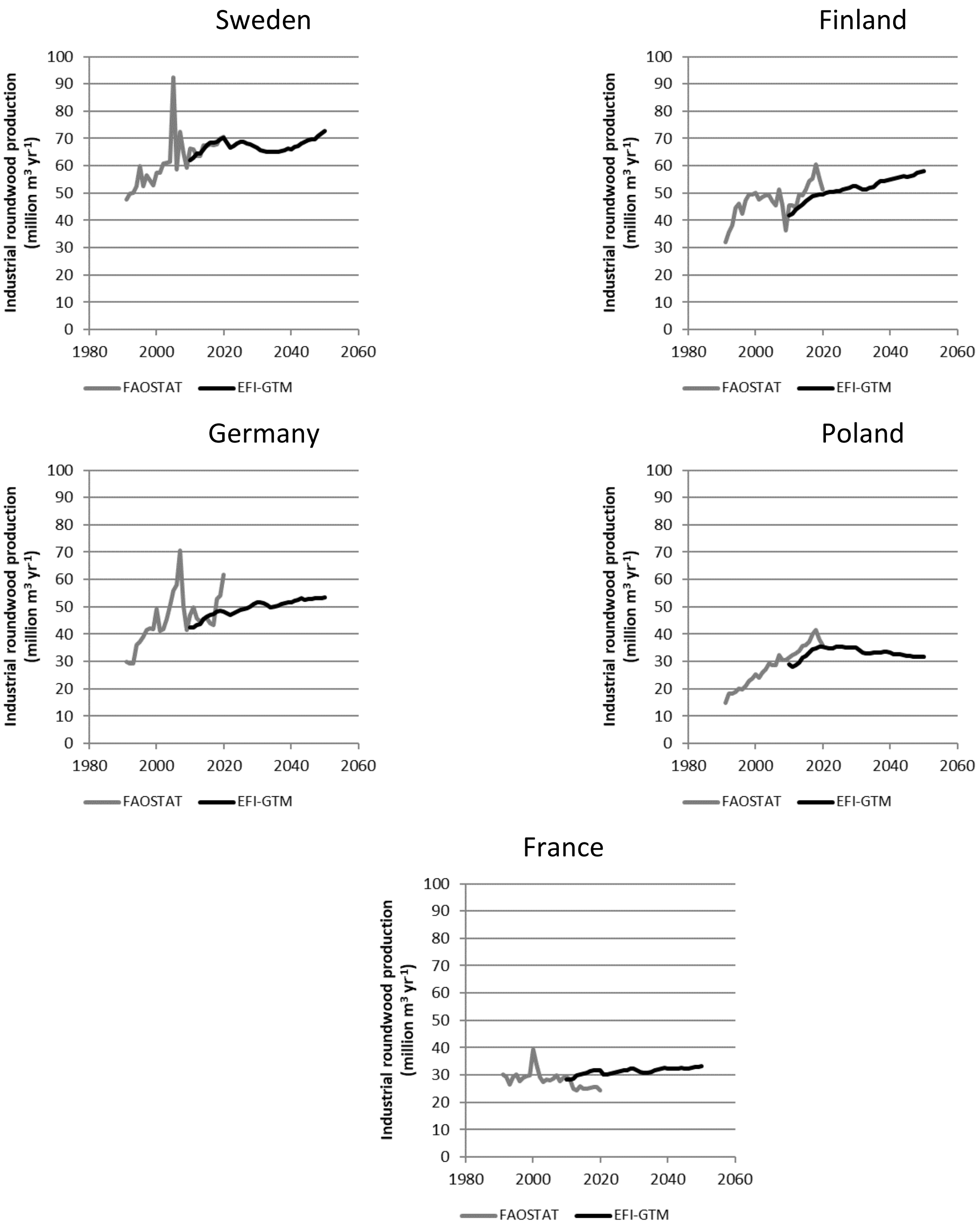

Figure 44 - Historic (FAOSTAT) and projected (EFI-GTM) industrial roundwood production the five largest industrial roundwood producers within the EU27.

8.4.3 Comparison to other studies

Figure 45 shows a comparison of our results for forest products demand (consumption) and production in 2030 with the results obtained by Jonsson et al. (2018, 2020). Overall, there are quite some similarities between the results, but there are also important differences. The main differences relate to paper and paperboard demand and production. According to our results for the BioMonitor reference scenario, both newsprint and printing & writing paper demand is projected to decline moderately until 2030 (more substantial decline is expected after 2030 toward 2050), whereas Jonsson et al. (2018, 2020) project an increasing demand until 2030. Conversely, for the packaging paper & paperboard demand, our results indicate a modest increase, whereas Jonsson et al. estimate a moderate reduction by 2030. Overall, the total paper & paperboard demand is projected to grow more substantially in Jonsson et al. (2020) and to a lesser extent in Jonsson et al. (2018) mainly due to growth for graphic papers), while we estimated only a marginal reduction as result of the declining graphic papers demand and modest growth for packaging papers demand. For the total sawnwood demand, our results suggest a modest increase in demand for the EU27 region by 2030, while Jonsson et al. (2020) project more growth in 2030. However, Jonsson et al. (2018) project a marginally higher growth compared to our results. For the total sawnwood production in 2030, we find almost identical volumes as Jonsson et al (2020) and also for total wood-based panels demand and production in 2030, our results are almost identical to those by Jonsson et al. (2020).

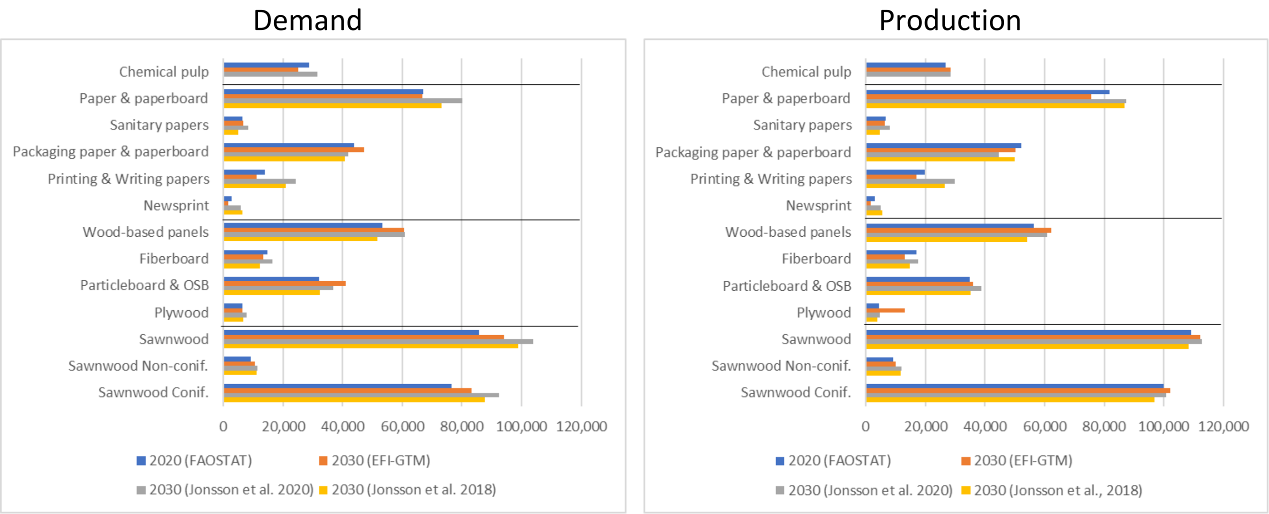

Figure 45 - Comparison of EU27 consumption and production of wood-based products between historical (FAOSTAT) and projected (EFI-GTM and Jonsson et al. 2018, 2020). Units: sawnwood, plywood, particle board & OSB, and fibreboard: thousand m^3 under bark; newsprint, printing & writing paper, packaging paper, household & sanitary paper, and chemical pulp: thousand metric tons).

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Annex I Methods applied to fill data gaps in PRODCOM

AI.1 Introduction

In the context of BioMonitor, the Eurostat PRODCOM database is used in combination with the bio-based share of individual products to determine size of the bio-based economy in the entire economy of EU and the Member States. PRODCOM ("PRODuction COMmunautaire", in English, Community Production) is an annual Eurostat publication on statistics about industries at product level. It gathers and organises information provided by National Statistical Institutes, which are responsible to conduct surveys in firms collecting data on the value (in €) and physical volume (e.g. kilograms, items, litres) of their sold products of a specific country and year. In addition, Eurostat calculates EU totals from the country based data, providing a comprehensive picture of industrial production in EU and its Member States. PRODCOM database contains information on about 4,500 manufactured goods, which normally contains 8 digit codes based on the European CPA (Classification of Products by Activity) system, where the first four digits indicate the Division, Group and Class that the product is belonging to according to the NACE system, the Statistical Classification of Economic Activities in the European Community.

To reduce the administrative burden on small companies, the National Statistical Institutes do not conduct surveys in companies with less than 20 employees, which makes it difficult to know if a given product is entirely covered by PRODCOM, or even to know the percentage coverage. Moreover, PRODCOM data has many records flagged as 'confidential' in case they are traceable to a specific country or company. Confidential records are more frequent in potential innovative commodities that are in an upscaling stage of development though yet produced in a few plants. In this context, note that National Statistical Institutes have the full PRODCOM dataset for their country available, but are not allowed to publish and share at deepest detail level. On the other hand, Eurostat publishes EU totals accounting for confidential data as long as the confidential items are not specifically revealed. This creates the opportunity to calculate the percentage coverage as well as to estimate confidential records. The BioMonitor project has developed methods to handle and fill data gaps in the PRODCOM database, which are applied for EU28 and all individual Member States for the years 2008 to 2018. The methods are divided in three main steps:

- Step 1: data preparation.
- Step 2: data estimation.
- Step 3: consistency checks and validation.

Figure A1 summarizes the workflow of the methods and the embedded steps to produce a complete and consistent PRODCOM database. The orange elements refer to the data preparation. The blue elements refer to the estimation steps, which represents the majority of the workload. The green element refers to the validation of the complete PRODCOM database.

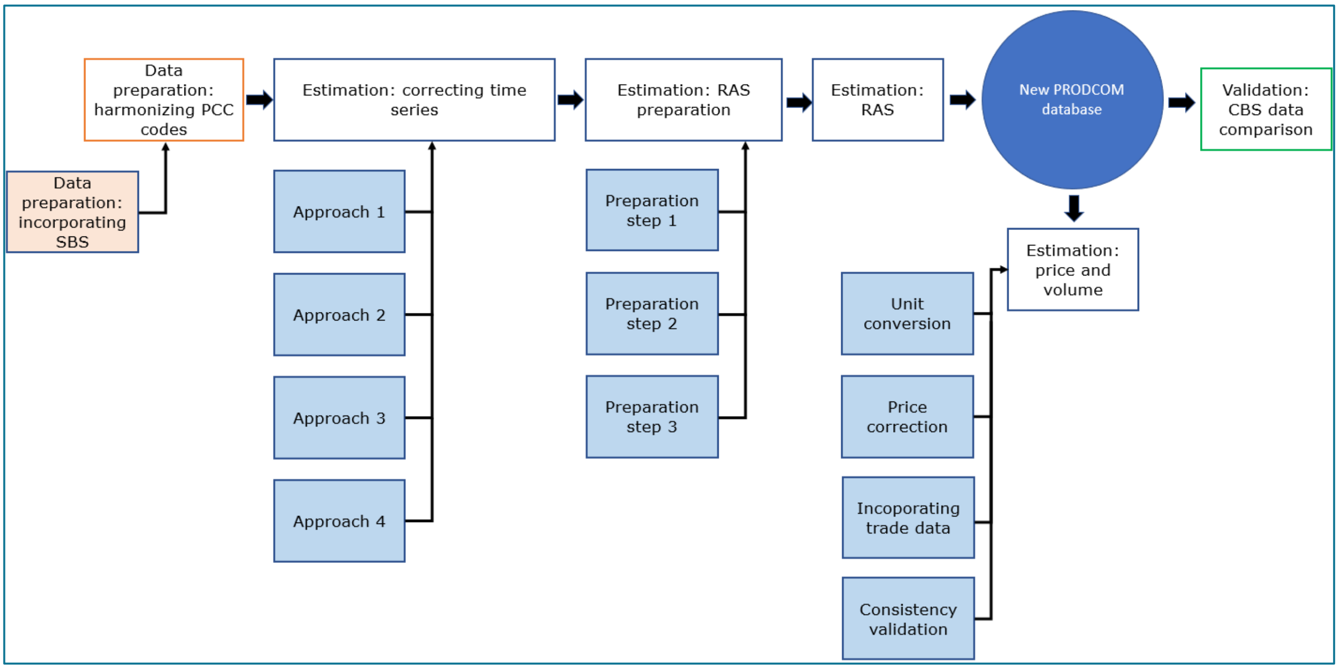

Figure A1 - Workflow of methods in BioMonitor project to produce a complete and consistent PRODCOM database.

AI.2 Data preparation

The PRODCOM database can be downloaded for separate years from the Eurostat website. This database contains values and volumes for a long list of 8 digit PCC codes for EU28 and individual EU Member States. In general, EU28 data is already completed by Eurostat, whereas data for individual EU Member States contains a large number of unavailable records labelled as “confidential”. In addition, PRODCOM classification is modified periodically, which means that from year to year some products/codes are removed and other products are added. Hence, before starting the steps to estimate the unavailable cells for the Member States it is important to carry out key data preparation steps. Because we want to use a RAS-method combined with time series analysis for the value estimations, it is important to have a matrix with PCC codes (rows) and EU countries (columns). The RAS-method is applied for each NACE two digit group (e.g. C20 Manufacture of chemicals and chemical products). The right hand side of the matrix contains the EU values for each 8 digit PRODCOM code within this NACE group and the bottom line needs to be filled with fixed values (estimates based on Eurostat SBS data for each NACE group) for each country. The RAS-method can then, based on fixed column and row totals, calculate the best solution for the empty cells. This procedure will be described in more detail in section 2.2.

AI.2.1 Using SBS data for country boundaries

For each NACE group for which RAS-method is applied, information on the country boundaries corresponding the sector of which a product belongs is needed. These boundaries are taken from the Structural Business Statistics (SBS) data from Eurostat. The SBS data describes the structure and performance of businesses in the EU. SBS data is also rather incomplete and inconsistent, and requires a lot of data gap filling work to complete this database. In this respect, BioMonitor build upon a methodology developed to estimate employment and value added in the bioeconomy of EU regions (Lasarte-López et al., 2022).

AI.2.2 Harmonisation of PRODCOM codes

The PCC codes are modified periodically by Eurostat as some products are removed and other products are added to the PCC list from year to year. In the Eurostat metadata system RAMON, classifications and changes over time are available and described. In many cases, the changes over time are very clear, but sometimes it's very hard to understand which codes are replaced and which codes don't have a relation at all with a new or an old code. Hence, because we want to use the complete PRODCOM data in BioMAT model, it is important to have the PCC codes harmonised over time. The harmonisation procedure described below in more detail is meant to bring structure in the changes and bring related codes together to one new code. This harmonisation is done for the period 2008-2018.

Classification trees and introduction of BM (BioMonitor) product codes; Our harmonisation process is based on the so called classification trees. The harmonised PCC product trees (created for 11 NACE groups) are used for selecting the relevant data for harmonisation and consistency purposes. Before the harmonisation, the PCC codes contain a long list of individual codes without any relation between them. After the harmonisation, these codes are more structured and relations are clarified by using levels between codes. In general, harmonisation is required in following five cases:

- *Recoding*: one old code is replaced by one new code: new code becomes parent with the old code as child.
- *Combining*: several old codes are combined to one new code: new code becomes parent with the old codes as children.
- *Splitting*: one old code is split up in several new codes: old code becomes parent with the new codes as children.
- *Replacing*: more old codes are replaced by more new codes without individual links: a special new parent code is created with all related old and new codes as children.
- *Merging*: a new code is merged with one existing code: a special new parent code is created with both codes as children.

Figures A2 and A3 show two examples of the harmonised C20 tree, on combining PCC codes and replacing PCC codes respectively.

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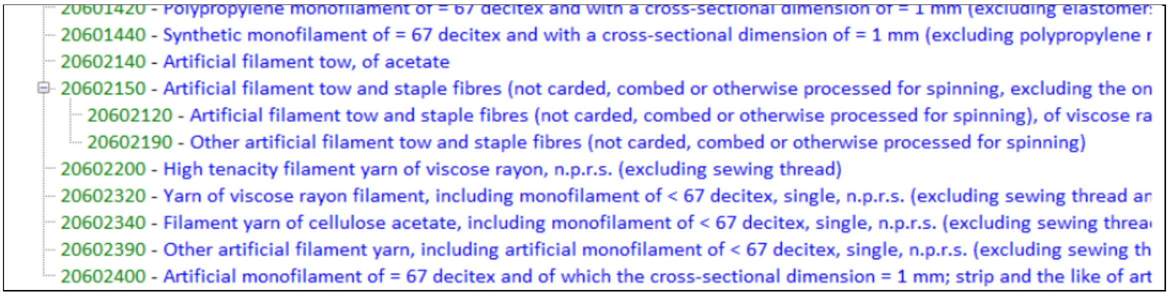
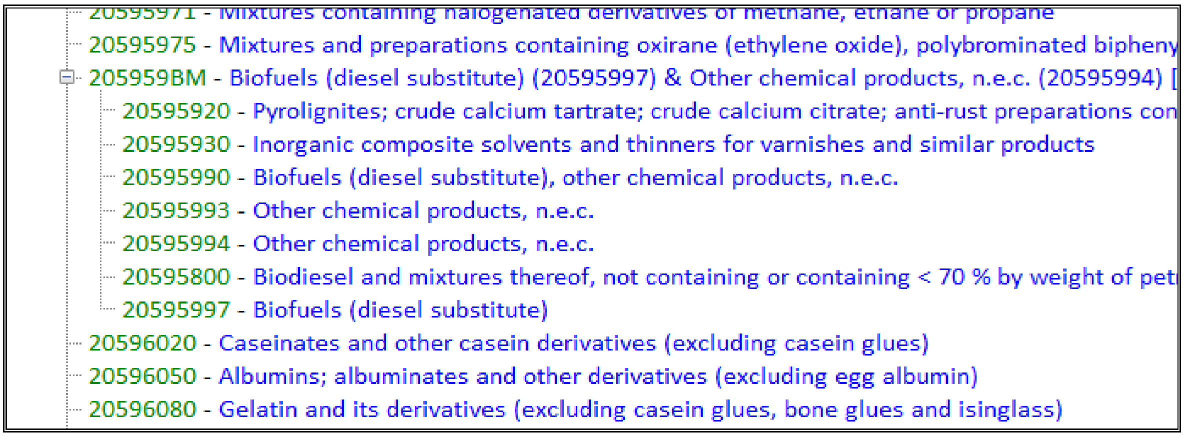


20601420 - Polypropylene monofilament of = 67 decitex and with a cross-sectional dimension of = 1 mm (excluding elastomer:
20601440 - Synthetic monofilament of = 67 decitex and with a cross-sectional dimension of = 1 mm (excluding polypropylene r
20602140 - Artificial filament tow, of acetate
20602150 - Artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning, excluding the on
- 20602120 - Artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning), of viscose ra
- 20602190 - Other artificial filament tow and staple fibres (not carded, combed or otherwise processed for spinning)

20602200 - High tenacity filament yarn of viscose rayon, n.p.r.s. (excluding sewing thread)
20602320 - Yarn of viscose rayon filament, including monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing thread ar
20602340 - Filament yarn of cellulose acetate, including monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing threa
20602390 - Other artificial filament yarn, including artificial monofilament of < 67 decitex, single, n.p.r.s. (excluding sewing th
20602400 - Artificial monofilament of = 67 decitex and of which the cross-sectional dimension = 1 mm; strip and the like of art

Figure A2 - Combining PCC codes 20602120 and 20602190 into code 2060150

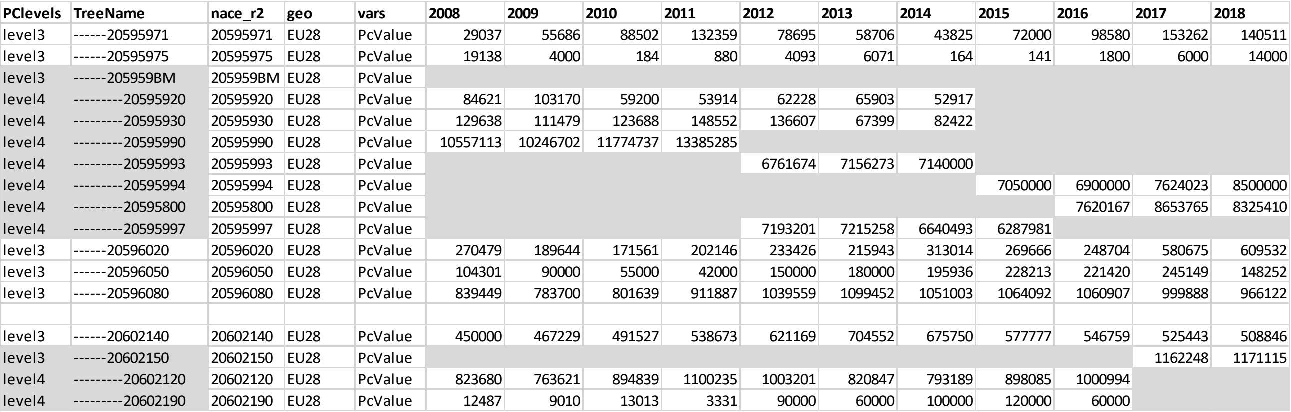


20595971 - Mixtures containing halogenated derivatives of methane, ethane or propane
20595975 - Mixtures and preparations containing oxirane (ethylene oxide), polybrominated bipheny
205959BM - Biofuels (diesel substitute) (20595997) & Other chemical products, n.e.c. (20595994) [
- 20595920 - Pyrolignites; crude calcium tartrate; crude calcium citrate; anti-rust preparations con
- 20595930 - Inorganic composite solvents and thinners for varnishes and similar products
- 20595990 - Biofuels (diesel substitute), other chemical products, n.e.c.
- 20595993 - Other chemical products, n.e.c.
- 20595994 - Other chemical products, n.e.c.
- 20595800 - Biodiesel and mixtures thereof, not containing or containing < 70 % by weight of pet
- 20595997 - Biofuels (diesel substitute)

20596020 - Caseinates and other casein derivatives (excluding casein glues)
20596050 - Albumins; albuminates and other derivatives (excluding egg albumin)
20596080 - Gelatin and its derivatives (excluding casein glues, bone glues and isinglass)

Figure A3 - Replacing old PCC codes by a new BM code (205959BM) without individual links

Figure A4 gives an example of original PRODCOM values with data gaps for existing PCC and starts with empty cells for the BM code (parent). The BM code should be filled by aggregation of the underlying codes (children).



PClevels	TreeName	nace_r2	geo	vars	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
level3	------20595971	20595971	EU28	PcValue	29037	55686	88502	132359	78695	58706	43825	72000	98580	153262	140511
level3	------20595975	20595975	EU28	PcValue	19138	4000	184	880	4093	6071	164	141	1800	6000	14000
level3	------205959BM	205959BM	EU28	PcValue											
level4	---------20595920	20595920	EU28	PcValue	84621	103170	59200	53914	62228	65903	52917				
level4	---------20595930	20595930	EU28	PcValue	129638	111479	123688	148552	136607	67399	82422				
level4	---------20595990	20595990	EU28	PcValue	10557113	10246702	11774737	13385285							
level4	---------20595993	20595993	EU28	PcValue					6761674	7156273	7140000				
level4	---------20595994	20595994	EU28	PcValue								7050000	6900000	7624023	8500000
level4	---------20595800	20595800	EU28	PcValue									7620167	8653765	8325410
level4	---------20595997	20595997	EU28	PcValue					7193201	7215258	6640493	6287981			
level3	------20596020	20596020	EU28	PcValue	270479	189644	171561	202146	233426	215943	313014	269666	248704	580675	609532
level3	------20596050	20596050	EU28	PcValue	104301	90000	55000	42000	150000	180000	195936	228213	221420	245149	148252
level3	------20596080	20596080	EU28	PcValue	839449	783700	801639	911887	1039559	1099452	1051003	1064092	1060907	999888	966122
level3	------20602140	20602140	EU28	PcValue	450000	467229	491527	538673	621169	704552	675750	577777	546759	525443	508846
level3	------20602150	20602150	EU28	PcValue										1162248	1171115
level4	---------20602120	20602120	EU28	PcValue	823680	763621	894839	1100235	1003201	820847	793189	898085	1000994		
level4	---------20602190	20602190	EU28	PcValue	12487	9010	13013	3331	90000	60000	100000	120000	60000		

Figure A4 - Original PRODCOM values for some changed codes which are only filled in part of the time series and are brought together at the harmonised level 3)

For the BioMonitor project, these introduced special 'new parent codes' in the classification tree have 'BM' at the end of the 8 digit code ('BM' in 7th and 8th position). The addition is only created in very specific situations when there is no useful existing parent code. In the harmonisation process the combined 'BM' code is placed at the top of the related codes in the classification tree. Adding up the data of the child(ren) to the parent level results in a harmonised and complete time series at the parent level.

There are also some special cases in which PCC codes are partially split or merged to codes of another NACE group. In this case it is assumed to keep these codes in their 'own' NACE group.

Finally, there are also cases where Eurostat does not clearly describe all changes which required solutions:
- in many cases a PCC code corresponds to one or more Combined Nomenclature (CN) codes.
- In other cases, PRODCOM headings are further disaggregated than the CN heading for analytical purposes. Some of these detailed codes are also the legacy of a time when some CN codes could be linked to several CPA headings.

In order to maintain the link to CN for such headings, special aggregates are created. These are known as Z aggregates since they have a Z in the seventh position of the PRODCOM code. The *Z* codes are additional aggregated PRODCOM headings to allow comparison with CN codes of trade data and shouldn't be taken into account in the estimation procedure. PCC codes with *Z* are therefore not included in the harmonised trees and not used in the estimation process and results to avoid double counting.

AI.3 Data estimation

AI.3.1 Value estimation

The selection of valid PCC-year combinations along the entire times series of the PCC codes (rows) and the use of SBS data for country boundaries (columns), described in section AI.2, has resulted in one consistent matrix for each year. This annual matrix however still contains a lot of confidential records along product dimension (PCC) and the regional dimension (EU Member States). This section describes the steps towards an annual matrix which is fully filled with actual and estimated production values for all PCC codes and all Member States. In particular, missing values in time series database from 2008 to 2018 covering 11 NACE sectors are estimated for EU and its 28 Member States (2018 level). The entire procedure is developed in R statistical software supported by ancillary spreadsheets to visualize and validate the effectiveness of the methods applied. Note that all rules and methods applied to estimate missing records are based on decisions taken by the data analysts working in this task in order to build a complete and suitable database needed for model development in WP5 of the BioMonitor project.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773297.

The value estimation of product values in PRODCOM consists of three steps, i.e. i) correcting time series like replacing zeros and 'not available (NA), detecting and solving outliers), (iii) preparations for applying the RAS method, (iii) applying the RAS procedure to produce for each of the 11 NACE sectors a single-year matrix with production values. The R method is chosen because it leads to consistency between the entries of the non-negative matrix and pre-specified row and column totals. Each step is described in more detail below.

AI.3.1.1 Correcting time series

The goal of correcting time series is to create coherent time series, i.e. without large variations to surrounding years. In the first approach (Table A1), existing zeros are flagged as 'confidential' flag. in the case a time series contains at least one value greater than zero. In short, if a time series contain zeros followed by values greater than zero, the existing zeros are converted to confidential (NA). In this way, we allow the RAS method to generate values. This procedure is illustrated by the example below with the input time series in red and the output time series in green.

Table A1 - Correcting time series: first approach

PCC	Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
XXXXXXXX	XX	1300	NA	0	0	870	972	1001	1800	1762	0	NA
XXXXXXXX	XX	1300	NA	NA	NA	870	972	1001	1800	1762	NA	NA

In the second approach (Table A2), NA is replaced by zero when there are no original values greater than zero in the time series. This is to avoid the RAS method to come with values in a time series with only zeros. The input time series are again in red and the output time series in green.

Table A2 - Correcting time series: second approach

PCC/Years	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CodeXX	0	NA	0	0	0	NA	NA	0	0	0	NA
CodeXX	0	0	0	0	0	0	0	0	0	0	0

In the third approach (Table A3), an interpolation of existing values in time series is carried out if it contain at least two existing original values greater than zero in order to estimate the remaining confidential years. This approach allows for the time series to keep within the range of existing ones, thereby avoid potential outliers that might result from the year-level RAS application.

Table A3 - Correcting time series: third approach

PCC/Years	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CodeXX	2000	NA	3000	2500	2000	NA	NA	4000	3900	4500	4200
CodeXX	2000	2500	3000	2500	2000	2667	3333	4000	3900	4500	4200

In the fourth approach, outliers in the time series are detected and replaced by the nearest value. The outlier procedure is filtering out values that are 10-fold higher or lower than surrounding years.

The goal is to provide the RAS method with more realistic data and degrees of freedom to fill data gaps where needed. The outlier detection, removal and replacement also provides smoother results in post calculation steps.

AI.3.1.2 Preparation for applying RAS

The RAS method is applied at individual year level of a NACE total, but over all Member States and all products. From whole time series a two-dimensional matrix is defined for a single year containing the PCC codes belonging to certain NACE in the rows and country's NACE totals (taken from SBS statistics) in the columns. For small Member States mainly, the entire set of PCC codes of a given NACE sector contains zero values, whereas the SBS 2 digit of the given NACE sector shows existing totals greater than zero. In these cases, all the PCC codes of the Member State are converted to confidential and RAS provides estimates for the confidential values and make them ions consistent with SBS totals.

Another preparation step for the RAS is the rescaling of each NACE for all member states (including EU 28) by the ratio between the SBS total and the sum of all PCCs. The EU level PCC records are the only ones that do not contain confidential values, therefore a consistency check between product totals (from SBS) and the sum of all PCC codes at EU level of a given NACE are made. As expected, there will be non-negligible differences because these are different data sources representing different product levels. In summary, the ratio between SBS and the sum of all PCC codes of a given NACE is calculated and used to rescale the PCCs of all Member States.

Another source of inconsistency is the problematic codes, where the summation of existing PCC values is greater than the country (Member State) totals. For these cases, existing PCCs values are reduced by scaling them down to level up with country (Member State) totals. However, as the PCC code still contain confidential (NAs) that should be estimated by RAS, the country level NACE totals are increased by a factor based on the number of existing confidential in order to accommodate the forthcoming PCC figures estimated by RAS.

AI.3.1.3 RAS-method

The final step is the application of the RAS method. It brings consistency between the entries of a nonnegative matrix and pre-specified row and column totals (see a detailed description in https://ec.europa.eu/eurostat/cros/content/ras-method_en). Therefore, a consistent single-year matrix is produced as a result of RAS-method with remained confidential derived from the pre-processing steps being fully estimated.

AI.3.2 Price and volume estimation

The approach for production value estimation described in section AI.3.1 has resulted in a complete database of values for all PCC codes and EU Member States for the years 2008 to 2018. The next step is the creation of a complete database of *production volumes* and *prices*. A different approach is required than applied for production values to avoid ending up with inconsistent relations between values and volumes, and consequently prices. Therefore, the method applied for the determination of volumes firstly relies on the estimation of prices; secondly, the completed values are divided by these prices to get the production volumes.

AI.3.2.1 Transforming all volumes in kg

The unit of volumes in PRODCOM differs between PCC codes. Most product volumes are presented in kilograms (kg) and other products in a so-called supplementary unit. Besides, there are also products without a volume because it is defined 'not applicable'. To be able to combine volumes of different products, all supplementary units should be first converted to kg.

Eurostat COMEXT trade data makes a similar distinction between kg and supplementary units. Eurostat also publishes (INTRASTAT NET MASS SINCE 2006 - version 2021 (2021-01-29).docx) conversion factors for all supplementary units at EU level by year. These Eurostat conversion factors are for EU28 at CN level. Eurostat states that: "*To support the Member States, Eurostat compiles every year European average conversion factors for all the CN codes with a supplementary unit. These conversion factors are established on the basis of EU historical trade data after filtering out outliers. For the majority of the PCC codes, the factors are weighted averages or medians, but for some codes (mostly for wood products) industry estimates are applied. Technical conversion factors (unit mass) based on physical characteristics of the commodity are also established (for example, the weight of one litre of mineral water equals one kilogram), as well as 'Value per kg' conversion factors. However, Eurostat recommends using the 'unit mass' conversion factors for estimates wherever possible as the supplementary quantity is usually better correlated with the net mass*".

The Eurostat 'unit mass' conversion factors at CN level are aggregated to PCC level, weighted by the trade with World (INTRA-EU + EXTRA-EU) export volumes in supplementary unit (*Export_Quantity_Sup*) at CN level. These weighted EU28 conversion factors are applied on EU and MS level.

The trade with the World (INTRA-EU + EXTRA-EU) export values and volumes in kg (at CN level) are also aggregated to PCC level to calculate an export price at PCC level (*ExpPrice_KG*).

Conversion of the original PRODCOM volumes (*PcSdVol*) to PRODCOM volumes in kg (*PcSdVolKg*) takes three conditional steps:

- if the unit mass conversion factor is available the original volume is divided by the conversion factor. Else,
- if the original volume is already in kg, the original volume is kept. Else,
- if the other steps do not work the original value is divided by the export price to obtain volumes in kg.

$PcSdVolKg = PcSdVol / ExpConvUnitMass$

$PcSdVolKg = PcSdVol$

$PcSdVolKg = PcValue / ExpPrice\_KG$

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AI.3.2.2 Determining EU and MS price

The first step is to calculate (initial) prices based on the original PRODCOM values and volumes, solving following challenges. Due to the large amount of confidential values and/or volumes, initial prices could not be calculated in many cases. Further, the initially calculated prices show large fluctuations within the time series of EU28 and of MS, while there are also large differences between MS and EU prices. To cope with this, an outlier and filling procedure is applied to the calculated initial prices, first for EU and second for MS (taking into account the revised EU price).

PcPrice= PcValue/PcSdVolKg
PcValue = Original PRODCOM value
PcSdVolKg = Original PRODCOM volume (transformed in kg)
PcPrice= PRODCOM price (initial)

EU price correction

The second step is the revision of the calculated initial EU price (*PcPriceEu*) by using an outlier procedure and replacing outliers with the nearest remaining EU price in the time series. The outlier procedure is based on first calculating the median (*PcPrEuMed*) of the time series and then calculating the share (*PcShPrEuPrEuMed*) of each price in the time series against the median. The prices for the years which have a share of <=50% or >=200% related to the median price are considered to be an outlier (*PcPrEuOut*) and are removed from the time series and replaced by the nearest remaining price in the time series. The resulting EU price series (*PcPriceEuRev*) for each PRODCOM code is used for correcting outlier prices and filling gaps in the time series of the EU Member States.

MS price correction

The third step is the revision of the initial MS price (*PcPrice*) by using an outlier detection procedure and recalculating the MS price with the use of the revised EU prices (*PcPriceEuRev*). The same outlier detector as used for the EU price correction is used for MS price. Firstly, the median (PcPrMSMed) of the time series is calculated, and next the share (*PcShPrMsPrMsMed*) of each price in the time series related to the median. The prices for the years which have a share of *<=50% and >=200%* related to the median price are considered to be an outlier (*PcPrMsOut*) and removed from the time series. An additional second MS outlier detection procedure using the mean of time series of MS and EU is applied by calculating the share mean MS price in mean EU price and removal of MS price outlier with a share of *<=10% or >1000%* in mean of EU price outlier time series. MS price outliers are replaced and missing MS prices filled by using a combination of methods. There are three possible cases:

- If there is a MS price, it is kept.
- If there is no MS price in the time series the MS price gets the value of the revised EU price (*PcPriceEuRev)*.

- If there is a MS price in part of time series, missing years are filled by using a procedure based on available MS prices and the revised EU price (*PcPriceEuRev*). The share of the MS price in the revised EU price is calculated for the years with a MS price. The years without a MS price are first filled with the nearest share of the MS price in the EU price in the time series, which is multiplied by the EU price to get the MS price.

Revised volume

The calculation of revised volumes is based on the completed PRODCOM value described in Section AI.3.1, in combination with the revised prices described above by simply dividing the RAS results with the revised price.

AI.3.3 Adding trade data

Trade data are needed to complete the balances and to determine the domestic use of each PRODCOM code. Import and export values (*PcImpVal and PcExpVal*) and volumes (*PcImpQnKg and PcExpQnKg*) are based on the Eurostat COMEXT database. The Eurostat metadata system RAMON provides concordances between PRODCOM product codes and COMEXT trade CN codes by year. These trade figures contain the aggregated COMEXT volumes in kg. Only aggregation without other conversions. COMEXT provides kg for all codes and for part of the codes also a supplementary unit. The MS trade figures presented refer to trade with World (INTRA-EU + EXTRA-EU) while the EU28 trade figures presented only refer to EXTRA-EU trade.

AI.4 Consistency checks and validation

AI.4.1 Consistency geo

After all revisions in the steps above, on the PRODCOM data at EU28 and MS level, the calculated values (PcValueRev) and volumes (PcSdVolKgRev) are no longer consistent anymore between EU28 and MS. To end up with a complete and consistent PRODCOM data set the EU28 is made consistent with the sum of MS, based on the choice that revised MS data are leading. This means that the EU28 data are replaced by the sum of the MS data. After making the EU28 consistent with MS for value and volume, the prices (*PcPriceRev*) for EU28 have to be recalculated.

AI.4.2 Consistency nace_r2

In a next step to ensure consistency, the PCC codes (PRODCOM product codes) are aggregated to the NACE two digit code Cxx. This aggregation to NACE two digit code is also done for the trade figures.

AI.4.3 Comparison of original and revised PRODCOM data

It is important to validate the results of the different steps undertaken in the whole procedure as described above. In order to provide an overview of the impact of all steps on PRODCOM values, volumes and prices, differences between original and revised figures are presented as share of the original in revised (%).

PcShValueValueRev = *PcValue / PcValueRev * 100*
PcShSdVolKgSdVolKgRev = *PcSdVolKg / PcSdVolKgRev * 100*
PcShPricePriceRev = *PcPrice / PcPriceRev * 100*

We have developed and applied a generic, stepwise procedure to complete PRODCOM dataset for products that belong to the bioeconomy sectors as defined in Deliverable 1.1. This way, data completion is applicable to different subsets within PRODCOM, e.g. subset C20 *Manufacture of chemicals and chemical products* or subset C22 *Manufacture of rubber and plastics*' - in a consistent way, while also a repetition of the approach is guaranteed when there are PRODCOM updates.

The completed PRODCOM production dataset that is compiled in the BioMonitor project can differ significantly from the data that are published in official Eurostat statistics. Absolute and relative size of the difference depends on the Member State. There are both changes in the levels, e.g. small countries like Malta and Cyprus do not have any data in the C20 product group reported in PRODCOM, but get some numbers in our estimation procedure. More importantly, significant level shifts are visible in the Member States that have a significant share in C20 product group, like the Netherlands. To understand if results of the data completion procedure applied in the BioMonitor project make sense and are accurate, it is important to compare them with the PRODCOM information detail that is available at statistical offices. Therefore, we have validated the production values of sub-set C20, that contains around 550 chemical products, in the Netherlands in the year 2015 by comparing BioMonitor outcomes with detailed information of the Dutch Statistical Office (CBS). Though the Statistical Office is not permitted to share full details, they can provide more details at the level of product groups within the C20 group, respectively represented by codes C201, C202, C203, C204, C205 and C206 (Table A4) .

Table A4 - Product groups within C20 Manufacture of chemicals and chemical products

C201	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
C202	Manufacture of pesticides and other agrochemical products
C203	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
C204	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
C205	Manufacture of other chemical products
C206	Manufacture of man-made fibres
C20	*Manufacture of chemicals and chemical products*

Table A5 shows aggregates for these 6 product groups within C20 in the situation before (2nd column) and after the data completing work (6th column) in BioMonitor, and compares both situations with the ('true') values that are available at the SBS premises (3rd and 7th columns). It shows that production values for Dutch C20 products in the analysed year as reported in official PRODCOM statistics are significantly underrepresented (ca 50%) compared with CBS numbers.

Table A5. Production values for C20 product classes, before and after data compilation procedure, and their comparison with CBS values, the Netherlands, 2015

C20 Product classes in PRODCOM	Published value by Eurostat	Value in CBS statistics	*Difference*	Estimated value by BioMonitor	Value in CBS statistics	*Difference*
C201	14,341	28,737	*-50%*	28,650	28,737	*0%*
C202	0	220	*-100%*	214	220	*-3%*
C203	1,611	1,648	*-2%*	1,690	1,648	*3%*
C204	1,127	1,687	*-33%*	1,792	1,687	*6%*
C205	1,887	3,259	*-42%*	3,316	3,259	*2%*
C206	0	751	*-100%*	614	751	*-18%*
C20 - total	*18,966*	*36,302*	*-48%*	*36,276*	*36,302*	*0%*

Last three columns of Table A5 show the impact of the developed data completion procedure applied in BioMonitor, and how it has adapted levels considerably, especially in the dominant C201 product group with its large share of 'non-available' and 'confidential' product data (206 products out of 352 products). The procedure described in this Annex has several characteristics: (i) it is an ongoing and iterative activity, (ii) it provides understanding on the variety of reasons underneath data gaps, (iii) it provides solutions and translates these into generic algorithms and guidelines to close data gaps, (iv) it interacts with other statistical sources (e.g. using SBS data for setting country and sector boundaries in PRODCOM), (v) it balances the products to country levels and country results to EU levels, and lastly (vi) it validates the outcomes with data and sector experts at statistical and research institutes.

CBS provided suggestions for adapting estimation procedure during the review process. The difference between BioMonitor estimates and CBS data has reduced obviously in this specific case – production value of the complete set of C20 products in the Netherlands in 2015 – which is a promising result. Steps undertaken to achieve this result have been generically applied to other countries (all member states) and other years (2008-2018), though this will not automatically lead to the conclusion that outcomes for other country-year combinations will fit as good to 'true' data as the case depicted in Table 5. That would need additional validation rounds, not only to other years with the CBS, but also data of other countries should be discussed with the respective Statistical Institutes. Due to time and budget constraints, such additional effort could not take place within the BioMonitor project, but is recommended as a future step.

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