Setting up a bioeconomy monitoring:

Resource base and sustainability

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List of Abbreviations

AGEB	Energy Balances Group (Arbeitsgruppe Energiebilanzen)
AGEE	Stat Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien)
AMI	Agricultural Market Information Company (Agrarmarkt Informations-Gesell-schaft)
BLE	Federal Agengy for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung)
BMEL	Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft)
CEFS	Committee of European Sugar Producers (Comité Européen des Fabricants de Sucre)
CF	Conversion factor
CfW 2.0	Charter for Wood 2.0
CN	Combined (traffic and statistical) Nomenclature
CPA	Statistical Classification of Products by Activity
CRF	Common Reporting Format
DBFZ	German Biomass Research Centre (Deutsches Biomasse Forschungszentrum)
DEPV	German Pellet Association
DESTATIS	Official statistics published by the Federal Statistical Office of Germany
DTI	German Frozen Food Institute (Deutsches Tiefkühlinstitut e.V.)
EP	Eutrophication Potential
EPAL	European Pallet Association
ES	Earning Survey
EUROSTAT	European Statistical Agency
FAO	Food and Agriculture Organization of the United Nations
FNR	Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e.V.)
GP	National version of PRODCOM list (Güterverzeichnis für Produktionsstatistiken)
GVA	Gross Value Added
GWP	Global Warming Potential
HS	Harmonized Commodity Description and Coding System
ISIC	International Standard Industrial Classification of All Economic Activities
LCA	Life Cycle Assessment
LfL	Bavarian State Institute for Agriculture (Bayerische Landesanstalt für Landwirt-schaft)
LFS	Labour Force Study
LOFASA	Logical Framework for a Sustainability Assessment
LULUCF	Land use, land use change and forestry
LWE	Live weight equivalent
m^3(f)	Cubic meters of wood fibre equivalent
m^3(r)	Cubic meters of roundwood equivalent
MFA	Material flow analysis
MGrE	Material and Goods received Enquiry
mil.	Million

MVO	Reporting Regulation for Goods with Market Regulations (Marktordnungswaren-Meldeverordnung)
NACE	Statistical Classification of European Activities
NIR	National Inventory Report for the German Greenhouse Gas Inventory
OVID	Association of the Oilseed Processing Industry in Germany (Verband der ölsaatenverarbeitenden Industrie in Deutschland e.V.)
PRODCOM	Products of the European Community
SBS	Structural Business Statistics
SDG	Sustainable Development Goals
SES	Structure of Earnings Survey
SME	Small and Medium Enterprises
t	Metric ton, metric tonnes
TFZ	Technology and Promotion Centre in the Competence Centre for Renewable Resources (Technologie- und Förderzentrum am Kompetenzzentrum für Nachwachsende Rohstoffe Technologie- und Forschungszentrum)
TI-WF	Thünen Institute of International Forestry and Forest Economics
UFOP	Union for the Promotion of Oil and Protein Plants (Union zur Förderung von Oel- und Proteinpflanzen e.V.)
VDGS	Association of German Grain Processors and Starch Manufacturers (Verband der deutschen Getreideverarbeiter und Stärkehersteller e.V.)
VDP	German Paper Association
VLOG	Association Food Without Genetic Engineering (Verband Lebensmittel ohne Gentechnik e.V.)
WA	National version of Combined Nomenclature (Warenverzeichnis der Außenhandelsstatistik)
WVZ	Wirtschaftliche Vereinigung Zucker (German Sugar Industry Association, Economic Association for Sugar) e.V.
WZ	German NACE version of 2008 (Klassifikation der Wirtschaftszweige)

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Preface

The presented Thünen Working Paper was elaborated within the research project „Setting up a systematic bioeconomy monitoring – Dimension 1: resource base and sustainability/ biomass production (acronym MoBi). We present detailed results with a strong focus on methodological aspects. Dimension 1 was funded by the Federal Ministry of Food and Agriculture (Funding Code 22002416). We would like to thank the ministry for its support and open discussions. We hope our efforts are the basis for a frequent monitoring of the German bioeconomy and possibly also in other countries.

The project was part of an initiative of the Federal German Government to elaborate a comprehensive monitoring of the German bioeconomy. This initiative included two further projects, in total three dimensions. Firstly, the development of economic key figures and indicators (Dimension 2), funded by the Federal Ministry of Economic Affairs and Energy. And secondly, a systemic observation and modelling (Dimension 3), funded as a joint research project SYMOBIO by the Federal Ministry of Education and Research. Project results are jointly presented in the pilot report on monitoring the German bioeconomy. We would like to thank the two other research consortia for fruitful discussions and good cooperation.

Special thanks go to Johanna Schliemann for her tireless support in elaborating e!sankey charts, Stefanie Stenner for converting our ideas into expressive graphics and Sandra Gostkowski for final proofreading.

Vorwort

Das vorliegende Thünen Working Paper wurde im Rahmen des Forschungsvorhabens „Aufbau eines systematischen Monitorings der Bioökonomie – Dimension 1: Ressourcenbasis und Nachhaltigkeit/Erzeugung der Biomasse“ (Akronym MoBi) erstellt. Im vorliegenden Bericht werden die Ergebnisse der Dimension 1 im Detail und mit Fokus auf methodische Aspekte vorgestellt. Das Vorhaben wurde mit Mitteln des Bundesministeriums für Ernährung und Landwirtschaft unter dem Förderkennzeichen 22002416 gefördert. Wir danken dem Ministerium für seine Unterstützung und den offenen Austausch. Wir hoffen, dass unsere Arbeiten eine Grundlage für ein verstetigtes Monitoring der Bioökonomie in Deutschland und möglicherweise in anderen Ländern darstellen.

Das Vorhaben war Teil einer Initiative der Bundesregierung zur Erarbeitung eines umfassenden Monitorings der Bioökonomie. Diese Initiative umfasste mit zwei weiteren geförderten Vorhaben insgesamt drei Dimensionen. Zum einen die Entwicklung wirtschaftlicher Kennzahlen und Indikatoren (Dimension 2), gefördert vom Bundesministerium für Wirtschaft und Energie, zum anderen eine systemische Betrachtung und Modellierung (Dimension 3), gefördert als Verbundvorhaben SYMOBIO vom Bundesministerium für Bildung und Forschung. Die gemeinsame Darstellung der Ergebnisse aller Dimensionen erfolgte im Pilotbericht zum Monitoring der Deutschen Bioökonomie. In diesem Zusammenhang danken wir den Kolleginnen und Kollegen für die gute Zusammenarbeit und die konstruktiven Diskussionen.

Besonderer Dank gilt Johanna Schliemann für ihre unermüdliche Unterstützung bei der Erstellung der Abbildungen mit e!sankey, Stefanie Stenner für die grafische Umsetzung unserer Ideen und Sandra Gostkowski für das abschließende Korrekturlesen.

Abstract

The transition of the current economic system from non-renewable and fossil-based towards a more sustainable system using renewable resources is a dedicated objective of the German National Bioeconomy Strategy. In order to provide sound information on the status of the bioeconomy, a monitoring concept that assesses the bio-based resources and sustainability effects associated with German bioeconomy was developed.

The general monitoring approach includes a definition of the bioeconomy and its implementation in terms of material flows and economic sectors at a given point in time. Based on this, available data is collected and bio-based material flows and economic sectors are quantified. These quantifications are used in the following sustainability assessment of material flows and economic sectors. This procedure can be repeated, starting again with a definition of bioeconomy that may change over time according to changing policies, market development and public perceptions of bioeconomy. Thus, bioeconomy monitoring considers the dynamics of the bioeconomy transition concerning processes, products, available data and connected sustainability goals.

Understanding and quantifying material flows provides the foundation for comprehending the processing of biomass along value chains and final biomass uses. They also provide information for sustainability assessment. For biomass from agriculture, forests and fisheries including aquaculture, relevant material flows are compiled. Material flow data is not available consistently but must be collected from a broad variety of sources. Consequently, inconsistencies regarding reference units and conversion factors arise that need to be addressed further in a future monitoring.

Bio-based shares of economic sectors can be quantified using mostly official statistics, but also empirical data. Bio-based shares vary considerably between economic activities. The manufacture of food products, beverages and wooden products has the highest bio-based shares. Bioeconomy target sectors like chemicals, plastics and construction still have rather small bio-based shares.

The suggested assessment of sustainability effects foresees two complimentary levels of evaluation: material flows and economic sectors. The latter quantifies total effects of bioeconomy in a country and relates them to the whole economy or parts of it. The presented indicators were selected based on the Sustainability Development Goal Framework, the German Sustainable Development Strategy and the availability of data. The selection of effects and indicators to be measured in a future monitoring is a crucial point of any quantification. With sustainability being a normative concept, societal perceptions of sustainability should be taken into consideration here. In that context, we suggest to follow the approach of LOFASA for indicator selection. Sustainability assessment of material flows is demonstrated on the example of softwood lumber material flow and its core product EPAL 1 pallet using a combination of material flow analysis and life cycle assessment.

Major challenges for a future monitoring of the bioeconomy’s resource base and sustainability are availability of detailed and aggregated data, identification of bio-based processes and products within the economic classifications, identification and quantification of interfaces between biomass types, selection of indicators for sustainability assessment and the inclusion of bio-based services.

Keywords: bioeconomy, material flow, sustainability, monitoring, bio-based, assessment

Zusammenfassung

Der Übergang des derzeitigen, auf nicht erneuerbaren Rohstoffen basierenden Wirtschaftssystems zu einem nachhaltigeren System, in dem erneuerbare Ressourcen genutzt werden, ist ein zentrales Ziel der Deutschen Bioökonomiestrategie. Um belastbare Informationen zur Entwicklung der Bioökonomie bereitstellen zu können, wurde ein Monitoringkonzept entwickelt, welches die mit der Bioökonomie in Deutschland in Zusammenhang stehenden biobasierten Ressourcen und Nachhaltigkeitseffekte erfasst und beziffert.

Grundsätzlich beginnt ein Monitoringzyklus mit der Definition von Bioökonomie und der Implementierung dieser Definition in Form einer Zuweisung konkreter Stoffströme oder wirtschaftlicher Aktivitäten zur Bioökonomie zum Untersuchungszeitpunkt. Basierend auf diesen Zuweisungen erfolgt die Auswahl geeigneter Datenquellen und die eigentliche Quantifizierung der relevanten Stoffströme und der biobasierten Anteile der Wirtschaftszweige. Diese Daten werden nachfolgend für die Bestimmung der Nachhaltigkeitseffekte von Stoffströmen und auf sektoraler Ebene genutzt. Der Monitoringzyklus kann zu jedem späteren Zeitpunkt wiederholt werden. Dabei ist die Überprüfung der zugrundeliegenden Bioökonomiedefinition von großer Bedeutung, da sich neben Marktentwicklungen auch politische Zielstellungen und gesellschaftliche Ansprüche verändern können.

Identifizierung und Quantifizierung von Stoffströmen legen die Grundlage für das Verständnis von biobasierten Wertschöpfungsketten und der Endverwendung von Biomasse und liefern so Informationen für eine stoffstrombasierte Nachhaltigkeitsbewertung. Im vorliegenden Bericht werden Stoffströme der relevanten Biomassen aus Land- und Forstwirtschaft sowie Fischerei und Aquakultur in einer einheitlichen Struktur zusammengeführt. Die dafür benötigten Daten sind in konsistenter Form nicht verfügbar, sondern müssen aus vielen verschiedenen Quellen zusammengestellt werden. Im Zuge dessen ergeben sich Inkonsistenzen v.a. in Bezug auf Basiseinheiten und Umrechnungsfaktoren, die in zukünftigen Arbeiten im Rahmen eines verstetigten Monitorings noch stärker adressiert werden müssen.

Biobasierte Anteile der Wirtschaftszweige können unter maßgeblicher Nutzung amtlicher Statistiken berechnet werden. Die Anteile variieren sehr stark in Abhängigkeit vom betrachteten Wirtschaftszweig. So zeigt die Herstellung von Lebensmitteln und Getränken sowie von Produkten aus Holz die höchsten biobasierten Anteile. Wirtschaftszweige, für die eine verstärkte Nutzung nachwachsender Rohstoffe erwartet wird, wie die Chemieindustrie, die Kunststoffherstellung und das Bauwesen, weisen im Betrachtungszeitraum noch vergleichsweise geringe biobasierte Anteile auf.

Das formulierte Konzept zur Nachhaltigkeitsbewertung umfasst zwei komplementäre Ansätze: stoffstrombasierte und sektorale Bewertung. Letztere quantifiziert die Gesamteffekte der Bioökonomie eines Landes und setzt sie in Beziehung zur gesamten Wirtschaft oder bestimmter Wirtschaftsbereiche. Die vorgestellten Nachhaltigkeitseffekte und zugehörigen Indikatoren wurden basierend auf den Sustainability Development Goals, der Deutschen Nachhaltigkeitsstrategie und in

Abhängigkeit der Datenverfügbarkeit ausgewählt. Der Auswahl der zu quantifizierenden Nachhaltigkeitseffekte kommt in einem zukünftigen Monitoring eine wesentliche Bedeutung zu, da es sich bei Nachhaltigkeit um ein normatives Konzept handelt. Bei der Auswahl der zu untersuchenden Effekte sollte das Nachhaltigkeitsverständnis verschiedener Anspruchsgruppen berücksichtigt werden. Vor diesem Hintergrund empfehlen wir die Anwendung der LOFASA-Methodik für die Auswahl von Kriterien und Indikatoren zur Nachhaltigkeitsbewertung. Die Methodik für die stoffstrombasierte Nachhaltigkeitsbewertung wird anhand des Leitproduktes EPAL 1 Palette und des zugehörigen Nadelholzstoffstroms vorgestellt und kombiniert Stoffstromanalyse und Lebenszyklusanalyse.

Die wichtigsten Herausforderungen für ein zukünftiges Monitoring der Bioökonomie bestehen in der Verfügbarkeit aktueller Daten verschiedener Aggregationsebenen, der Identifizierung biobasierter Prozesse und Produkte in den amtlichen statistischen Klassifikationen, der Beschreibung von Schnittstellen zwischen verschiedenen Biomassetypen, der Auswahl geeigneter Indikatoren der Nachhaltigkeitsbewertung und in der Berücksichtigung biobasierter Dienstleistungen.

Schlüsselwörter: Bioökonomie, Stofffluss, Nachhaltigkeit, Monitoring, biobasiert, Bewertung

1 Setting the Scene

1.1 Introduction

The change of our current economy from a non-renewable and fossil-based into a more sustainable and more renewable one is a political target expressed in many national and international strategies. One pillar towards a more sustainable economy is the shift towards a bioeconomy. What a bioeconomy is, significantly varies between countries and organisations that tried to define it. The EU Bioeconomy Strategy is focused on the production and conversion of biological resources in a circular and sustainable way (EC 2018; DESTATIS 2018d). The German National Bioeconomy Strategy defines six strategic goals (BMBF and BMEL 2020). First, it couples the National Strategy with the United Nations 2030 agenda for sustainable development. Second, it recognises the potential of bioeconomy within its ecological boundaries. Third, it wants to enhance and apply biological knowledge. Fourth, it wants to establish a sustainable raw material source for industry. Fifth, it wants to promote Germany as the leading location for innovation in bioeconomy. Finally, it wants to involve society and strengthen international collaboration. Although targets of bioeconomy strategies also in other countries of the EU like Finland or other countries of the world differ, the underlying principle is the same. That is the shift to renewable resources, use of biological processes without putting sustainability at risk.

One important aspect the German National Bioeconomy Strategy also addresses is the monitoring of bioeconomy. In order to get sound information on the status of bioeconomy, a frequent monitoring is essential. In 2016, the German government initiated three research projects that were assigned to develop bioeconomy monitoring concepts. Each research consortium had a different focus. One consortium, supported by the Federal Ministry of Economic Affairs and Energy, had a focus on economic indicators relevant for the monitoring of bioeconomy. The consortium supported by the Federal Ministry of Education and Research develops scientific basics for a systemic monitoring and modelling of the German bioeconomy with respect to sustainability aspects on a national and international level.

On behalf of the German Ministry for Food and Agriculture, the Thünen Institutes of Market Analysis, Sea Fisheries and International Forestry and Forest Economics were assigned to develop a monitoring approach that is able to assess the bio-based resources and sustainability effects associated with German bioeconomy. This report describes the methodological approach the Thünen Institutes have taken in detail and presents first results. The approach is based on a material flow analysis of all relevant material flows associated with bioeconomy. As a consequence, it allows delimiting bioeconomy from the economy as a whole. A material flow-based as well as sectoral assessment of sustainability effects is integrated.

The focus of this report is to describe the monitoring approach in detail. Further, it is on how it is done and not so much on the first monitoring results. They are also provided but in contrast to the methodology and the current data gaps not critically discussed.

The report is rather technical and detailed. It is structured into four chapters. Chapter 1 introduces data sources that are essential for the monitoring and introduces the objectives of the project. Chapter 2 presents the conceptual framework for material flow analysis of bio-based material flows as well as the quantification of bio-based shares in the economic sectors. The results of the material flow analysis of major bio-based material flows that origin form agriculture, forestry and fisheries as well as the bio-based shares are also presented. In chapter 3, methodological approaches for material flow-based as well as sectoral assessment of sustainability effects of bioeconomy are presented together with first results. In the final chapter 4, the main findings are summarized and open questions are discussed regarding data needs, data gaps and the selection of indicators for the assessment of sustainability effects. Finally, interfaces to other monitoring systems that support bioeconomy monitoring are discussed.

1.2 Available Data

Currently, significant data sources can be grouped in (i) official statistics published by the Federal Statistical Office of Germany (DESTATIS) and other Federal Agencies, (ii) specified statistics compiled by relevant associations, and (iii) empirical studies. Data provided by the first group is the backbone of a continuous monitoring as the data is collected based on standardized and often internationally harmonized classification schemes and methods and in defined time intervals. Thus, official statistics allow for comparisons over time and between regions and even national states. Statistics revisions as a matter of routine, due to methodological adaptation or extraordinary reasons are transparently communicated and result in improved data quality (DESTATIS 2017a).

In the following subchapters, we give an overview on the harmonized statistics classification system (chapter 1.2.1) and on the statistics that are relevant for monitoring production and use of agricultural, forest and aquatic biomasses (chapters 1.2.2 to 1.2.5). The variety of bio-based products and uses is the result of a variety of production, processing and manufacturing processes that convert biomass in one way or another. Biomass contents change during these processes and vary considerably in the finished products. Details regarding conversion factors are given in chapter 1.2.6.

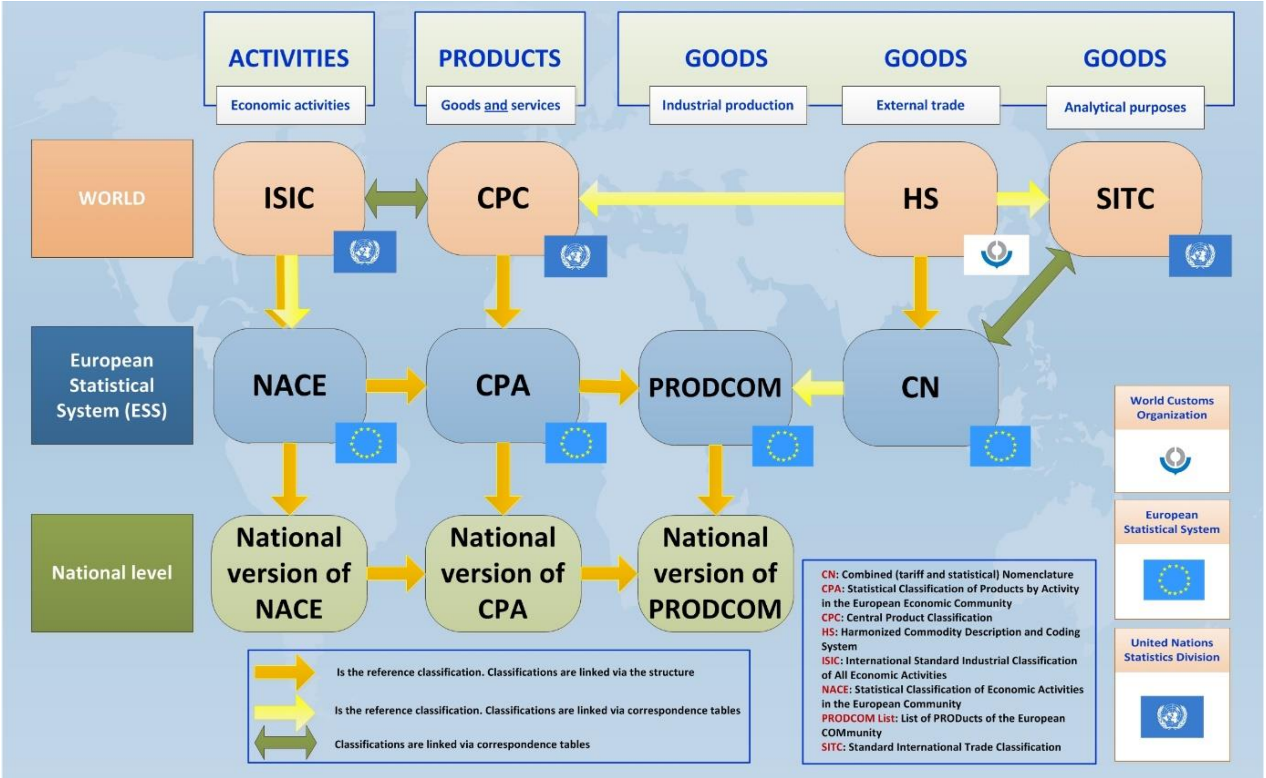
Data sources specific to agriculture, forestry and fisheries including aquaculture as well as sustainability assessment are described in detail in the corresponding parts of chapter 2.4 and chapter 3, respectively.

1.2.1 Economic Classifications

All data officially provided by international, EU- and national statistical agencies like the European Statistical Agency (EUROSTAT) and DESTATIS is based on a marmonized system of statistical classifications. These classifications structure data submissions of contributing countries or member states and they allow for comparison of submitted data. Figure 1.1 outlines relevant classifications and illustrates connections between them. The classifications refer to economic activities, to products or services as outputs from economic activities or to traded goods. Mostly, classifications are linked to each other as they have the same structure or via correspondance tables. However, single positions in the classifications are not always unambiguously linked to each other, which inevitably results in an certain level of inaccuracy.

In Germany, the national versions of the Statistical Classification of Economic Activities in the European Community, Rev. 2 (NACE Rev. 2 **N**omenclature européenne des **a**ctivités economiques dans la **C**ommunauté **e**uropéenne), i.e. Klassifikation der Wirtschaftszweige (WZ) and PRODCOM (**Prod**uction **Com**munautaire), i.e. Güterverzeichnis für Produktionsstatistiken (GP) are the most relevant classification systems as official federal data on economic activities and production is structured accordingly. In order to represent economic developments and trends that result in new economic activities, products, goods and services, classifications are updated regularly. In the context of bioeconomy monitoring concept development, German NACE version of 2008 (**WZ08**) and German PRODCOM of 2012 (**GP09**) were used, as the relevant period of time was 2010 to 2017. Data on external trade is provided by the national version of Combined Nomenclature (CN), the “Warenverzeichnis der Außenhandelsstatistik” (WA).

Figure 1.1: Integrated System of Statistical Activity and Product Classifications



Source: EUROSTAT 2020d

WZ08

WZ08 classifies economic activities. Structure and codes correspond to codes in NACE Rev. 2 down to the 4-digit level (i.e. classes). For some classes, WZ08 is more detailed and further disaggregated into subclasses (5-digits). Further description of economic activities classified into one (sub-)class can be derived from the "Klassifikationsserver" online (DESTATIS 2008). Companies are allocated to a statistical economic activity, depending on the share of generated gross value added attributed to different activities that companies may follow. If no data on gross value added is available, production value, turnover or number of employed persons are used for allocation. For example, manufacturer of wooden pallets often also run saw mills in order to produce their own sawn wood for production and repair of pallets. If the value added share of pallet manufacture is larger than the share for saw milling, the company is allocated to WZ08 code 16.24, i.e. *Manufacture of wooden containers* and not in code 16.10 *Sawmilling and planing of wood*. This method for allocation leads to errors in estimating wood material flow-based on official classification of economic activities. In order to reduce errors, other statistics have to be included. Main and sideline activities of companies are registered in the official business register.

GP09

The German PRODCOM classification GP09 is directly related to PRODCOM codes. Produced goods are coded into a 9-digit numerical code, instead of 8 digits. According to the aim of harmonization between European and national classifications, the first four digits are identical to the equivalent classes of NACE Rev. 2 and WZ08, respectively. Together with the next two digits, the six digits are identical to those of the Statistical Classification of Products by Activity (CPA) code; therefore, fully consistent with the CPA. The GP09 codes correspond to one or more codes of the CN, which enables production data to be related to foreign trade data. The first eight digits are mainly identical to the PRODCOM list and the ninth digit allows a further subdivision on national level.

Table 1.1: Correspondence of GP09 and WA/CN

	GP09	WA/CN
I to XXI	Product section	section
2-digit code	Product division (Abteilungen)	chapters
3-digit code	Product group (Gruppen)	headings
4-digit code	Product class (Klassen)	
5-digit code	Product category (Kategorien)	
6-digit code	Product subcategory (Unterkategorien)	HS subheadings
8-digit code		CN subheadings
9-digit code	Product code (Güterarten)	

Source: own compilation

The PRODCOM list is updated annually and is always valid from the January 1st till December 31st of the same year. An updated GP (**GP19**) came into force January 1st 2019 and replaced GP09. It adapts the current version of PRODCOM on EU level and comprises minor changes as compared to GP09. Before 2019, the GP09 had not been adapted to PRODCOM, in order to reduce additional bureaucratic efforts for companies and Statistical Agencies in Germany. However, this adaptation time lag increasingly required that Federal Statistical Agencies of the German Federal States needed to give only estimates when delivering national data to EUROSTAT (DESTATIS 2019a). In a future bioeconomy monitoring, the respective valid classification will be referred to and possible correspondance changes between classification types and levels will be taken into account. The codes of the PRODCOM list are normally related to one or more CN headings; therefore, the calculation of the domestic availability of products is possible with some restrictions.

WA, CN

The WA is the national classification of the CN and used for categorizing traded goods. The classification is annually revised and implemented on January 1st. The list is annually updated and therefore allows a fast adaptation to innovations and changes in the market. An important characteristic is the trade volume. If this increases further, WA/CN are established. On the other side, WA/CN with reducing trade volume may be closed and aggregated. Consequently, the changes of CN reflect changes in markets and integrate market observations.

1.2.2 Production Statistics

The purpose of the product statistics is to report amount and value of production of all listed products at the respective aggregation levels and for the respective year. Consequently, the statistic is related to products and not to activities. The production statistics record the domestic production of all local units belonging to a legal unit, which is totally or primarily engaged in production and services of NACE sectors B and C Mining, Quarrying, and Manufacturing. That means the statistic contains also data of local units, which do not belong to the respective economic activity. The statistic covers the activities of enterprises with 20 or more employees; for sawmills, the cut-off is at less than 10 employees. Thus, over all product codes, production statistics cover around 93 % of the total production, the remaining production is estimated on the basis of administrative data and econometrical procedure for estimation of characteristics of new units (multilevel model) (EUROSTAT 2018b). In the case of sawn wood, the applied cut-off thresholds lead to a substantial underestimation. Collection quota of official production statistics for unplaned sawn softwood ranged from 76.7 % to 87.3 % and was 38.1 % for unplanned sawn hardwood in average for the years 2002 – 2015 (Döring et al. 2017c). For agriculture, the use of on-farm produced feed describes a problem to calculate the exact amount of produced cereals or oilseeds.

Production statistics provide data at the level of a 9-digits numerical code, i.e.at the highest level of detail possible. The survey is conducted monthly for local units with 50 or more employees and quarterly for remaining local units. Both data sets are combined for the quarterly published production statistics. The monthly and annual data are published with a delay of 4 months. The comparability of the results over time results may be limited, if methodological changes concerning cut-off threshold, sample size or other have occurred. The data are used by the national accounts, input-output accounts and the monthly production index (EUROSTAT 2018b; Flores and Baumgärtner 2019; DESTATIS 2019c).

Statistical data and information are confidential if at least one of the following criteria apply:

- statistical data which enables the identification of a specific local unit,
- statistical data which contain information of less than three legal units,
- data at production code level with one or two dominant legal units.

Around 70 % of the data are open to the public (EUROSTAT 2018b). However, independent research institutions may gain access to disclosed data if they guarantee that research results do not allow for an identification of single companies (DESTATIS 2019a; BMJV 10/20/2016). For a future bioeconomy monitoring, it is advisable to use this disclosed data source.

The survey population is selected from the Business Register and done as a cut-off survey that means all units above a threshold are included. Grossing up for units below the threshold is not carried out. Undercoverage takes place when local units are not registered as a manufacturing industry even though they belong to those. Further errors can occur, like measurement errors and data editing errors, e.g. delivering incorrect data, misallocation of products or non-response or delayed answers (EUROSTAT 2018b).

The production statistics includes data at different level of aggregation (2-digit, 4-digit and 9-digit level) with different information (Table 1.2). At each level, the number of legal units is summed up, but may be different to the numbers provided by the structural business statistics (SBS) because only legal units which are allocated to the same economic activity are summed up within the latter, i.e. companies are surveyed instead of local units (EUROSTAT 2018b).

Volume and quantity of total production and production intended for sale are given in varying, branch-specific units. These units do not always allow for an unambiguous calculation of bio-based material contained in a product (see also chapter 1.2.3).

Table 1.2: Data delivered by the production statistic at different aggregation levels

2-digit and 4-digit codes	- value of products intended for sale - quantity of legal units (companies)
9-digit code	- value, volume and quantity of sold production (products intended for sale) - volume and quantity of total production (sold production plus the production intended for further processing inside the legal unit) - quantity of legal units with production intended for sale - quantity of legal units with production

Source: own compilation

1.2.3 Foreign Trade Statistics

The foreign trade statistic records the value and quantity of goods that are exported from one country and imported into another country. Data is collected by customs authorities. Recording of trade between Germany and non-EU Member States (extra EU-trade) is done by custom declaration. In contrast, trade between EU Member States (intra EU-trade) is recorded by a system called Intrastat and the data are directly collected from traders. In addition, it is interlinked with the value added tax (VAT) system; therefore, it ensures the completeness and quality of the statistical data. To simplify data provision and to reduce the burden on traders, a threshold is established. Trading companies with an annual export value of less than 500,000 € or annual import value of 800,000 € are exempted. The value and quantity is estimated and listed in the statistic. Both results, extra EU-trade and intra EU-trade, are summarized in the foreign trade statistic (EUROSTAT 2020a).

Besides product value and quantity, the custom authorities collect data about the partner country, reference period (month), direction of the trade (import or export) and mode of transport. The traded products are allocated to the CN classification which is based on the globally applied HS (more information see chapter 1.2.1). The unit of quantity is mainly the net weight (without packaging), exceptions are for example pairs for shoes, liters for wine or square meters for carpets. Wood-based products are registered in a variety of units, for example wooden window frames in absolute numbers, wooden flooring in m², but also in tons (net weight). Data on monetary value and net weight allow the calculation of a price per unit which can be applied to production value of the respective GP09-code in order to estimate produced amounts, if in the production statistics only the production value is recorded. For this derivation of prices, the export value should be used. The export value of a traded good includes the value added by economic activity in Germany; therefore, it represents the true production value more likely.

The data of the foreign trade statistic can query at different aggregation levels. On the one hand, product data can be aggregated according to different classification systems of interest for analysis, e.g. CN at different levels, or 2- or 4- digits GP09. On the other hand, data of trade with certain countries, all EU Member States or all non-EU Member States can be displayed. Monthly and annually data are available.

1.2.4 Structural Business Statistics

Based on data provision from EU countries, EUROSTAT provides the structural business statistics (SBS) (EUROSTAT 2018d). Main indicators are collected and presented as monetary values or as counts. SBS covers NACE Rev.2 sections B to N and Division 95, i.e. industry, construction, distributive trades and market services. Relevant statistics on the Federal level are manifold and structured according to NACE sections and the availability of data varies between sections. SBS are based on two different structural surveys: **cost structure survey** for entities with more than 20 employees and a **structure survey** for entities with less than 20 employees.

Traditionally, in manufacturing only companies with more than 20 employees are surveyed. However, on the EU level and for international comparisons, data from companies of all sizes is needed. Thus, both statistics are needed for secondary calculations like contributions of economic activities to gross domestic product as part of national accounting or in Input-Output-Table. At the same time, data requirements of the EU are fulfilled (DESTATIS 2018h). Survey results constitute an important data source for sectoral bioeconomy monitoring (chapter 2.5) and sustainability assessment (chapter 3).

Cost structure survey depicts economic performance and the respective expenditures of companies of selected economic sections (DESTATIS 2016c). These are sections C (manufacturing), D and E (energy supply, water supply, sewerage, waste management and remediation activities), F (construction), parts of section Q (Human health activities) and other service activities (DESTATIS 2017b). The sample consists of 5 % of all companies of the respective economic section and selected companies are obliged to report based on Federal Laws (BMJV 7/21/2016, 10/20/2016). On the national level, surveyed data is used for policy advice, for calculation of National Accounts as well as for scientific and educational purposes; also economic associations use the data. Collected data covers personnel and non-personnel expenses, taxes, number of employed persons and value of traded goods. The functional unit of most indicators is their monetary value in € (DESTATIS 2016c). Cost structure statistics in manufacturing provide information on production output, exerted production factors as well as value added at different levels of aggregation (Ebnet 2014).

Structural statistics sample size is 6.000 companies with less than 20 employees. Thus, structural statistics results complement the cost structural survey for manufacturing, for example in National Accounts or Input-Output-Tables to estimate the material use of small enterprises. The underlying assumption is that small and bigger enterprises are structured equally. Compared to the cost structure survey, the structure survey has fewer indicators, lower accuracy of results and is not officially published by DESTATIS.

1.2.5 Material and Goods received Statistics

The Material and Goods received Enquiry (MGrE) surveys type and acquisition costs (in €) of inputs that are processed or consumed in companies classified in NACE section B and C. Legislative basis of the MGrE is the Federal Statistics Act. Data is collected every four years and is published with a delay of 30 months. Collected data represents companies with 20 or more employees. At the time of survey conduction, about 18,000 companies are selected from the total number of approximately 48,000 (DESTATIS 2017c). Companies with more than 500 employees are obliged to report in every survey, smaller companies do not necessarily participate in every enquiry. Consequently, the composition of the surveyed group of companies (i.e. the sample) varies and MGrE results of different years can be compared to each other only to a certain extent. Significant changes in the time line may be a result of the sampling method, i.e. changes in the composition of the sample (reporting companies).

Surveyed inputs are categorized into raw and auxiliary materials (I), consumables including packaging (II) and fuels/combustibles (III). Category IV states the sum of all inputs (I – III).

Inputs of category I are classified according to a dedicated classification which is based on the production statistics classification, but also includes products related to section A (i.e. primary sectors). Data collection is conducted online (DESTATIS 2020d). There, companies participating in the survey are provided with questionnaires specialized for the NACE code they are assigned to. Companies can also report inputs that are not listed in the questionnaire. Inputs that are no longer reported by companies will be delayed from the dedicated questionnaire.

The inputs of categories II and III are not classified into statistical classification units for which production data is provided or that are unambiguously connected to classification within the international system (see Figure 1.1). Inputs are classified into broad categories and are the same for every economic activity included in MGrE (DESTATIS 2017c).

Category II includes consumables (code 921), i.e. all inputs that do not become part of the manufactured goods, but that are consumed during production or in maintaining production facilities. These include for example repair materials, tools and lubricants as well as office and marketing materials, working and protective clothing, dressing material and cleansing agents. Packing materials (code 922) include packaging made of wood, paper, paperboard, metal, plastics and glass. Code 923 refers to all materials and goods that are processed or further traded in kitchens or canteens owned and operated on the own account of the respective company. Category III involves solid (code 931) and liquid fuels (932), natural and liquid gas (933), electricity (934), district heating and compressed air (935).

1.2.6 Units and Factors

Agricultural biomass

Compared to forest and aquatic biomass, the complexity is the highest for the agricultural sector in which very different biomasses are produced and processed to food, feed and other final products. Data on the use of agricultural biomass is collected in the usual units without a common denominator as in the wood sector. The BLE publishes data on milk production and deliveries to dairy companies as well as on the manufacture of dairy products and their consumption in Germany on a monthly base. This data also includes conversion factors and enables to translate the amount of delivered milk from litres to kilograms. Another common denominator is to translate all arable crops into “cereal units”. Useful balance weighting factors are only available for individual agricultural balance groups and in combination with the commodity codes of the foreign trade statistics (CN codes). However, a uniform version of conversion factors that allow the conversion of all agricultural raw materials into dry matter is not available, but must be compiled for each occasion from various sources. In this area, a common understanding and harmonisation of conversion coefficients would be urgently needed for a long-term monitoring of the bioeconomy.

Forest biomass

Processing of timber, manufacturing and production of wood products is highly diverse and the actual wood content of semi-finished and finished wooden products varies. In production and trade statistics, amounts of wood and wood products are listed in customary units like m^3, t or m^2 and m. Besides wood, these amounts may contain other materials like chemicals, glue or resins. Consequently, statistics do not give numbers on the sheer amount of wood contained in a product and conversion factors are needed to calculate respective wood contents. Furthermore, shrinking and swelling of wood and wood products have to be considered.

Against this background, Weimar (2011) developed a new reference unit, the wood fibre equivalent (m^3(f)). It defines the volume equivalent to all wood or wood-based fibres at fibre saturation point contained in a defined product. For every wood-based product, a specific conversion factor has to be calculated (Bösch et al. 2015). Furthermore, for WA 8-digit codes, information on carbon content (carbon factors) are available (Diestel and Weimar 2014).

For forest biomass material flows, the wood fibre equivalent should be used as it allows for full comparability of different wood products. However, for the compilation of aggregated material flows, tonnes dry matter were chosen as the common unit.

Aquatic biomass

Aquatic biomass is traded at different levels of processing. Whole fish and seafood as well as semi-finished and finished products are consumed by the final consumer. Most data relevant for the aquatic biomass are available in net weight and the fish content or the amount of total caught fish and seafood required for the products (live weight equivalent – LWE) is not considered. Estimations about the used raw material are only possible by using conversion factors (CF). The European Market Observatory for fisheries and aquaculture (EUMOFA) offers a list of factors based on the 8-digit code of CN to calculate the LWE (EUMOFA 2019). Justified by the purpose of application, the list describes the processing procedure for Europe. A further list is used by the BEL to calculate the supply balance, per capita consumption and level of self-sufficiency. This list is not published, but inspired by the list of AIPCE. A comparison between the CF of EUMOFA and AIPCE is done for the most relevant fish products and published in several finfish studies (AIPCE, 2018). Due to the structure of the EUMOFA CF, this list is handier, can be applied easily and has been used for this study. But it has to be considered that calculation of LWE and their application describes the real usage only approximately, because processing techniques and recipes undergo changes continuously.

For calculating the supply balance for Germany, LWE is used. LWE covers the whole catch, but fish is also processed at sea. Consequently, the amount of landed fish contains both, whole and processed fish. That means landed weight differs from the LWE. Consequently, in calculating aquatic biomass material flows for core products, product weight and landing weight were used. This also allows for the estimation of fish processing residues.

Fish and seafood have a high-water content which differs from species to species. To calculate the dry mass, the CF published by Gurria et al. (2017) is used that specified the dry mass proportion of 25 %.

For compiling aggregated material flows and despite the limitations, the variety of units used in the different sectors was transferred to tonnes dry matter. However, for detailed analysis and dedicated material flows, commonly used units should be used.

1.3 Objectives

Major objective of the project *“Aufbau eines systematischen Monitorings der Bioökonomie – Dimension 1: Ressourcenbasis und Nachhaltigkeit / Erzeugung der Biomasse“* (MoBi) was to lay the ground for a national German monitoring of existing and future biomass flows and for the assessment of sustainability effects connected to biomass production and use. Besides the development of methodological approaches to monitor material flows, bioeconomy sectors and their sustainability, the project aimed at giving guidance on a common understanding of bioeconomy.

In detail, objectives are:

- Provision of solid sector-specific and cross-sectoral data and quantification methods in order to describe development and the current status of biomass production and uses.
- Based on that detailed data, development of balances, flow charts and indicators on appropriate aggregation levels.
- Identification of data gaps and development of approaches to fill these gaps in a continuous monitoring.
- Updateable/extensible design of bioeconomy monitoring to allow for inclusion of future production and use of biomass corresponding to market development and bio-based innovation.
- Development of a comprehensive assessment of material flow-based and sectoral sustainability effects.

The first basic premise is that biomass flows need to be monitored along the value chains starting from the primary production via various ways of manufacturing and processing to their final use either as raw material or as a manufactured bio-based product. As a matter of fact, there is no single data source which provides all relevant information. Hence, a first step is to identify all relevant sources, either from official statistics or from additional sources. Official statistics are preferred as they are based on well-defined methods, provided continuously and therefore allow for comparisons over time and between regions, national states or in the context of the European Union. The development of sustainability assessment includes identification of sustainability targets and related indicators, identification and evaluation of available data and the development of assessment methods.

2 Resource Base, Material Flows and bio-based Sectors

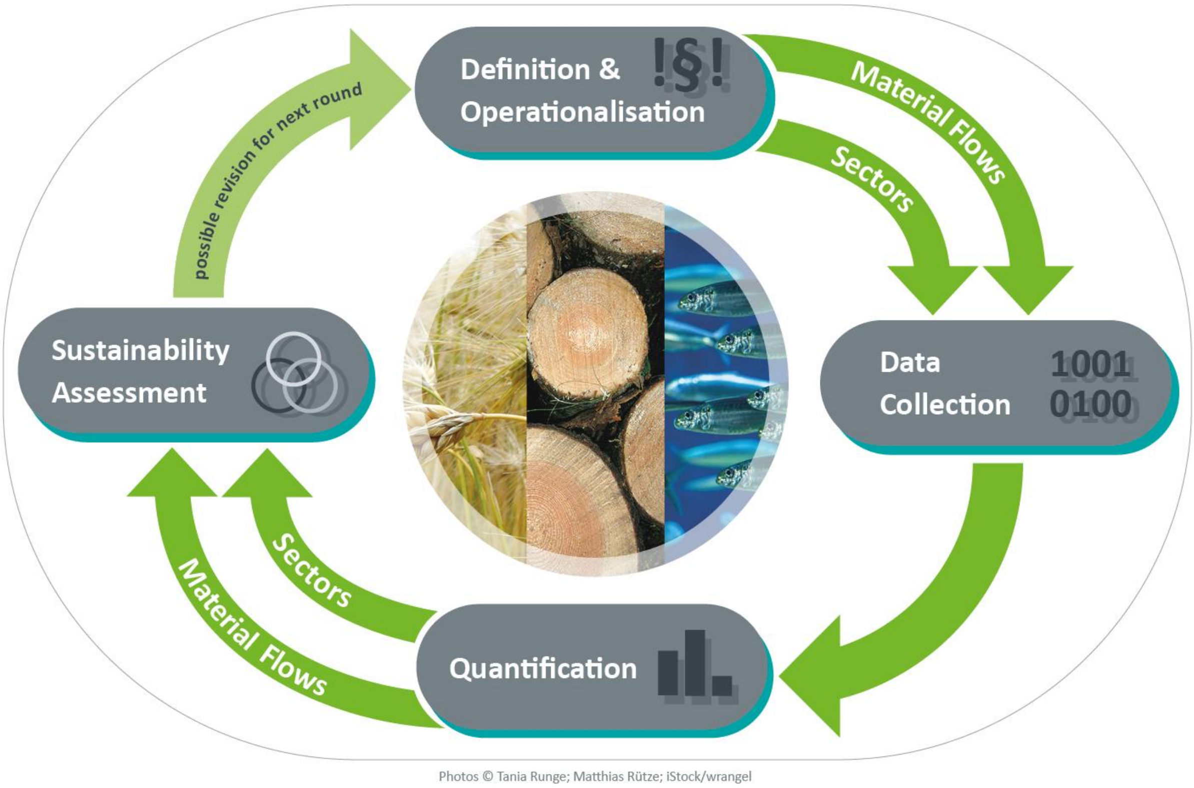
2.1 Conceptual Framework

The framework of monitoring German bioeconomy is presented in Figure 2.1. We identified two major scopes for the bioeconomy monitoring: economic sectors and material flows (chapter 2.2). For both, in a first step, bioeconomy is defined and operationalised (chapter 2.3). Next, data relevant for sectors and material flows is collected (chapter 2.4) and used for quantification of bio-based shares of sectors and underlying economic activities and the size of bio-based material flows in relevant value chains (chapter 2.5).

However, the level of detail in monitoring does not only depend on definition and operationalisation of the term bioeconomy and the underlying objectives connected to bioeconomy, but is strongly interconnected with data availability. Thus, data collection may also reveal data gaps and lead to the conclusion that targeted quantifications cannot be done at a specified point of time. Several iterations between data collection and quantification of targeted bio-based shares, material flows and indicators may be necessary.

Finally, sustainability can be assessed (chapter 3). Again, this assessment can be done for (i) bioeconomy sectors (chapter 3.4) and (ii) material flows (chapter 3.3). In a continuous monitoring, this procedure is repeated for each monitoring cycle. The development of the bioeconomy is and will be characterized by the substitution of fossil with renewable resources. In this context, it is expected that value and supply chains, processing and manufacturing will change and become more bio-based. Products, processes and services that as of today are not attributed to the bioeconomy, may be bio-based in the future. Consequently, every monitoring cycle has to review definition and operationalisation of the bioeconomy against the background of policies, market development and societal perceptions.

Figure 2.1: Conceptional Framework for Monitoring Bioeconomy



Source: own illustration

2.2 Monitoring Scopes

Generally, monitoring requirements depend on the subject to be monitored. In the case of bioeconomy monitoring, the requirements are deduced from the objectives formulated in the German Policy Strategy on Bioeconomy (BMEL 2014). In the strategy, central themes are food security, reduction of dependency on fossil resources, climate protection, sustainable production and efficient use of renewable resources while securing biodiversity and soil functions, but also securing and creation of added value and jobs, as well as strengthening of innovation and competitiveness. These central themes together illustrate the comprehensive claim of bioeconomy. A future monitoring also aims at providing data for a comprehensive sustainability assessment. Against this background and during the revision of available data, two major monitoring scopes became evident, which we suggest taking into consideration in future monitoring activities as well.

First, the sectoral scope covers the wider context of economic sectors and underlying economic activities whose quantification allows for accounting significance and development of bioeconomy in the context of national economy and for comparisons on the international level. Sectoral bioeconomy monitoring uses existing national and international statistics and classification schemes and official sectoral data provided by Federal and EU statistics agencies. The most commonly used socio-economic indicators for sectoral monitoring in Europe are value added, turnover and employment (Ronzon and M'barek 2018). Basically, further data is available on the sectoral level that allows for the monitoring of developments relevant within the German bioeconomy strategy. For example, final energy productivity and raw material input productivity are indicators of resource efficiency (DESTATIS 2019e) that are calculated at sectoral level. However, due to the high level of aggregation, these indicators are not sufficient to detect inefficient resource use within value chains. Biomass processing and steering measures to improve resource efficiency cannot be derived.

Therefore, the second monitoring scope covers material flow analysis (MFA) of relevant biomasses. In MFA, all possible modification steps of a certain biomass from production (harvest or catch) to final disposal are described and quantified. Every modification step is considered as a process and may constitute in industrial processing, manufacturing, final use, disposal or recycling (Schweinle et al. 2020). Thus, MFA provides data for evaluation of efficient use of resources and substitution of fossil resources in production, processing and manufacturing as well as use and post-use phases (Schweinle et al. 2020). Thinking along material flows helps to depict existing and possible uses and any processing of biomass, also residues and side-streams can be covered. As of today, biomass is already used in multiple ways but detailed data to quantify all used amounts in detail is not available (Bösch et al. 2015; Budzinski et al. 2017). As a starting point of a continuous monitoring and to reduce complexity, we chose to identify and quantify all material flows of biomass from agriculture, forestry and fisheries on a highly aggregated level (Figure 2.3). From all biomass uses, we selected so-called lead products for description and quantification of detailed value chains and material flows (chapter 2.5.2). Selection criteria were data availability and relevance for end use. Specific material flow data provides the basis for sustainability assessment of bio-based value chains and products and as such contributes to assessing the effects of resource substitution in a developing bioeconomy.

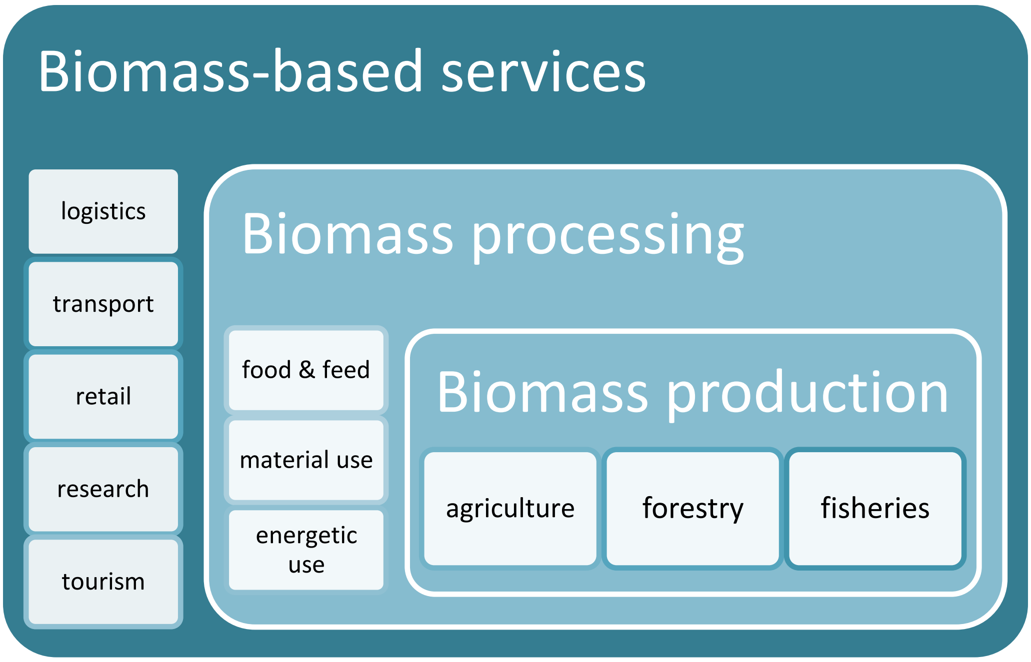
2.3 Definition and Operationalisation

Elaborating the conceptional framework and running the first cycle was based on the following definition (Iost et al. 2019): 'Bioeconomy includes the production of biomass, bio-based manufacturing along the complete value chains as well as bio-based provision of services, like transport of retail of bio-based products. "Bio-based" refers to products that fully or partially consist of renewable material resources, i.e. biomass. […] The use of bio-based products and product-related services encompasses food and feed, material, and energetic use.' This definition was operationalised by selecting economic activities as classified by NACE Rev. 2 that in some way process or convert biomass (see Iost et al. 2019). Selected economic activities are listed in Table 2.1. The underlying definition of bioeconomy includes transport and retail, but respective economic activities were not selected during operationalisation of the definition. Transport and retail are partly bio-based and existing methods for estimation their bio-based shares are only rough estimates (Efken et al. 2012).

To our understanding, at this point no data is available to calculate reliable bio-based shares. Consequently, transport and retail were not included in this first monitoring cycle. This aspect underlines that the single steps of the monitoring cycle are closely connected and that iterations between them may be necessary. As exception from the rule of including only biomass-based economic activities, we also included certain divisions of NACE sector M due to the high importance of research in the fields of biotechnology, natural and engineering sciences for the bioeconomy (BMBF 2018b).

Figure 2.2 assigns general economic activities to production and processing of biomass and biomass-based services and Table 2.1 gives more detail on the selected economic activities. Together, they illustrate the chosen definition of bioeconomy. Different national strategies basically include the same economic sectors into their respective bioeconomy definitions (Besi and McCormick 2015; Staffas et al. 2013). However, there are still different perceptions of bioeconomy which result in the attribution of varying sector and economic activities to bioeconomy. An example is the Spanish bioeconomy strategy. There, contrary to other national strategies, “uses and services linked to ecosystems, ranging from harvesting activities to tourism and leisure” are included in the definition bioeconomy, as especially tourism has a potential for generating jobs and value added (MINECO 2016, p. 12). Against this background and in order to be able to compare monitoring results in Germany to other countries, at the beginning of every monitoring cycle (Figure 2.1), the underlying definition of bioeconomy should be revised as societal, political and market conditions as well as objectives related to bioeconomy may have further developed and changed.

Figure 2.2: Proposed definition scheme of bioeconomy



Source:own illustration based on Iost et al. (2019)

Table 2.1: Selected economic activities for quantification and sustainability assessment of the bioeconomy

Section	Description	Bio-based share	Data source
A	Agriculture, Forestry, Fisheries	100 %	
C	Manufacturing	Bio-based inputs into economic activities	Material and Goods Received Enquiry; Production Statistics
D	Electricity, gas, steam and air conditioning supply	Use of biomass related to all energy sources	Official data from environmental accounting (DESTATIS 2018j)
F	Construction		
41.20.1 & 41.20.2	Construction of residential and non-residential buildings (except prefabricated constructions) & Assembly and erection of prefabricated constructions	Wood construction share	Official data on construction permits (DESTATIS 2018b)
43.32.0 & 43.91.2	Joinery installation & Erection of frames and constructional timber works	100 %	(COM 1999)
I	Accommodation and food service activities		
56.1 – 3	Food and beverage service activities	100 %	Own assumption
M	Professional, scientific and technical activities		
72.11.0	Research and experimental development on biotechnology	100 %	Own assumption
72.19.0	Other research and experimental development on natural sciences and engineering	Expenses for natural and agricultural sciences	Official data on public sector expenses (DESTATIS 2016a)

Source: own illustration based on Iost et al. (2019)

2.4 Material Flows

Understanding and quantifying material flows are the foundation for comprehending the processing of biomass along value chains and final biomass uses, which also provides the basis for sustainability assessment. In the following subchapters, we first present an aggregated material flow which differentiates only biomass according to its origin in agriculture, forestry and fisheries including aquaculture. In chapters 2.4.2 to 2.4.4, we show different material flows in more detail and discuss available data and existing data gaps.

2.4.1 Overview

In material flows, the following **terms** will be used:

Domestic production: biomass that is produced in Germany; forest biomass includes roundwood (fellings), residues as well as recovered wood and paper. Aquatic biomass includes catches of the sea fishery and freshwater fishery and production in aquaculture.

Supply: is calculated as the sum of domestic production, imports and decrease in stocks, minus exports and decreases in stocks/ comprises domestic production, net imports.

Domestic consumption: use in Germany either as food or feed, for material or energetic purposes, or increase in stocks.

Raw materials refer to feedstock or unprocessed materials that are used to produce semi-finished and finished goods. Raw material from forests usually refers to felled logs. Aquatic biomass includes fish at most headed or gutted, unshelled crustaceans and bivalves at most boiled.

Semi-finished products refer to a product that has not been completely assembled or manufactured. Semi-finished or intermediate products are used as inputs in the production of other goods, such as flour which is either consumed by private households or used as an input in the baking industry. Aquatic semi-finished products include fillets, flaps and fish meat, as well as parts of crustaceans. Sawn wood is an example for a wood-based semi-finished product.

Finished products, also referred to as final or consumer goods, are consumed to satisfy current wants or needs and are not further used as inputs to produce other goods. Examples for wood-based finished products are furniture, paper or viscose textiles. Furthermore, also sawn wood sold in building supplies stores constitutes a finished product. Aquatic biomass includes smoked and/or dried products, prepared products e.g. fish canes and marinades, breadcrumb coated fillets, fish or crustaceans-based ready meals, fishmeal and oil. For food, a strict separation between intermediate (semi-finished) and final (finished) products often does not seem possible. For example, a product such as wheat flour is used in both ways, as an intermediate good in bakeries as well as a product used by private households. Other final food products are processed meat, sausages, cheese, butter, vegetable oil or jam and chocolate.

Figure 2.3 shows the aggregated material flow for all relevant agricultural, forest and aquatic biomass in million tonnes dry matter (million t). From production (top), biomass is processed and finally used either as food and feed, for material or energetic purposes (bottom). Imports (left) and exports (right) of raw materials and products on different processing levels are integrated in the material flow. In the Sankey diagram, material flows are shown in proportion to their quantity. In comparison to material flows of forest and agricultural biomass, aquatic material flows are very small and would not be visible if displayed in their true amount. Thus, they are shown slightly inflated which may result in imbalances between in- and output flows. Attributed labels indicate the correct size.

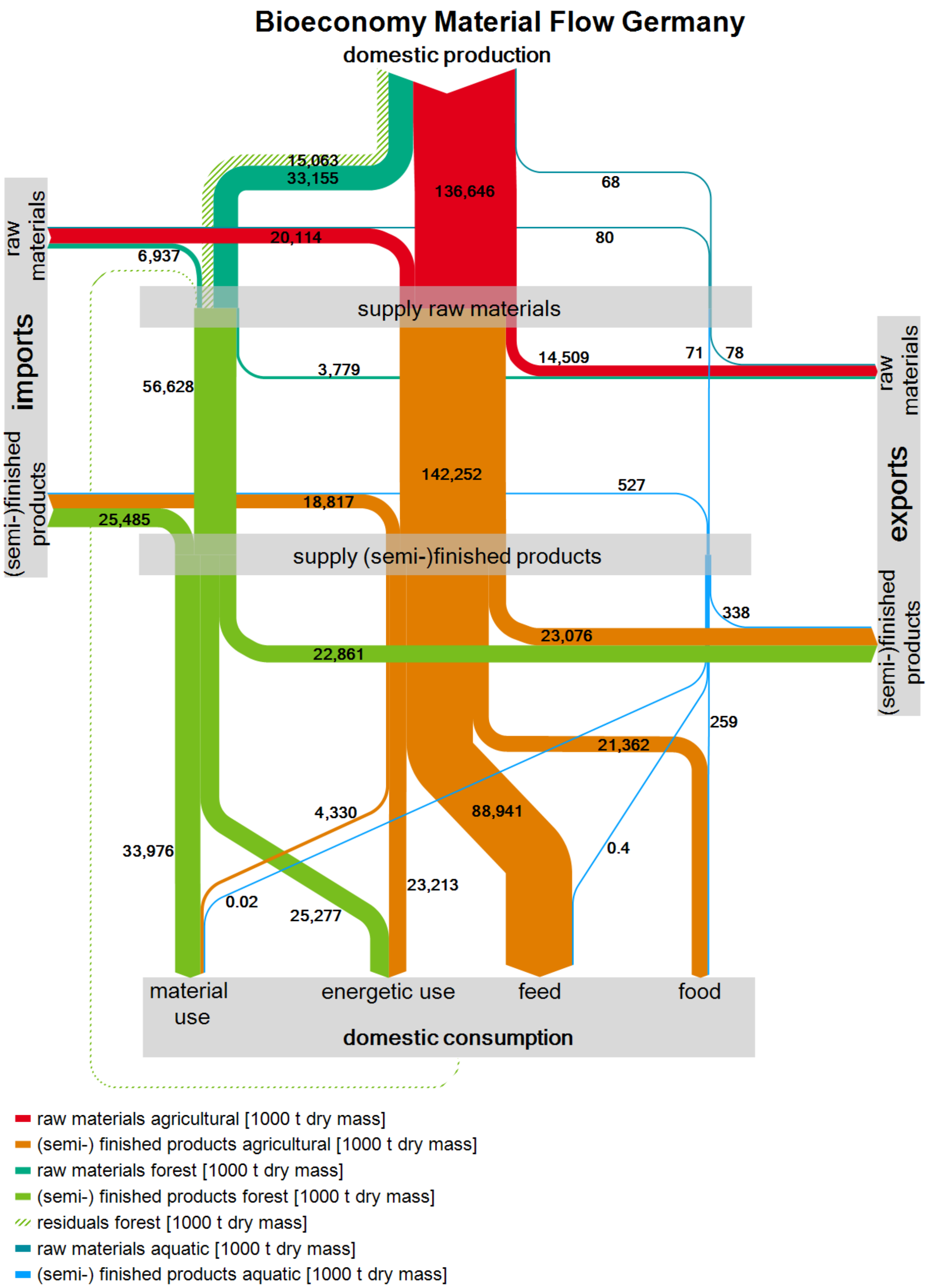
In 2015, the domestic production of biomass amounted to 184.9 million t. Agriculture contributed the largest share (136.3 million t) and forestry produced 48.2 million t. By far, fisheries and aquaculture produced the smallest part (0.068 million t).

The supply of forest biomass includes two types of residues related to forest biomass: recovered paper (ca. 10 million t) and recovered wood (ca. 5 million t). In Germany, both, recovered paper and wood are important raw material sources. Their amount constitutes about one third of the domestic production of wood-based raw materials. Recovered paper and wood are also important traded goods. However, in the aggregated material flow, these imports are summarized under imports and exports of (semi-)finished products, due to the structure and availability of trade data. The integration of such residue and recycling streams into main material flows remains a challenge that must be tackled in a future monitoring.

Imports considerably contribute to total supply with biomass. For forest biomass types, roundwood and felling residues imports are estimated at 6.94 million t, which amounts to 19.1 % of the supply with roundwood and residues (36.3 million t). The percentage of imports in relation to supply for agriculture is slightly higher (14.1 %, 20.1 million t). For aquatic biomass, the share of imports of supply amounts to 113 % (80.3 million t), i.e. more than half of the supply is provided by imports. Imports exceed domestic production. Total exports of raw materials amount to 3.8 million t, 14.5 million t and 77,676 t for forest, agricultural and aquatic biomass, respectively. Consequently, Germany is a net importer of biomass in all sectors, the self-sufficiency rate in 2015 was 24 % (BLE 2015a). Concerning imports and exports, fisheries play a special role. Imports and exports are each higher than domestic production. German consumers prefer Alaska pollock, salmon and tuna, these species are not caught by the German fleet and therefore have to be imported. In contrast, herring, mackerel and blue whiting are the main species of the German fleet. Mackerel and blue whiting are exported as demand is much lower than the domestic production. The German high seas fleet, accounting for more than half of the total catch, lands most of the catches in Dutch and Danish harbours which are trading or processing centres (BLE 2015a). These landings abroad count as export.

Final consumption of agricultural products is dominated by feed (65 %) which is more than four times the amount of agricultural products used as feed (15 %). Slightly more agricultural products are used for energetic purposes (17 %). Material uses of agricultural products can almost be neglected (3 %). However, in a developing bioeconomy, material uses are supposed to increase their share; therefore, they need careful monitoring. Timber and wood products are either used for material (57 %) or energetic uses (43 %). They are not used as food or feed in amounts that can be detected in the data sources used for this study.

Figure 2.3: Aggregated material flow of agricultural, forest and aquatic biomass in 2015



Source: own illustration

2.4.2 Agricultural Biomass

2.4.2.1 Introduction

Important core objectives of the German Bioeconomy Policy Strategy (BMEL 2014) are, on the one hand, to ensure the supply of the German population with high-quality food and, on the other hand, to secure the supply of sustainably produced, renewable raw materials for material and energetic use. The agricultural sector is the area in which all four possible uses of bio-based and renewable raw materials – (1) food, (2) animal feed, (3) material uses and (4) energetic uses – are produced in relevant quantities. Material flow analyses are, therefore, an important instrument for the agricultural sector to visualise the biogenic material flows of agricultural raw materials in Germany from primary production to the final use of products containing agricultural raw materials. Such a visualisation of agricultural material flows creates transparency and shows interrelationships as well as possible future starting points for the support of the bioeconomy.

In accordance with the main products and crop groups presented in German agricultural statistics, the following seven material flows in the field of crop production are particularly relevant for the agricultural sector:

- Cereals,
- Sugar,
- Vegetable oils and fats,
- Legumes,
- Potatoes,
- Fruit and vegetables,
- Plant-based fodder.

In the field of animal production there are three material flows:

- Milk,
- Meat,
- Eggs.

In addition, six further summarizing material flows are considered relevant for a bioeconomic analysis in the agricultural sector:

- Biomass for energetic use,
- Starch for material use,

- Oils and fats for the chemical industry,
- Sugar for chemical-technical industries,
- Plant fibres for textile production
- as well as a material flow for agricultural residues and waste materials.

Within the framework of the pilot project on monitoring the German bioeconomy, a total of 16 material flows were, therefore, compiled for the agricultural sector.

For the compilation of these material flows, different data sources with also different grade of data quality have been used. When merging data from different sources, the focus is on checking the plausibility of data to be merged. In addition, however, data gaps and the need for supplementary data collection become apparent. Due to the importance of the data source (source origin), a uniform presentation structure (bioeconomic material flow model agriculture) was developed for the agricultural sector, which focuses on the information on the data origin in addition to the various main uses of agricultural raw materials and their by-products.

Figure 2.4 shows the general principle of the material flow model of agriculture to illustrate the general structure of the agricultural material flows in the bioeconomy. All domestic processes in Germany are shown within the light grey, centrally positioned square. On the vertical axis, this square shows the sequence of processes: (1) Domestic production of agricultural raw materials (primary production); (2) Domestic production of the first processing stage; (3) Domestic production from the second processing stage onwards and (4) Domestic use of agricultural raw materials and agricultural products (final consumption). In the horizontal axis, the imports and exports of agricultural raw materials, agricultural products of the 1st processing stage and products of higher processing stages are shown in three nodes by inflows and outflows. The dotted connecting arrows between the process points show possible material flow flows.[1] As indicated for the figures below, the sums of used material often do not sum up completely which is mainly due to conversion coefficients between different stages of processing. Another reason for this kind of 'incompleteness' in monitoring the flow of agricultural biomass is due to the fact that not all inputs are 'marketed' intermediate inputs, e.g. farm-based feed grain production used to fatten pigs.

It is expected that the application of this uniform material flow model for agriculture will result in the following advantages: (a) an immediate recognition of the data origin, data gaps and the main utilisation paths of agricultural raw materials and products; (b) a quick assessment of the data quality, plausibility and a possible potential of by-products and residual material utilisation; as well as (c) an optimal orientation within the agricultural material flows and the identification of interrelationships between different material flows.

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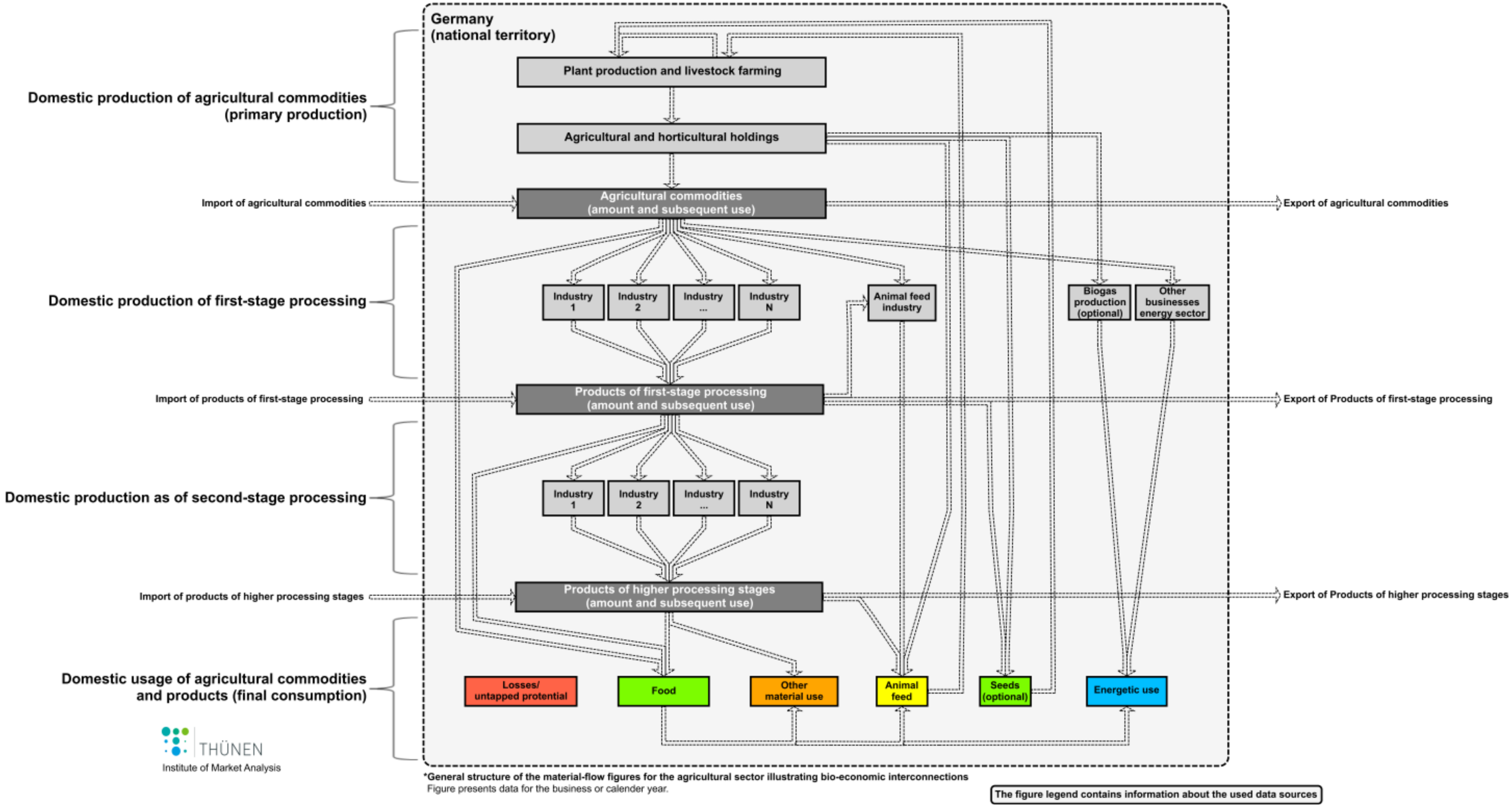
[1] Due to the fact that agricultural products at 1st processing stage are often already used for final consumption, we deviate from the word 'semi-final' or intermediate products.

Figure 2.4: Model of Material Flow: Agricultural



Source: own illustration

The data for the 16 agricultural commodity flows come from different official data sources. Extensive and regularly collected official statistics are available for the agricultural sector.

(1) For data on foreign trade, all material flow charts build on data published by DESTATIS. For German foreign trade in agricultural raw materials and products, additional data queries were also compiled on the base of Eurostat (COMEXT) data in combination with balance sheet weighting factors for the conversion of processed stages into main product quantities.
(2) For the production data at the level of raw agricultural products, the main data sources are the official statistics published by the Federal Agency for Agriculture and Food (BLE) and DESTATIS.
(3) For first stage processing data, the use of raw material is derived from data of the Marktordnungswaren-Meldeverordnung (MVO). This data is published by DESTATIS in close collaboration with the BLE.
(4) For higher stages of processing, data bases become very ‘product-specific’ and have to be derived from various sources of official and commercial statistics.

In addition to official statistics and market balance data published by the Agricultural Market Information Company (AMI) the material balances published here also contain data published by Producer Associations. Data published in various studies, e.g. AGBioRestMon on the recycling of residues were also used to compile the flows of agricultural commodities. The basis for the allocation of the domestic use of agricultural raw materials are national supply balances, which are compiled and published by the BLE on annual base for various balance groups.

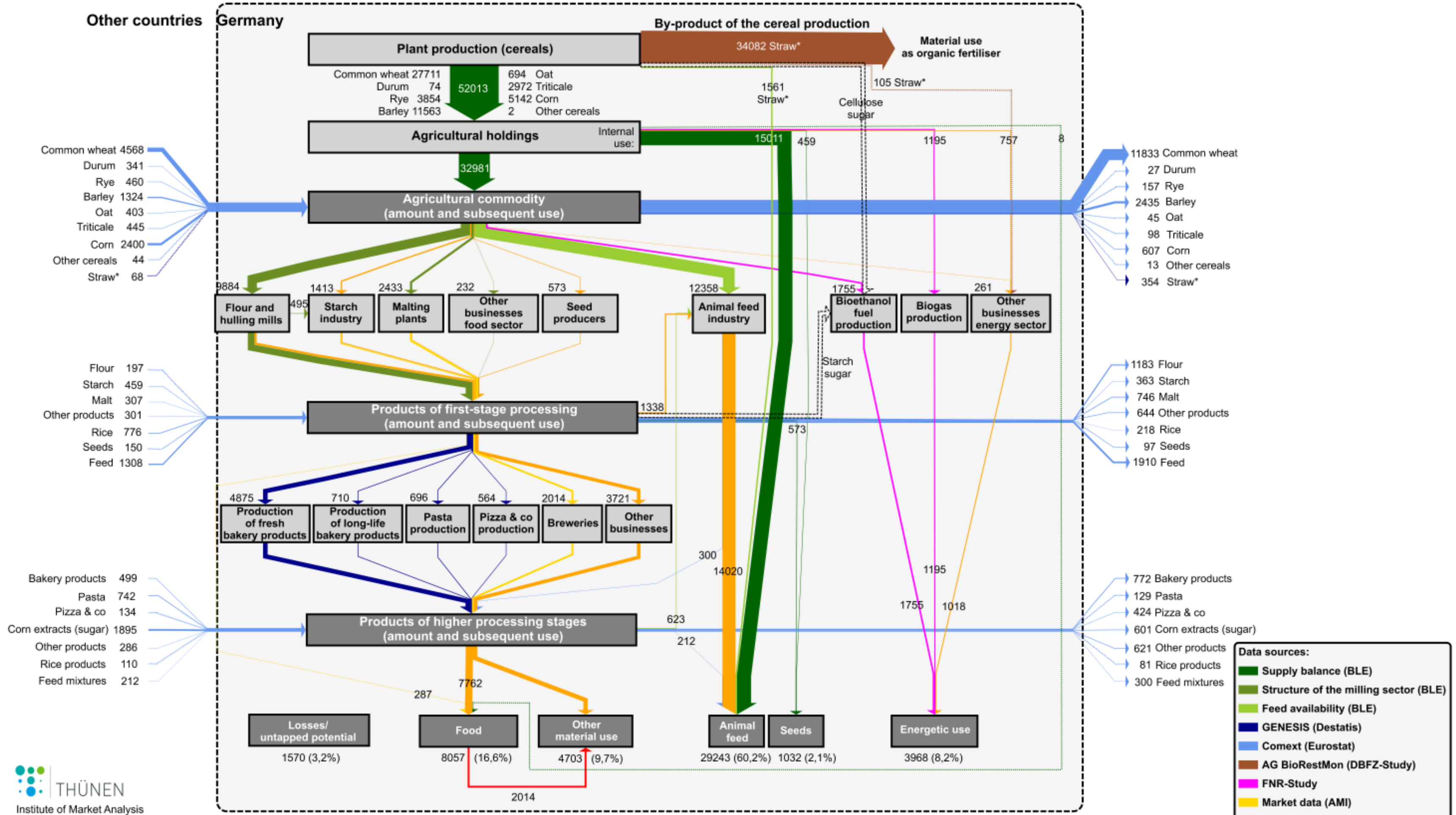
Reference year: Depending on the presented agricultural raw material, annual agricultural statistics refer either to marketing or calendar years. Marketing years are mainly applied in the area of crop production while livestock production often refers to calendar years. In the following, the 16 material flows for the agricultural sector based on the material flow model refer either to the 2014/15 marketing year or to the calendar year 2015. In addition to the individual material flows and their description, the data sources used for the compilation of the material flow as well as for the bioeconomy relevant linkages or connections to material flows are listed.

2.4.2.2 Material Flow Crop Production

Cereals (2014/15 marketing year)

Following the arrows in Figure 2.5 which are proportional to volume, 17 % of the agricultural raw material grain has been used as food in the 2014/15 economic year. In addition, however, 60 % of the grain was used as animal feed for processing, 2 % was used as seed, 10 % was material, i.e. non-food-feed-seed uses, and 8 % was energetic uses.

Figure 2.5: Material Flow Cereals



Data for the business year 2014/15 (01.07.2014 to 30.06.2015)
Quantities: 1.000 t cereals or cereal equals; quantities under 200 with dotted line
*Quantities of straw in 1.000 t product quantity
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Supply balance for cereals marketing year 2014/15 (BLE 2017c)
- Structure of the milling industry 2015 (BLE 2017c)
- Feed supply in the 2014/15 marketing year (BLE 2016a)
- GENESIS, production survey and foreign trade statistics (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Study AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- AMI market balance sheet Cereals, Oilseeds, Animal feed 2018 (AMI 2018b)
- AMI Market Report Consumer Research 2018 (AMI 2018f)

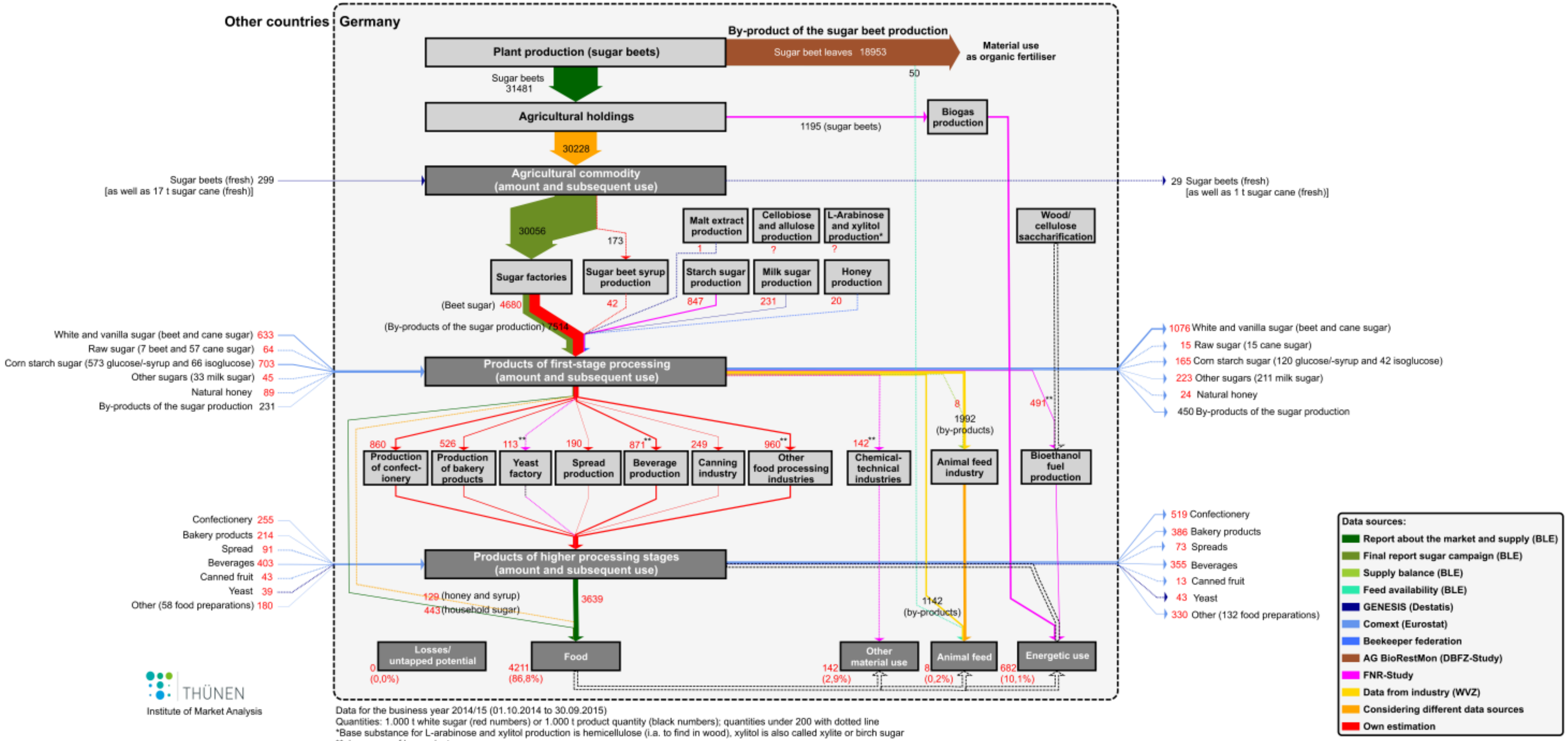
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flows milk, meat and eggs (processing industry) through use as animal feed
- Connection to the material flow starch for material use
- Linkage with material flow potato via starch industry
- Connection to the sugar material flow via the production of starch sugars
- Linkage with material flow of sugar and potatoes for bioethanol fuel production
- Linkages with the material flow of agricultural residues and waste materials

Sugar (2014/15 marketing year)

For sugar, a different distribution in end use resulted compared to the material flow of grain (Figure 2.6). The majority of the sugar produced (87 %) was used as food in the 2014/15 marketing year. Only small quantities of sugar (< 1 %) were used in the compound feed industry. By-products of sugar production were mainly used as animal feed. In 2014/15, 3 % of the sugar volume was used for "material uses" and 10 % for "energetic uses" (almost exclusively for bioethanol fuel production).

Figure 2.6: Material Flow Sugar



Data for the business year 2014/15 (01.10.2014 to 30.09.2015)
Quantities: 1.000 t white sugar (red numbers) or 1.000 t product quantity (black numbers); quantities under 200 with dotted line
*Base substance for L-arabinose and xylitol production is hemicellulose (i.a. to find in wood), xylitol is also called xylite or birch sugar
**also usage of by-products
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for sugar (BLE 2017g)
- Final report sugar campaign 2014/2015 (BLE 2015b)
- Feed supply in the 2014/15 marketing year (BLE 2016a)
- Structure of compound feed producers (BLE 2017h)
- production survey and foreign trade statistics (DESTATIS 2020c)
- Fachserie 3, Series 3.2.1, Crops 2015 (DESTATIS 2015b)
- COMEXT (EUROSTAT 2020b)
- Final sugar production of marketing year 2014/2015 (Europäische Kommission 2020)
- CEFS Sugar Statistics (CEFS 2019)
- Study AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Annual report published by WVZ (WVZ 2020)
- Sugar Industry Europe 2018 (Bruhns 2019)
- Data published by (VGMS 2020)
- German Beekeepers' Association (Deutscher Imkerbund 2015)

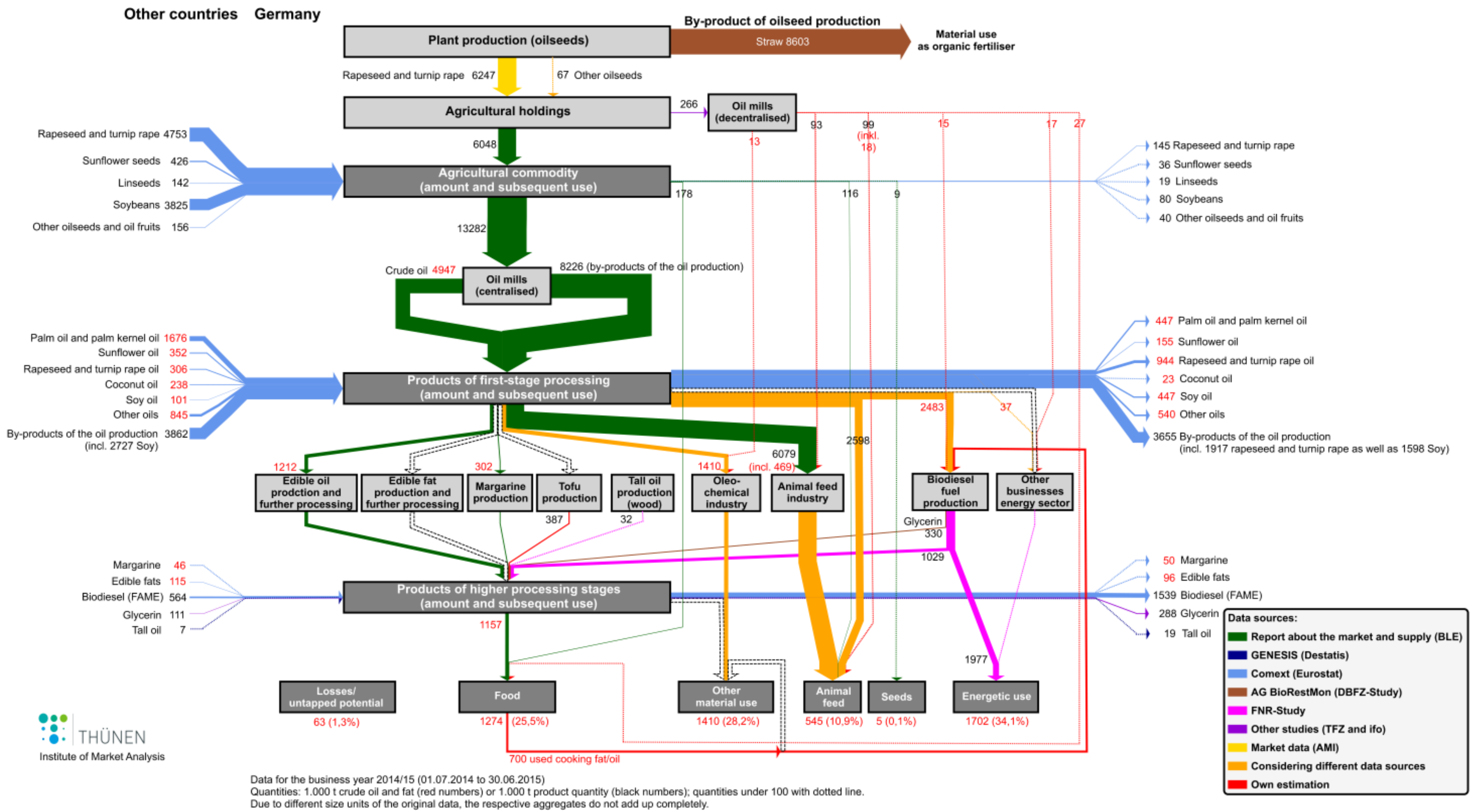
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flows of the processing industry through the use of by-products as animal feed
- Linked to material flows (including cereals, potatoes, milk, wood) via production of other types of sugar, e.g. starch and lactose, malt extract, L-arabinose and xylitol
- Connection to the sugar material flow for chemical-technical industries
- Linkage with material flow of grain and potatoes for the production of bioethanol fuel
- Linkages with the material flow of agricultural residues and waste materials

Vegetable Oils and Fats (2014/15 marketing year)

Compared to the presentation of the two previous material flows for cereals and sugar, the material flow for vegetable oils and fats describes a completely different situation with regard to end use (Figure 2.7). For this agricultural balance group, the import volumes in the 2014/15 marketing year were higher than the domestic production volumes. In 2014/15, 26 % of vegetable oils and fats were used as food and 11 % as animal feed. In addition, vegetable oils and fats in 2014/15 were used in relevant quantities (28 %) in the oleo-chemical industry (material use) and showed their main use (34 %) in energetic use (biodiesel fuel production).

Figure 2.7: Material Flow Vegetable Oils and Fats



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation of oilseeds, oils and fat (BLE 2017f)
- Structure of compound feed producers 2013 – 2015 (BLE 2017h)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- production survey and foreign trade statistics (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Study AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Identification of economic ratios and indicators for monitoring the progress of the bioeconomy (Wackerbauer et al. 2019)
- Report published by TFZ (TFZ 2013)
- DBFZ Report 2016 (Braune et al. 2016)
- AMI – Market Review Cereals (AMI 2018b)

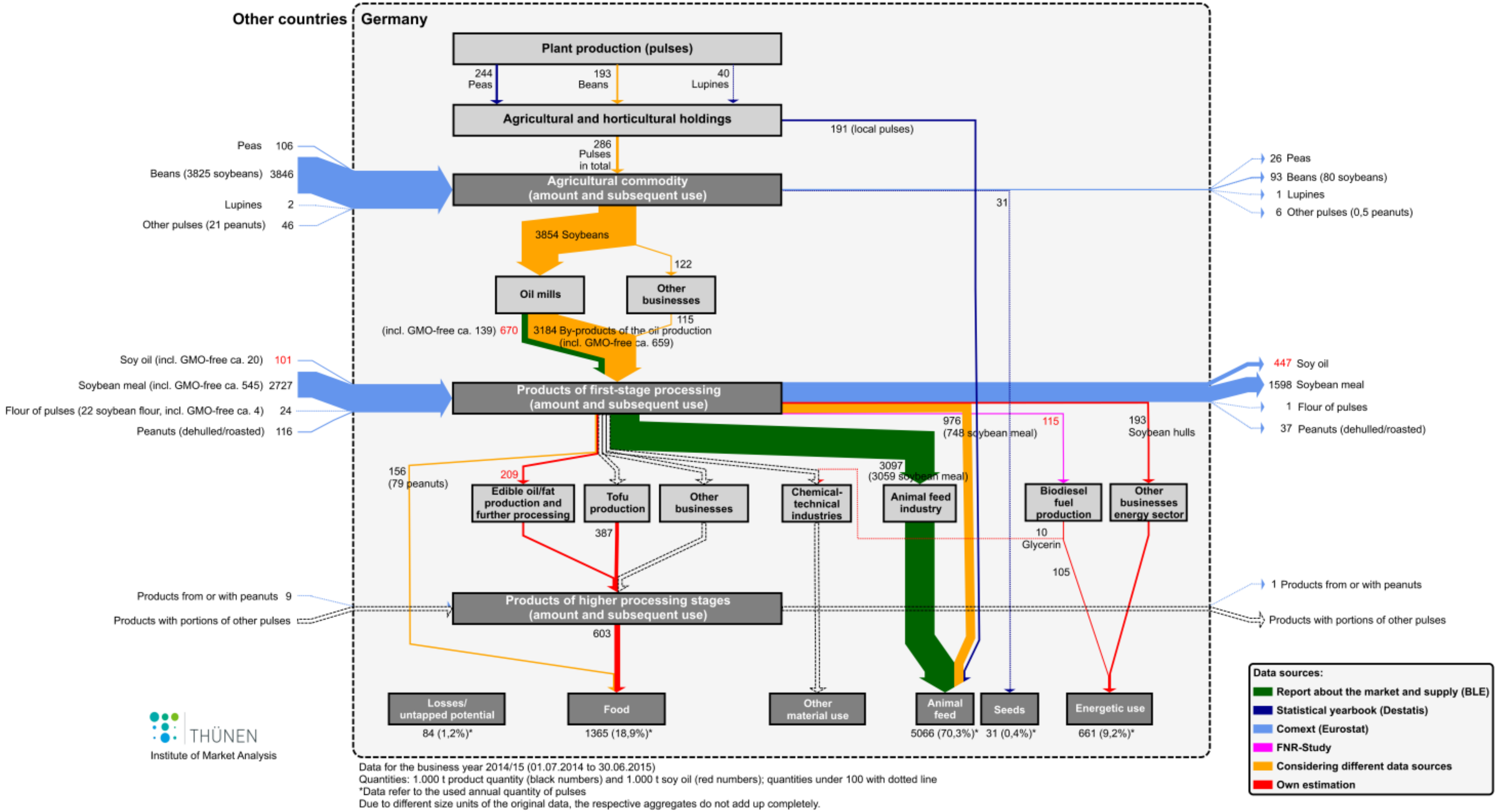
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flows of the processing industry through the use of the by-products as animal feed
- Connection to the material flow of oils and greases for the chemical industry
- Linkage with material flow meat via production slaughter animal fat to material flow oils and fats for chemical industry
- Linkage with material flow eggs in the production of mayonnaise
- Linkage via the production of tall oil to the material flow wood
- Linkages with the material flow of agricultural residues and waste materials

Legumes (2014/15 marketing year)

Due to its relevance for the German Protein Plant Strategy (BMEL 2019), Figure 2.8 shows the material flow for pulses separately. The material flow of legumes includes the material flow of soybean as well as the material flow of vegetable oils and fats. For the marketing year 2014/15, only very small quantities of pulses were cultivated in Germany. Looking at the annual quantities of pulses used, the majority (70 %) was used as animal feed in 2014/15. In 2014/15, 19 % of the annual amount was used as food. Part of the soya oil produced was also used for biodiesel production.

Figure 2.8: Material Flow Legumes



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation of oilseeds, oils and fats (BLE 2017f)
- Report on the market and supply situation for animal feed (BLE 2017b)
- Fodder volumes in the 2014/15 marketing year (BLE 2016a)
- Structure of compound feed producers 2013 – 2015 (BLE 2017h)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- Crops 2015 (DESTATIS 2015b)
- COMEXT (EUROSTAT 2020b)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- AMI Market Balance Sheet Cereals Oilseeds Animal Feed 2018 (AMI 2018b)
- Data published by OVID (OVID 2020)
- Data published by VLOG (VLOG 2019)

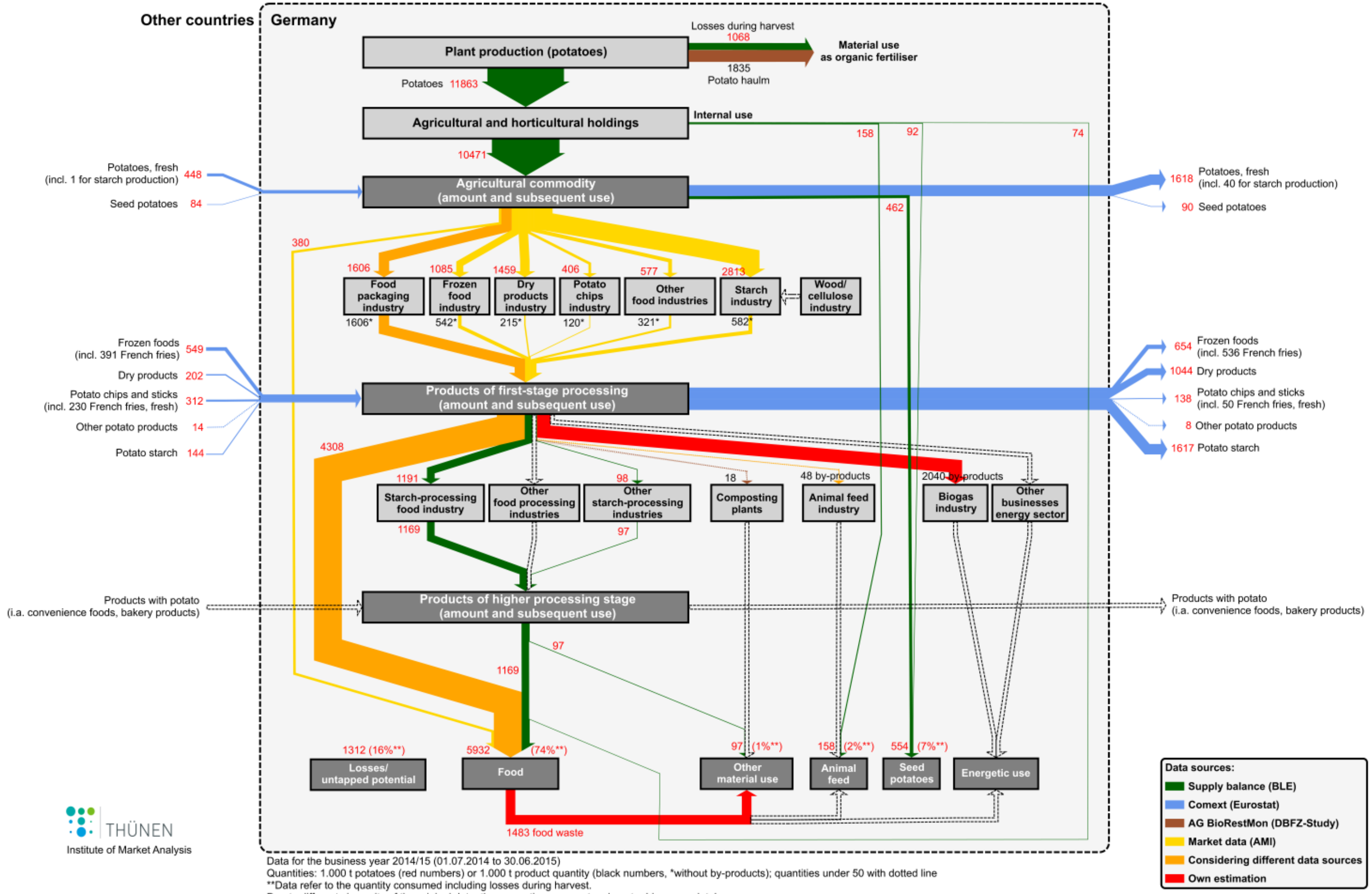
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flows of the processing industry through the use of the main and by-products as animal feed
- Linkage via the agricultural raw material soya bean to the material flow of vegetable oils and fats
- Linkages with the material flow of agricultural residues and waste materials

Potatoes (2014/15 marketing year)

The material flow for potatoes shows that the quantities consumed in Germany in the 2014/15 marketing year are mainly based on domestic production (Figure 2.9). A large part of the potato volume produced in Germany is used in the starch industry. Looking at the end use, 74 % of the available potato quantities were used as food in the 2014/15 marketing year.

Figure 2.9: Material Flow Potatoes



Data for the business year 2014/15 (01.07.2014 to 30.06.2015)
Quantities: 1.000 t potatoes (red numbers) or 1.000 t product quantity (black numbers, *without by-products); quantities under 50 with dotted line
**Data refer to the quantity consumed including losses during harvest.
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for potatoes (BLE 2017d)
- Supply balance potatoes (BLE 2019a)
- Potato starch supply balance (BLE 2019b)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- Fodder volumes in the 2014/15 marketing year (BLE 2016a)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- AMI Market Balance Sheet Potatoes 2018/19 (AMI 2018c)
- AMI Market Report Consumer Research 2018 (AMI 2018f)
- Data published by VGMS (VGMS 2020)
- Statistics published by DTI

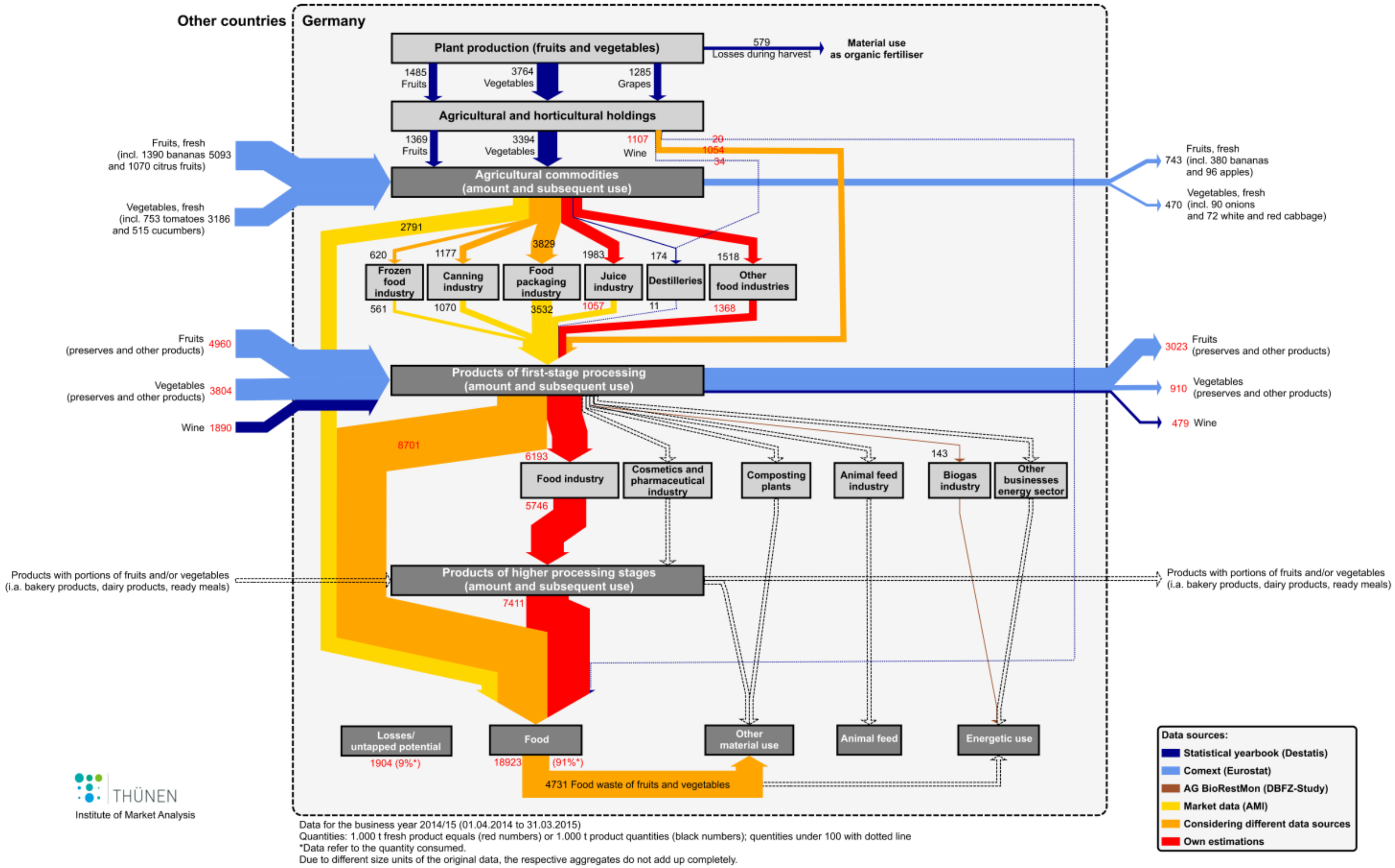
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flows of the processing industry via use as animal feed
- Linkage to the material flow starch for material use
- Linkage with material flow cereals via starch industry
- Connection to the sugar material flow via the production of starch sugars
- Linkage with material flow of grain and potatoes for the production of bioethanol fuel
- Linkages with the material flow of agricultural residues and waste materials

Fruit and Vegetable (2014/15 marketing year)

Figure 2.10 shows the material flow quantities for fruit, vegetables and grapes. For the 2014/15 marketing year, larger quantities of fruit and vegetables were imported in fresh and processed form. Similar to the case of potatoes, a large part of the quantities consumed goes to the end consumer or to the final consumer already after the first processing stage. In the 2014/15 marketing year, 91 % of the consumption quantities of fruit and vegetables were used as food. In the case of fruit and vegetables, a larger share of the consumption volume in 2014/15 ended up in waste, too.

Figure 2.10: Material Flow Fruits and Vegetables



Source: own illustration

Data sources used to compile the material flow:

- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- Vegetable survey 2015 (DESTATIS 2016b)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- AMI Market Balance Sheet Fruit 2019 (AMI 2019b)
- AMI Market Balance Sheet Vegetables 2019 (AMI 2019a)
- AMI Market Report Consumer Research 2018 (AMI 2018f)
- AMI Market Study Fruit and Vegetable Flow Analysis (AMI 2018a)
- Statistics of the German Frozen Food Institute e.V. (dti)
- Systematic collection of food waste from private households in Germany (GfK 2018)

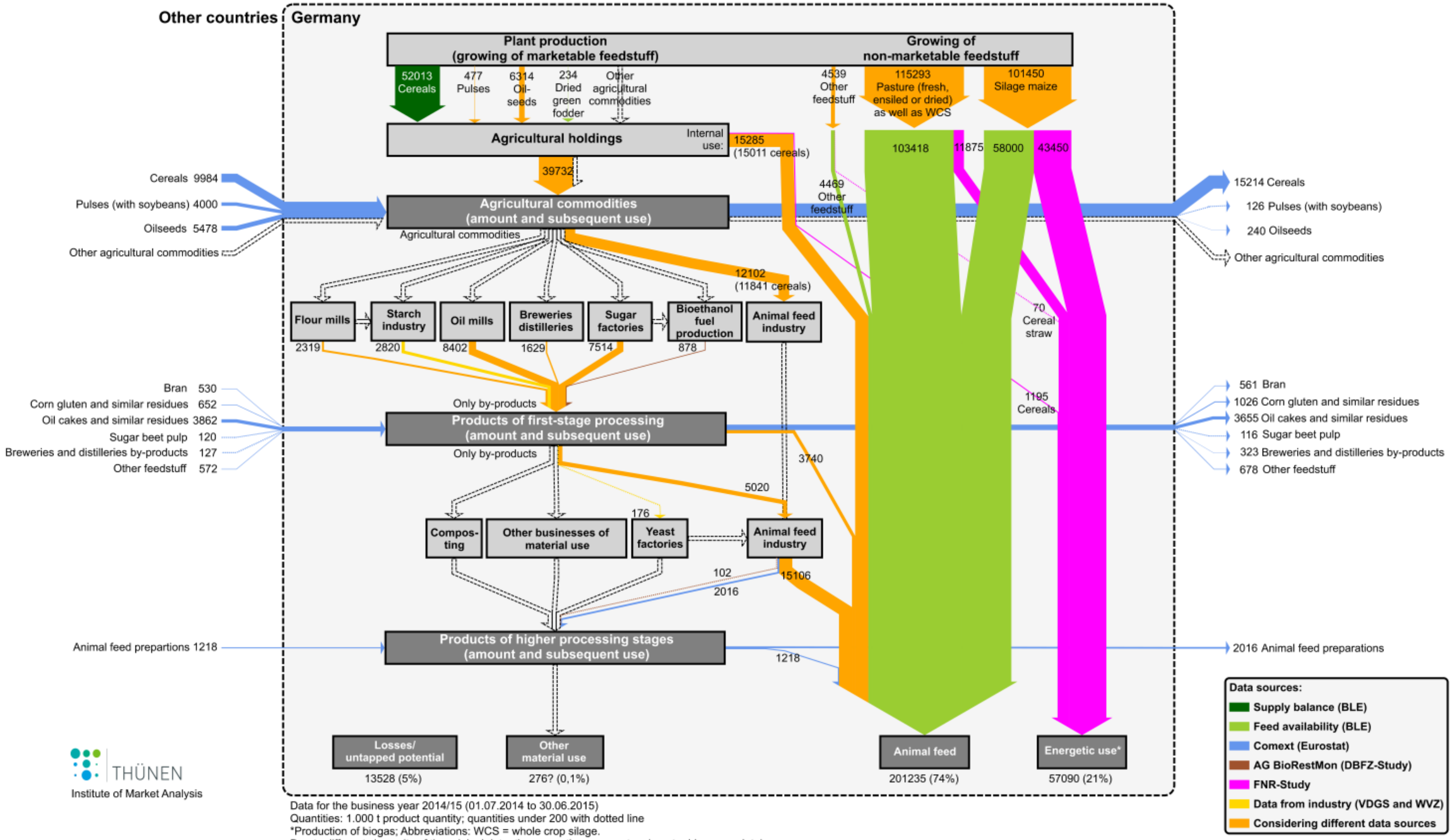
For bioeconomy relevant linkages or connections to material flows:

- Linkages with the material flow of agricultural residues and waste materials

Plant-based Feed (2014/15 marketing year)

The material flow of plant-based feed (Figure 2.11) summarizes the volume flows of marketable and non-marketable plant-based feed for Germany for the 2014/15 marketing year. The material flow shows that in 2014/15 mainly non-marketable, plant-based material was used as animal feed. A larger share of the non-marketable, plant-based animal feed (including grass and/or silage maize) was also used for energetic purposes. In the production of plant-based animal feed that is marketed, mainly by-products of first stage processing of agricultural raw materials have been used in addition to feed grain.

Figure 2.11: Material Flow Plant-based Feed



Data for the business year 2014/15 (01.07.2014 to 30.06.2015)
Quantities: 1.000 t product quantity; quantities under 200 with dotted line
*Production of biogas; Abbreviations: WCS = whole crop silage.
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Supply balance for cereals 2014/15 (BLE 2018d)
- Fodder volumes in the 2014/15 (BLE 2016a)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- Crops 2015 (DESTATIS 2015b)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Data published by VGMS (VGMS 2020)
- Data published by WVZ (WVZ 2020)

For bioeconomy relevant linkages or connections to material flows:

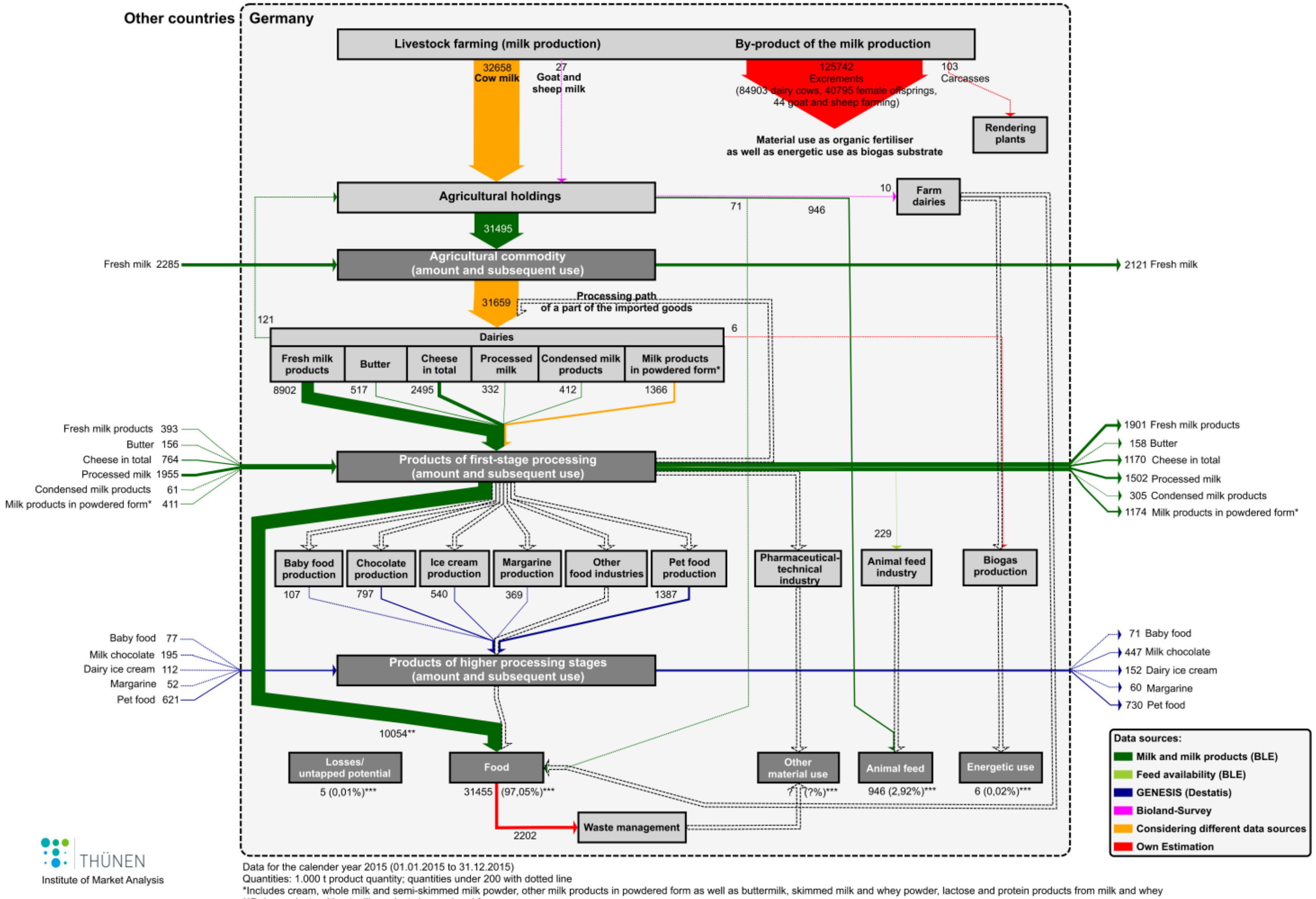
- Connection to the material flows of the processing industry via use as animal feed
- Through the use as substrate for biogas production connection to the material flow biomass for energetic use
- Linkages with the material flows cereals, pulses and vegetable oils and fats
- Linkages with the material flow of agricultural residues and waste materials

2.4.2.3 Material Flow Animal Production

Milk (2015)

Figure 2.12 shows the material flow of milk for the calendar year 2015. In addition to the quantity of milk produced, Fig. 9 shows that large quantities of animal excrement are also produced as a by-product of milk production. Animal excrements can be used as organic fertiliser or as biogas substrate. For the calendar year 2015, it was found that the majority of the milk delivered to the dairies went into the production of fresh milk products. Almost the entire quantity of raw milk (97 %) consumed in Germany in 2015 went to the food sector. Only small quantities (3 %) were used as animal feed in 2015.

Figure 2.12: Material Flow Milk



Data for the calender year 2015 (01.01.2015 to 31.12.2015)
Quantities: 1.000 t product quantity; quantities under 200 with dotted line
*Includes cream, whole milk and semi-skimmed milk powder, other milk products in powdered form as well as buttermilk, skimmed milk and whey powder, lactose and protein products from milk and whey
**Dairy products without milk products in powdered form
***Values are estimations in relation to consumed raw milk amount.
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for milk and milk products (BLE 2017e; 2018b)
- Report on the market and supply situation for animal feed (BLE 2017b)
- Feed volumes in the 2014/15 marketing year (BLE 2016a)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- Corporate structure of the dairy industry Germany (BLE 2018c)
- GENESIS (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- AMI Market Balance Sheet Milk 2018 (AMI 2018d)
- AMI Market Balance sheet Cereals, Oilseeds, Animal feed 2018 (AMI 2018b)
- System analysis of sheep and goat milk production in Germany (Manek et al. 2017)
- Calculation of storage space for liquid manure and stable manure for livestock farms (LfL 2019)
- Facts Milk (MIV 2017)

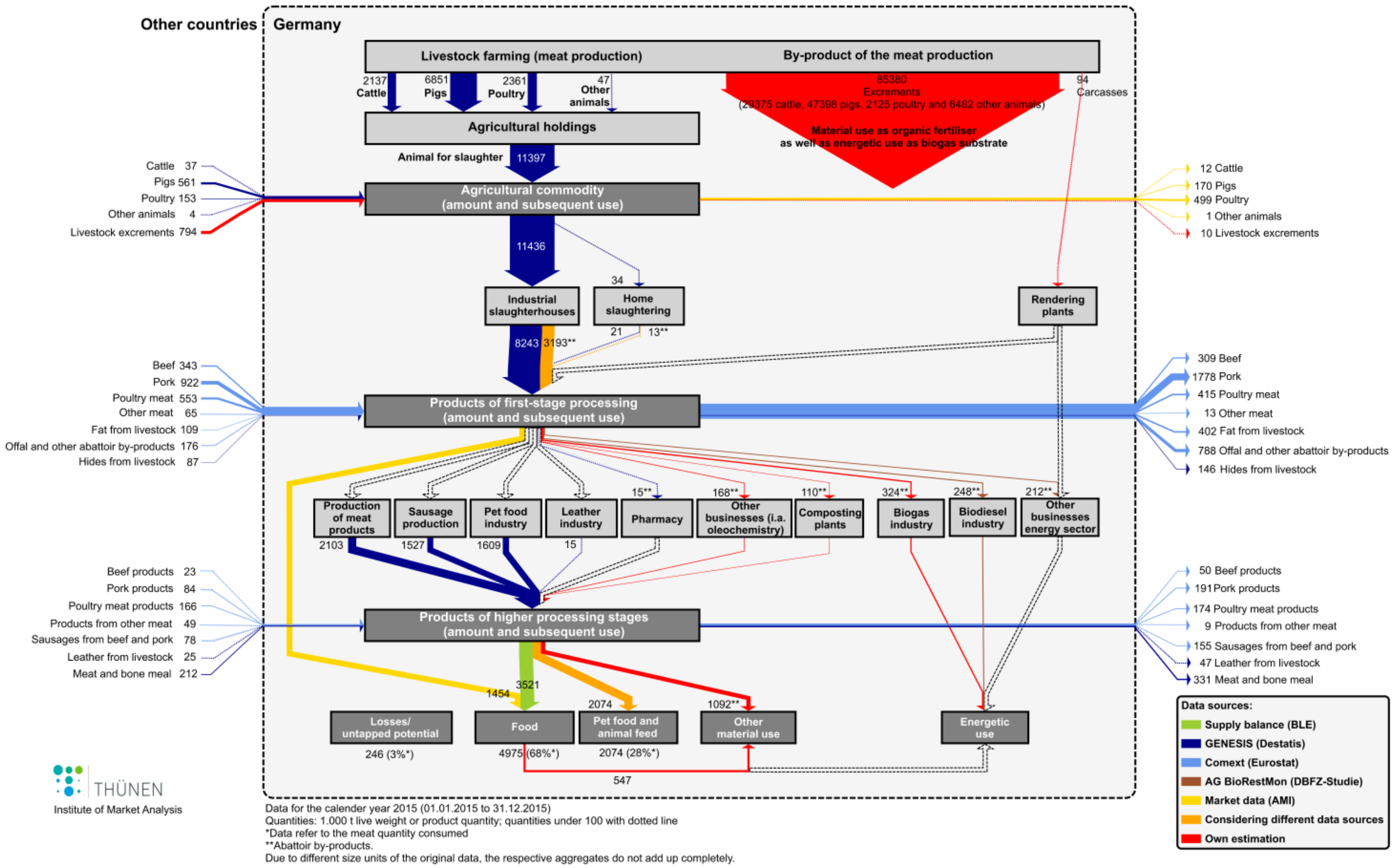
For bioeconomy relevant linkages or connections to material flows:

- Connection to all other agricultural material flows of plant production through the use of the main and by-products as animal feed
- Connection to the sugar material flow via the production of lactose
- Linkage with the meat material flow in the slaughter of dairy animals
- Linkages with the material flow of agricultural residues and waste materials

Meat (2015)

The material flow meat (Figure 2.13) also clearly shows that in the calendar year 2015, as a by-product of animal husbandry, large quantities of animal excrement were produced. Pigs account for the largest share of the quantities delivered to domestic slaughterhouses. A part of the domestically produced meat (especially pork) was exported in 2015. Significant quantities were also used as animal feed for pets in 2015. However, the largest share of the domestic consumption of meat was used as food in 2015.

Figure 2.13: Material Flow Meat



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for meat 2018 (BLE 2018a)
- Supply of meat in Germany since 1991 (BLE 2020a)
- Supply balance for poultry meat by poultry species since 1991 (BLE 2020b)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- GENESIS (DESTATIS 2020c)
- Livestock and animal production 2015 (DESTATIS 2016d)
- Manure of animal origin in agricultural holdings (DESTATIS 2017f)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- AMI Market Balance Sheet Livestock and Meat 2018 (AMI 2018e)
- AMI Market Report Consumer Research 2018 (AMI 2018f)
- Determination of the quantities of food thrown away and proposals for reducing the rate of food waste in Germany (Hafner et al. 2012)
- Meat Atlas Extra: Waste and Wasting (Heinrich-Böll-Stiftung 2014)
- Calculation of storage space for liquid manure and stable manure for livestock farms (LfL 2019)

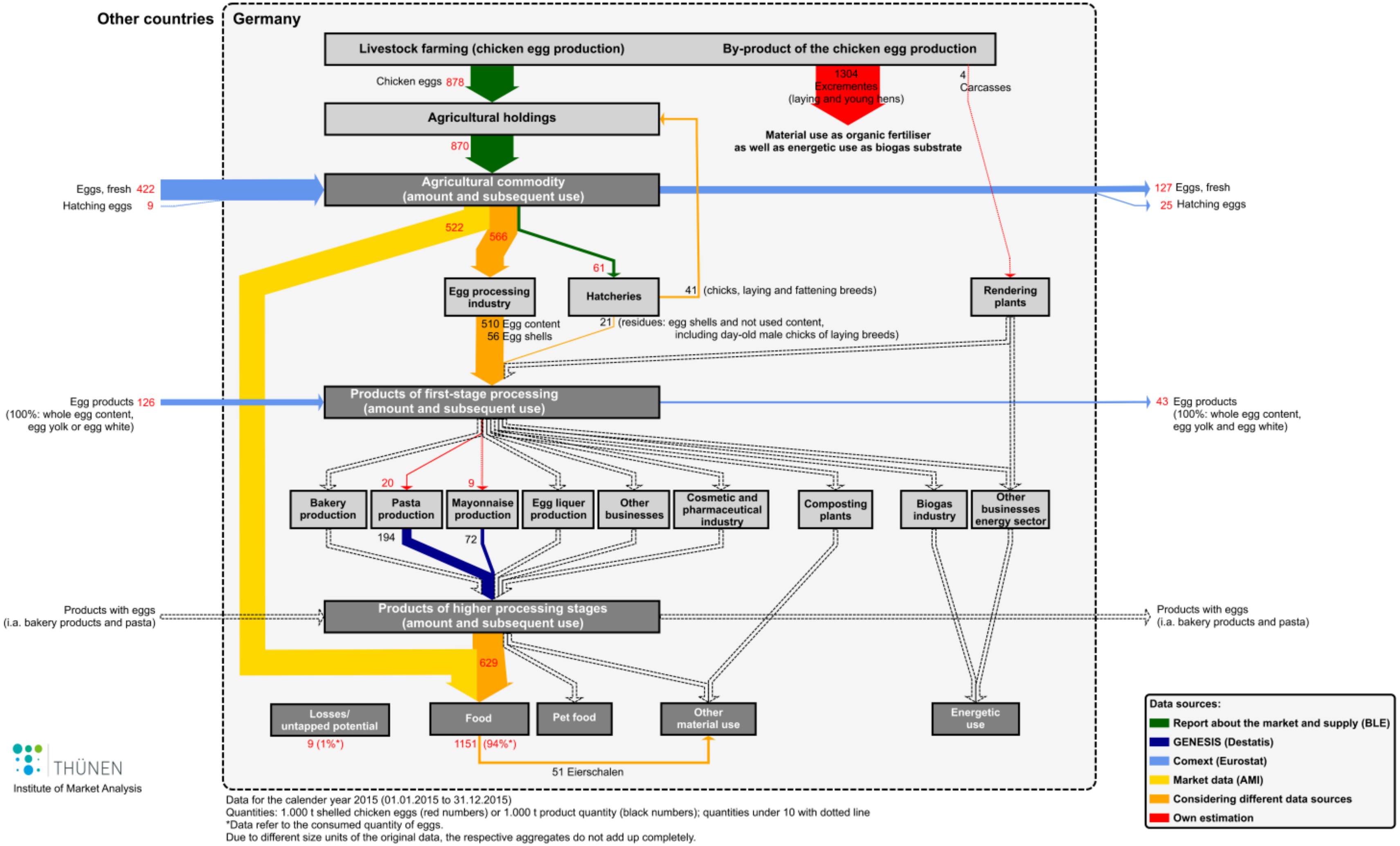
For bioeconomy relevant linkages or connections to material flows:

- Connection to all other agricultural material flows of plant production through the use of the main and by-products as animal feed
- Linkage with material flow of milk due to possible slaughter of milk production animals
- Connection to the material flow vegetable oils and fats via the material flow oils and fats for the chemical industry
- Linkages with the material flow of agricultural residues and waste materials

Eggs (2015)

Figure 2.14 shows the material flow volumes in Germany for hen's eggs in the calendar year 2015. In 2015, approximately 2/3 of the domestic consumption volume came from domestic production and 1/3 from foreign production. Almost half of the domestic consumption of hen's eggs reached the end user unprocessed. Almost the entire amount of domestic consumption of hen's eggs (94 %) went to the food sector in 2015.

Figure 2.14: Material Flow Eggs



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for eggs (BLE 2017a)
- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- GENESIS (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- AMI Market Report Consumer Research 2018 (AMI 2018f)
- Calculation of storage space for liquid manure and stable manure for livestock farms (LfL 2019)

For bioeconomy relevant linkages or connections to material flows:

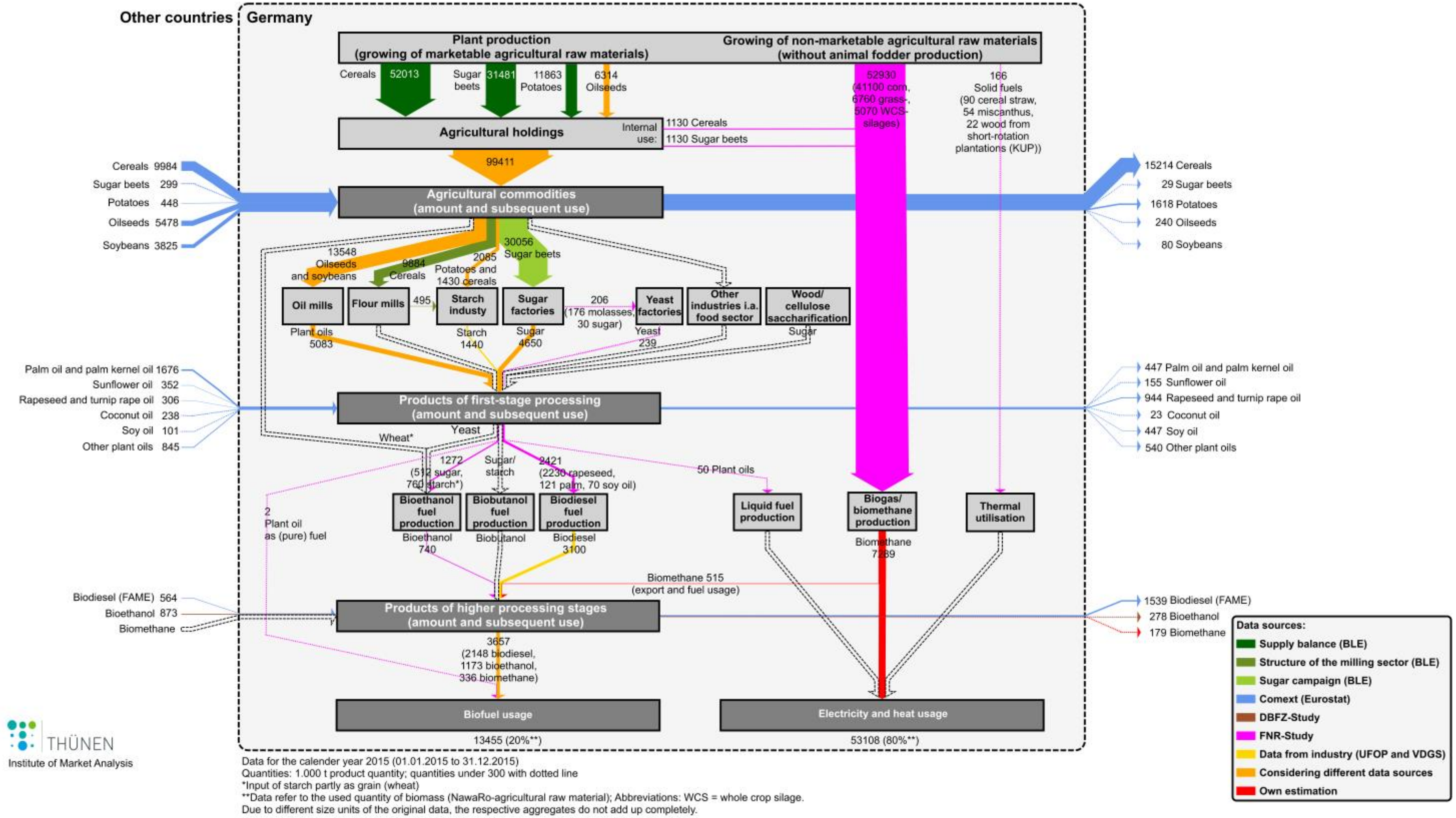
- Connection to all other agricultural material flows of plant production through the use of the main and by-products as animal feed
- Linkage with material flow of meat at slaughter of animals of the chicken egg production
- Linkage with material flow cereals in bakery and pasta production
- Linkage with material flow vegetable oils and fats in the production of mayonnaise
- Linkages with the material flow of agricultural residues and waste materials

2.4.2.4 Summarizing Material Flows

Biomass for Energetic Use (2015)

Figure 2.15 summarizes the volume flows of biomass that went into energetic use in the calendar year 2015. A distinction was made between biofuel use and electricity/heat use in terms of end use. The raw materials for biofuel use are sugar or starch (bioethanol and bio-butanol production) and oils (biodiesel production). However, vegetable oils can also be used as fuel directly or for liquid fuel (diesel) production. Marketable agricultural raw materials are used for biofuel production while non-marketable agricultural raw materials are mainly used for electricity/heat production. In biogas/bio-methane production, silage is used while solid fuel sources such as cereal straw, miscanthus and biomass from short-rotation coppice (SRC) are used for thermal utilization.

Figure 2.15: Material Flow Biomass for Energetic Use



Source: own illustration

Data sources used to compile the material flow:

- Supply balances (BLE 2018d, 2019b)
- Structure of compound feed producers (BLE 2017h)
- Final report sugar campaign 2014/2015 (BLE 2015b)
- GENESIS (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Monitoring the biofuel sector (Naumann et al. 2019)
- Biogas and bio-methane plant stock - biogas production and use in Germany (Daniel-Gromke et al. 2017)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Basic data Bioenergy Germany (FNR 2018b)
- Report: Biodiesel 2016/2017 (UFOP 2016)
- Data published by VGMS (VGMS 2020)
- Database: Biogas yields of various substrates (LfL 2020)

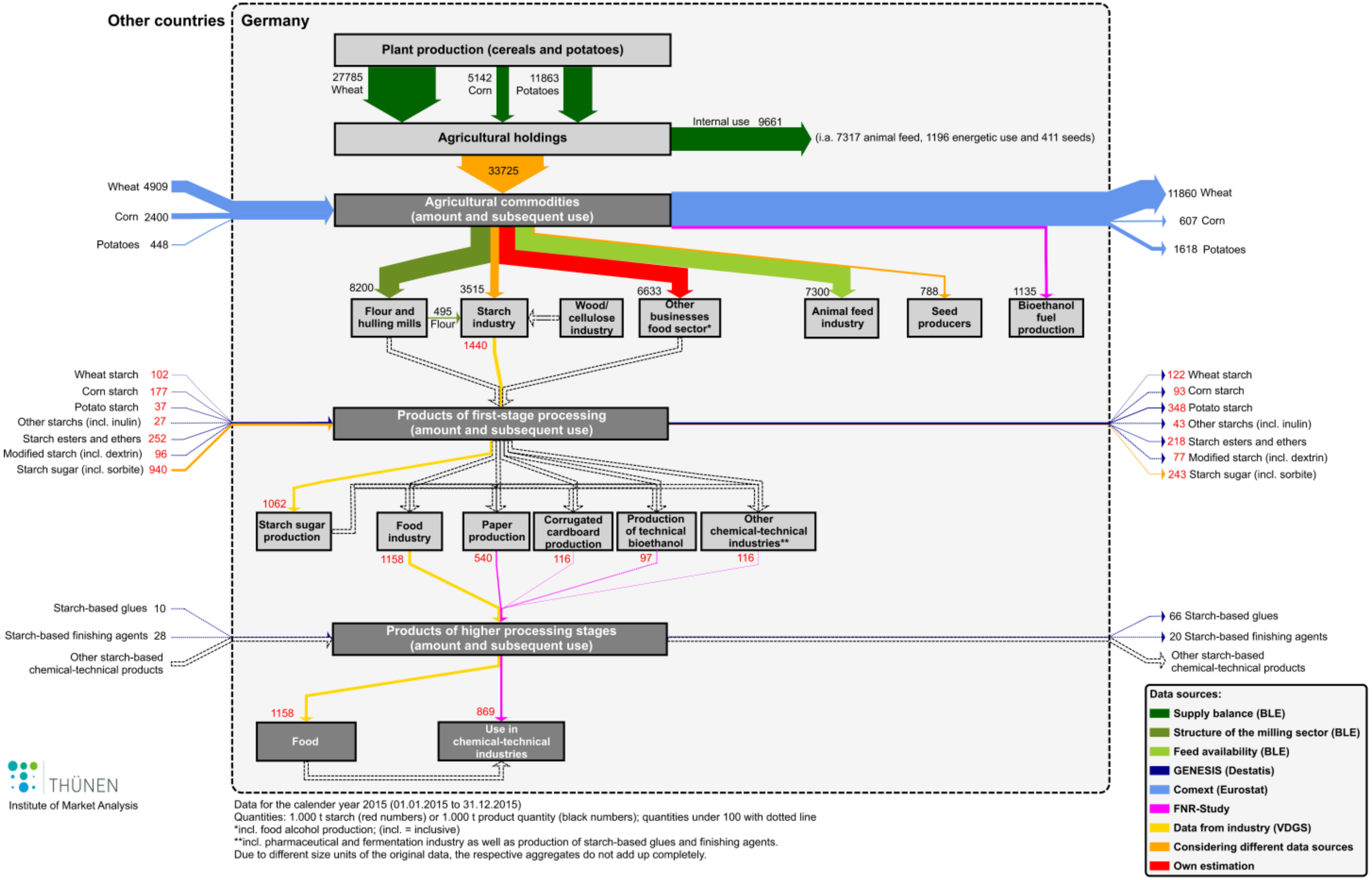
For bioeconomy relevant linkages or connections to material flows:

- Through the use of starch, sugar and oil in biofuel and liquid fuel production
- Linkage to the material flows of grain, sugar, vegetable oils and fats, potatoes and wood
- Through the use of maize, grass and whole plant silage in biogas/bio-methane production link to the material flow of plant feed
- Through the use of solid fuels, including cereal straw and wood from short rotation coppice (SRC) in thermal utilization connection to the material flows of cereals and wood
- Linkages with the material flow of agricultural residues and waste materials

Starch for Material Use (2015)

Figure 2.16 gives an indication of the material use of starch in Germany. Starch was produced from cereals and potatoes in the calendar year 2015. However, production from wood or cellulose would also be technically possible. Part of the domestically produced starch (55 %) was processed to sugar (saccharification). 60 % of the amount of starch available in 2015 went to the food sector, 40 % (869,000 t starch) was used by chemical-technical industries. The chemical-technical industries used the largest quantities of starch in the production of paper and corrugated board.

Figure 2.16: Material Flow Starch (Material Use)



Source: own illustration

Data sources used to compile the material flow:

- Supply balance for cereals in the 2014/15 marketing year (BLE 2017c)
- Structure of the milling industry 2015 (BLE 2016b)
- Feed volumes in the 2014/15 marketing year (BLE 2016a)
- Supply balance potatoes (BLE 2019a)
- Potato starch supply balance (BLE 2019b)
- GENESIS, foreign trade statistics (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Data published by Association of German Grain Processors and Starch Manufacturers (VDGS e.V.) (VGMS 2020)

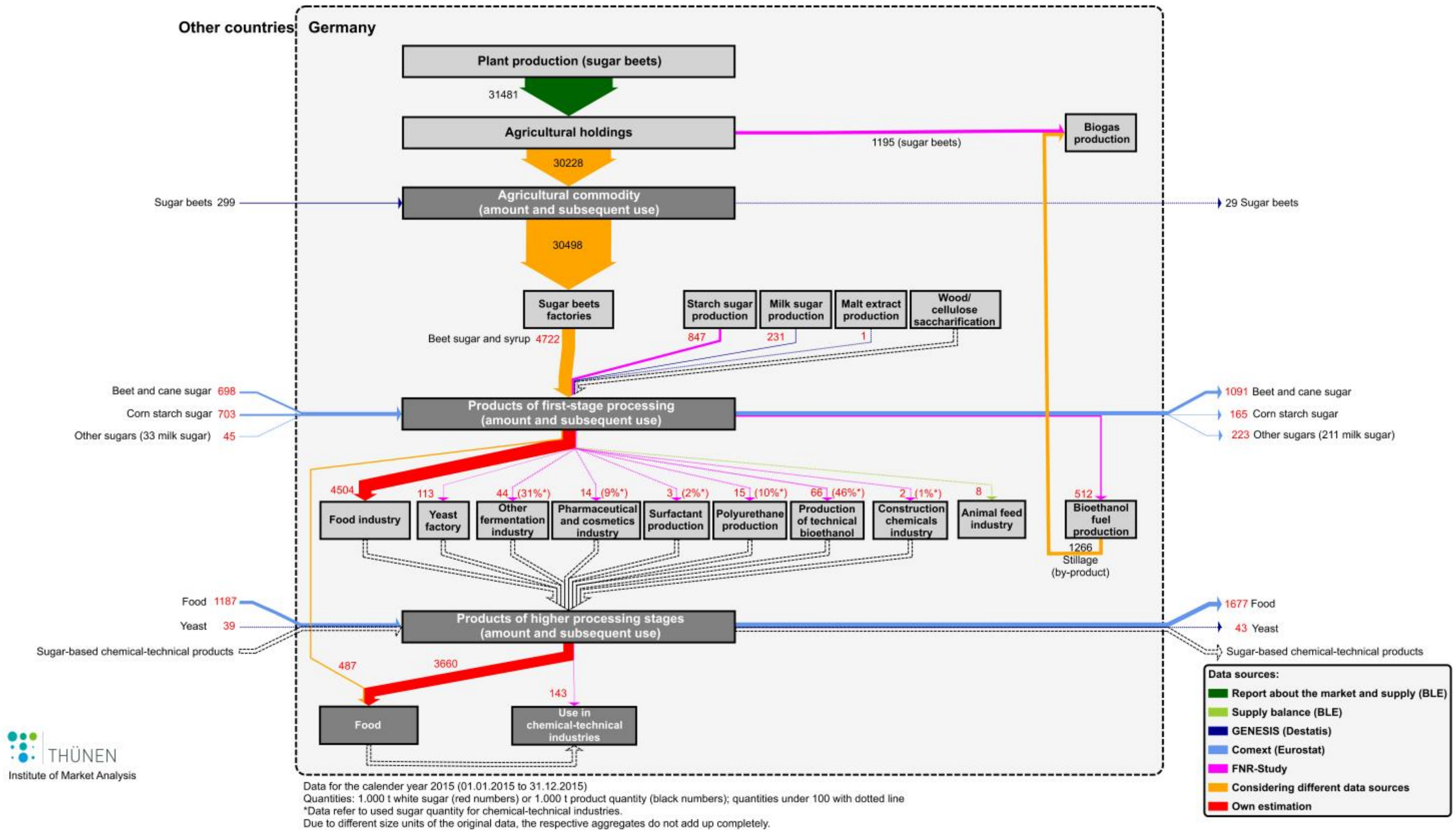
For bioeconomy relevant linkages or connections to material flows:

- Through the production of starch, connection to the material flows of grain and potatoes and optionally to wood
- Connection to the material flows of the processing industry via the use of the by-products as animal feed
- Connection to the sugar material flow via the production of starch sugars
- Linkage with the material flow of sugar for bioethanol fuel production
- Linkage with the material flow wood via paper and corrugated board production
- Connection to the material flow plant fibres for textile production and wood via the production of starch-containing finishing agents
- Linkages with the material flow of agricultural residues and waste materials

Sugar used in Chemical Industries (2015)

Figure 2.17 gives an overview of the use of sugar in the chemical sector. In Germany, sugar is mainly produced from locally grown sugar beet. However, sugar can also be produced from starch and cellulose or extracted from milk. In the calendar year 2015, the largest share of the sugar used in the chemical industry went into the production of technical bioethanol (46 %) and into the fermentation industry (31 %). However, sugar is also used in the pharmaceutical industry, e.g. lactose.

Figure 2.17: Material Flow Sugar used in Chemical Industries



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation for sugar (BLE 2017g)
- GENESIS, foreign trade statistics (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)

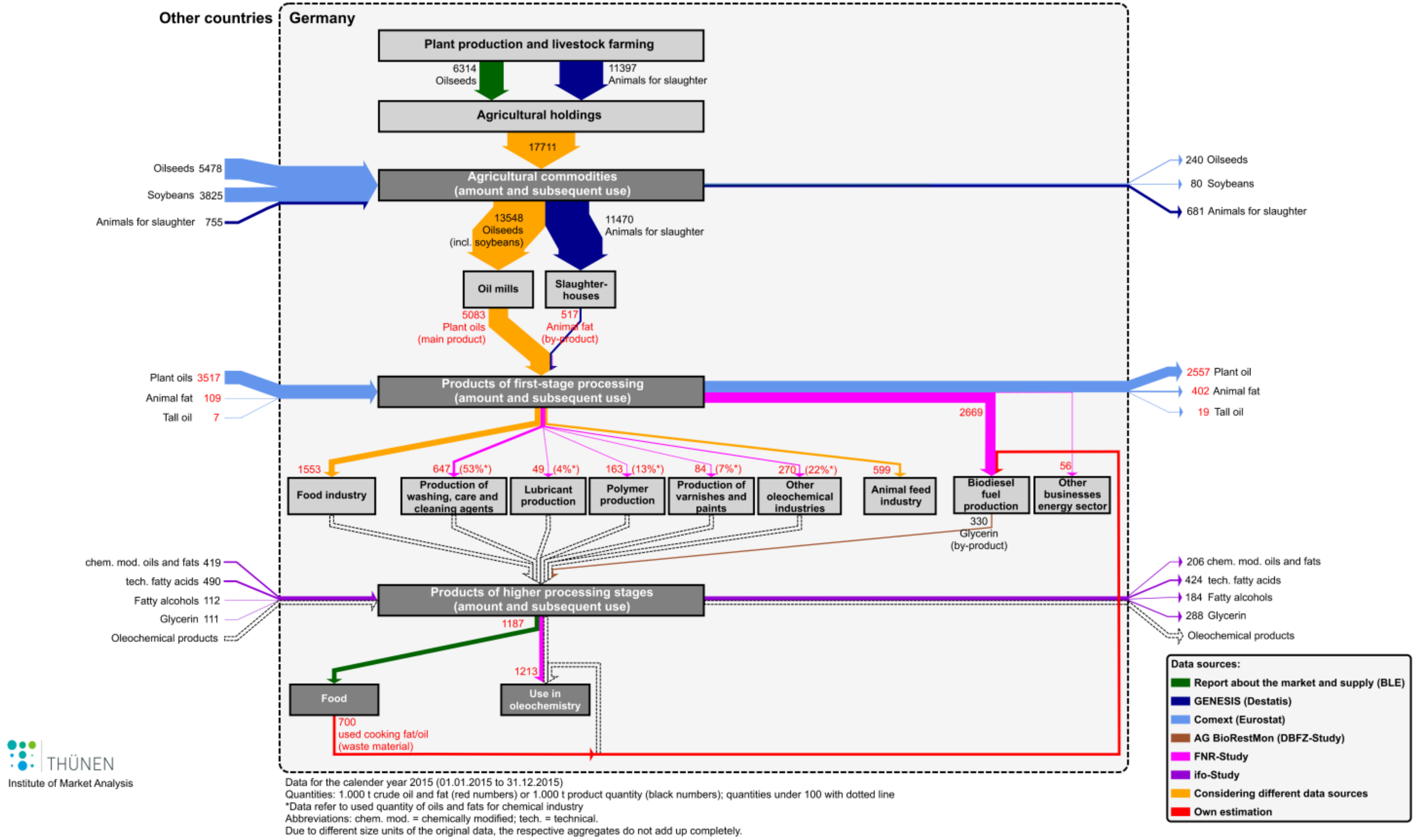
For bioeconomy relevant linkages or connections to material flows:

- Connection to the sugar material flow
- Connection to the material flows of the processing industry via the use of the by-products as animal feed
- Linkage to material flows (including cereals, potatoes, milk, wood) through the production of other types of sugar, e.g. starch and lactose and malt extract, and through the process of cellulose saccharification
- Linkages with the material flow of agricultural residues and waste materials

Oils and Fats in Chemical Industry (2015)

Figure 2.18 summarizes the volume flows of oils and fats used in oleo-chemical industry in the calendar year 2015. Oils and fats can be extracted from vegetable and deep-rooted agricultural raw materials. However, used cooking fats and oils can also be an additional source. 53 % of the oils and fats used in the chemical industry in 2015 went into the production of detergents and cleaning agents.

Figure 2.18: Material Flow Oils and Fats in Chemical Industry



Source: own illustration

Data sources used to compile the material flow:

- Report on the market and supply situation of oilseeds oils and fats (BLE 2017f)
- GENESIS, production survey and foreign trade statistics (DESTATIS 2020c)
- COMEXT (EUROSTAT 2020b)
- Study: BioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Identification of economic ratios and indicators for monitoring the progress of the bioeconomy (Wackerbauer et al. 2019)

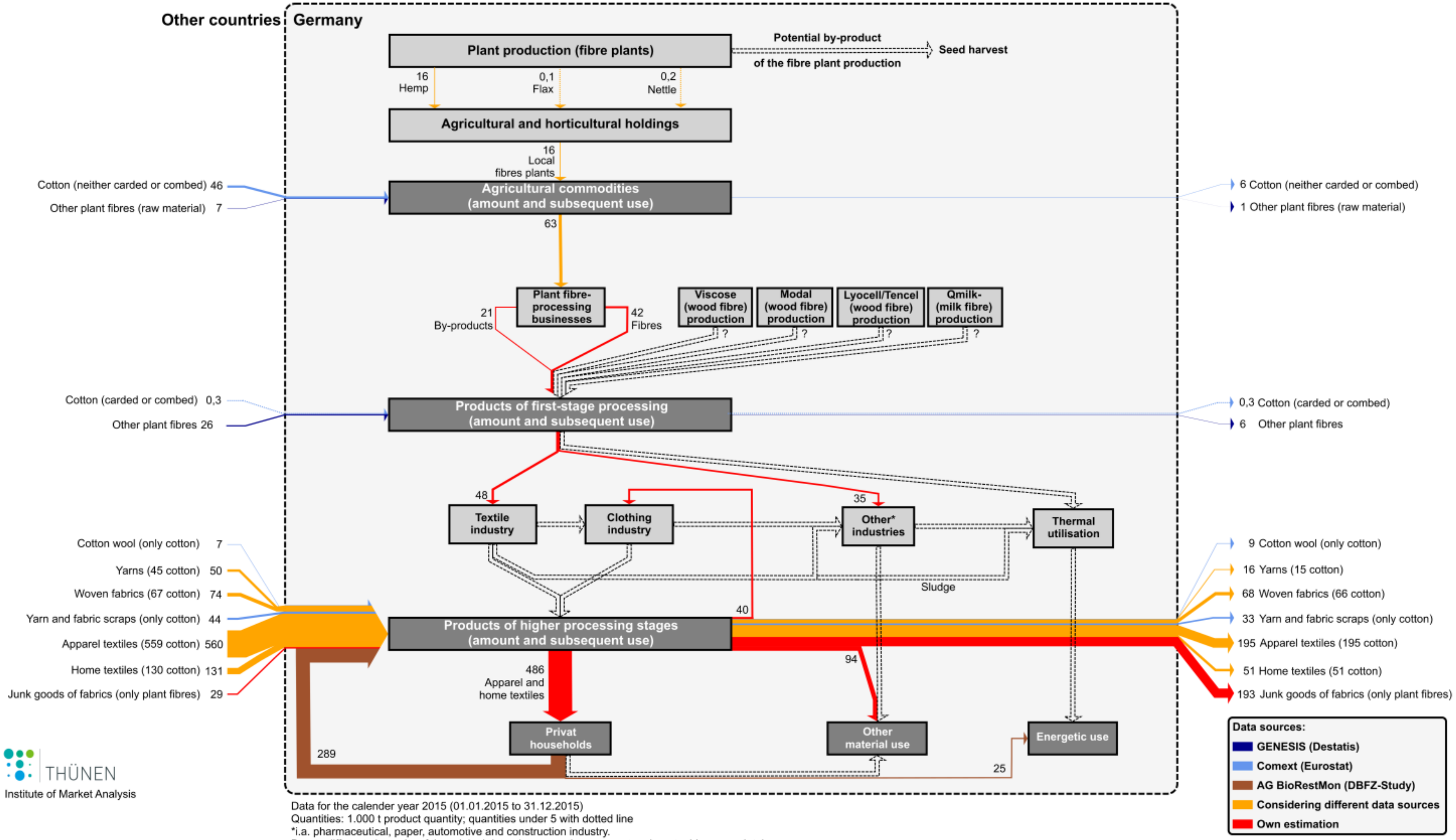
For bioeconomy relevant linkages or connections to material flows:

- Connection to the material flow of vegetable oils and fats and, via the soybeans, to the material flow of legumes
- Connection to the material flows of the processing industry via the use of the by-products as animal feed
- Additional connection to the meat material flow via the production of animal fat for slaughter
- Linkage via the production of tall oil to the material flow wood
- Linkages with the material flow of agricultural residues and waste materials

Plant Fibres in Textile Industry (2015)

For Germany, the material flow of plant fibres (Figure 2.19) summarizes the volume flows of plant fibres used in textile production. The compilation of the volume flows for 2015 shows that only small quantities of indigenous plant fibres (hemp, fibre flax and nettle) were produced. In addition, the diagram shows that there were also hardly any significant import quantities of plant fibres in 2015. The German textile and clothing industry uses only small quantities of plant fibres. The largest share of plant fibres was imported into Germany in 2015 in the form of finished cotton-based textiles.

Figure 2.19: Material Flow Plant Fibres in Textile Industry



Data for the calender year 2015 (01.01.2015 to 31.12.2015)
Quantities: 1.000 t product quantity; quantities under 5 with dotted line
*i.a. pharmaceutical, paper, automotive and construction industry.
Due to different size units of the original data, the respective aggregates do not add up completely.

Source: own illustration

Data sources used to compile the material flow:

- Statistical Yearbook on Food, Agriculture and Forestry of the Federal Republic of Germany 2017 (BMEL 2018b)
- GENESIS (DESTATIS 2020c)
- Land use of holdings 2015 (DESTATIS 2015a)
- COMEXT (EUROSTAT 2020b)
- AGBioRestMon (Brosowski et al. 2019)
- Cultivation and use of renewable raw materials in Germany (FNR 2020)
- Basic data on bio-based products (FNR 2018a)
- Renewable raw materials in industry (FNR 2010)
- Natural fibre reinforced plastics (Carus and Partanen 2020)
- Market and competition situation for natural fibres and natural fibre materials (Carus et al. 2008)
- Consumption, demand and reuse of clothing and textiles in Germany (Korolkow 2015)
- The German textile and fashion industry in figures (Gesamtverband Textil + Mode 2019)

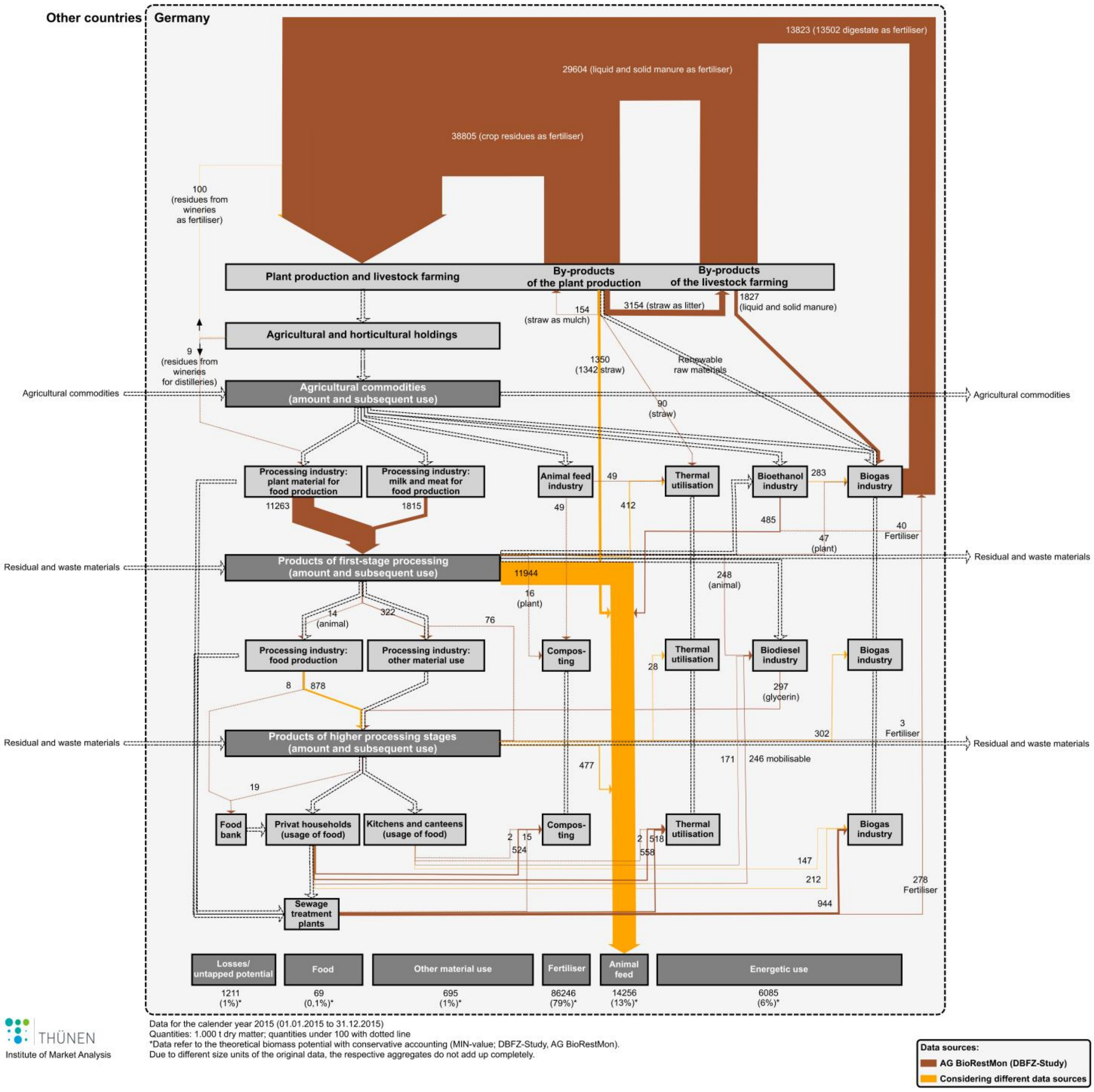
For bioeconomy relevant linkages or connections to material flows:

- Connection with the material flow wood via the production of viscose, modal as well as Lyocell and Tencel
- Connection with the material flow milk via the production of milk fibres (Qmilk)
- Linkages with the material flow of agricultural residues and waste materials

Agricultural Residues and Waste (2015)

The development of the agricultural material flows presented in Figure 2.5 – Figure 2.19 covers possible interfaces with the biomass residue monitoring of the DBFZ (Study BioRestMon). In addition, based on the data of the DBFZ study, a separate, summarized material flow of all agricultural residues and waste materials for the calendar year 2015 was prepared (Figure 2.20). The flow of the residual and waste materials shows that the two largest volume flows are the by-products of crop cultivation (cultivation residues) and liquid and solid manure as a by-product of livestock husbandry. Both can be reused as fertiliser on agricultural and horticultural farms. Parts of the cereal straw as a by-product of cereal cultivation can also be used as bedding in livestock farming. Some of the liquid and solid manure from livestock farming is also used in the biogas industry. From the biogas industry, the fermentation residues are then returned to the crop farms as fertiliser. By-products of food production are used almost exclusively as animal feed.

Figure 2.20: Material Flow Agricultural Residues and Waste



Source: own illustration

Data sources used to compile the material flow:

- AGBioRestMon (Brosowski et al. 2019)

For bioeconomy relevant linkages or connections to material flows:

- Linkages with all previous agricultural material flows

The aim of the material flow analysis for agriculture was to visualize the biogenic material flows of agricultural raw materials in Germany from production to final consumption of products containing agricultural raw materials. These figures cover associated imports and exports as well as the domestic use of by-products of production along the entire value chain.

The 16 material flows for the agricultural sector now available in a first draft show:

- Differences in utilisation paths of the respective raw materials and resulting products,
- cross-sectoral linkages along the value chain (e.g. between the material flow of grain and sugar through the production of starch sugars and bioethanol fuel or between the material flow of sugar and milk through the production of lactose (milk sugar)),
- linkages to the material flow of wood (e.g. to the material flow sugar through the production of xylitol and to the material flow plant fibres for textile production through the production of viscose, Modal, Lyocell and Tencel),
- apparent data gaps,
- high variation in the availability and number of existing data sources,
- need of different and independent sources to ensure the reliability of material flow balances.

Data gaps arise due to non-existent, uncollected data or existing data that have not been publicly reported by the authorities due to their non-disclosure policy. However, access to data subject to data protection is possible on request via research data centres of DESTATIS and the Federal States Länder or via the Federal Information Centre for Agriculture (BLE), if it can be ensured that the data used are summarized at a higher aggregated level when presented to the public.

The data of the MVO is based on monthly reports with data on trade and 1st processing stage of agricultural raw materials. Official statistics (e.g. production and foreign trade statistics) currently do not include direct purchases of agricultural raw material for products at higher processing stages. Useful balance weighting factors were only available for individual agricultural balance groups and in combination with the commodity codes of the foreign trade statistics (CN codes).

In individual cases, it is advisable to take a closer look at individual raw materials to provide a data base for further analysis, e.g. for sustainability assessment. For such an analysis, more data on the condition of production in countries of origin would be needed to achieve a comprehensive analysis of sustainability. Thus, two further material flow charts for the agricultural raw materials oilseeds and palm (kernel) oil were compiled, which are not based on the unified material flow model agriculture. For these material flows, an attempt was made to trace the use of raw materials in more detail along the domestic value chain from production to end use.

For a better comparability and presentation of the relationships between the different agricultural material flows, it would also be useful to prepare the material flow presentations for similar 12-month periods. It might also be of interest for a future application to link the quantities stated in the agricultural material flows with conversion coefficients in order to derive further, new material flows from them. Possible conversions could be made into flows of dry matter, energy or nutrients, but also into monetary values or with reference to ecological effects.

According to the National Bioeconomy Policy Strategy (BMEL 2014), the "knowledge-based bio-economy" or the "bio-based economy" is oriented towards natural material cycles and is based on a structural change from an economy based on finite fossil sources - mainly oil - to an economy based more strongly on renewable resources. For this upcoming and necessary transformation process from a fossil-based to a bio-based economy, material flow analyses of the agricultural sector are seen as a helpful instrument.

In conclusion, it can be said from the present work that a visualisation of the agricultural material flows in Germany:

- is possible,
- makes the current data situation recognizable,
- brings orientation,
- creates transparency,
- reveals bioeconomic relationships and possible starting points,
- helps to identify development trends based on a permanent monitoring and
- provides the basis for further evaluations and visualizations, e.g. used land area, monetary value added, CO_2 emissions.

The 16 agricultural material flows now available are, therefore, considered to be a reliable basis and can be used as a starting point for any greater differentiation and material flow links that may be necessary in some areas. This applies in particular to the areas of "material use" and "energetic use" which are important for the bioeconomy. As a next step, current and also possible future transformation processes of the German bioeconomy can be worked out and shown in more detail for these areas. This is especially the case for cascade and circular economy and with a focus on the utilization and upgrading of biogenic (agricultural) residual and waste materials. An agricultural material flow analysis also achieves the added value necessary to promote bioeconomic developments, especially if the material flows are digitised, regularly updated and provided through a public access (website).

2.4.3 Forest Biomass

2.4.3.1 Introduction

In 2012, forests in Germany covered 32 % of the country's area which amounts to 11.42 million hectares in total. Forests are protected by the Federal Forest Act which results in a stable forest area that even slightly increased between 2002 and 2012 (+ 0.4 % or 50,000 hectares). The major part of this area (10.9 million hectares) permanently serves wood production (BMEL 2016a).

In German history, the most recent reduction in forest area and timber stock was caused during and after World War II. Reparation clearcuttings and increased demand for reconstruction, heating and cooking resulted in substantial overuse of forests. For the first post-war years, this overuse is estimated to range between 9 and 15 times higher than annual increment; for reparations alone about 10 % of German forests were clear-cut (DFWR 2020). In the following decades, clear-cut areas were reforested; forested area and timber stocks increased again. In 2012, the Third National Forest Inventory (BMEL 2016a) registered an increase of timber stocks by 7 % as compared to 2002. Timber stocks were estimated at 3,663 million m³ in 2012 (336 m³/ha). Increasing stocks are a result of age structure and species composition of German Forests that were determined by the already mentioned clearcuttings and reforestations. Especially spruce trees planted in the 1950ies are currently in their most productive stage (BMEL 2016a). Furthermore, while in larger privately owned forests and Federal forests fellings match annual increment, in small (< 20 ha) privately owned forests fellings are on average below annual increment and timber stock further accumulates due to structural specifics of small private forests (BMEL 2016a; Hennig 2016). Timber harvest during the inventory period 2002 – 2012 was characterized by contrasting developments. In 2007, windstorm *Kyrill* downed almost half of the average annual fellings and the financial crisis in 2008/ 2009 caused a decline in timber demand, especially in the construction sector. However, since then, sectors recovered from the crisis. On the other hand, energetic wood use increased and prices rose continuously during the inventory period 2002 – 2012 (BMEL 2016b). Furthermore, against the background of silvicultural and forest policy objectives, during the same period, stock and area of spruce and softwood in general was reduced as a measure of forest conversion. Fellings and natural dieback of spruce result in removals that are 15 % higher than increment (BMEL 2016a). Most recently (2018/2019), climate change related summer drought and storms and following bark beetle calamities have caused considerable forest damages. The affected area in Germany is estimated at around 250,000 hectares. The amount of fallen timber in 2018 and 2019 is estimated at around 36 and 70 million m³, respectively (BMEL 4/27/2020). These quantities exceed forest management capacities. Thus, only parts of fallen timber could be removed from the forests.

In 2002, the German Federal Government agreed on the objective to increase domestic wood use by 20 % in ten years and initiated the Charter for Wood as a tool to achieve this goal (BMVEL 2004). The dedicated objective of the Charter for Wood in 2004 was to increase the per capita use of wood and wood products from sustainable production in German from 1.1 m^3(r) to 1.3 m^3(r)[2]. The term **sustainable** refers to production methods of wood and wood products, climate protection by means of increased CO_2-storage and the creation of jobs and value added, especially in rural areas. The targeted increase of per capita wood use was based on German wood balances that have been compiled since 1950 (Weimar 2018). Total supply and total consumption of wood and wood-based products are balanced. Total supply covers domestic fellings (production), domestic supply of recovered wood and recovered paper, imports and reduction of stocks. Total consumption covers stock increase, exports and apparent domestic use. The wood balance is calculated on an annual basis by the Thünen Institute (TI-WF 2020c) using calculations of annual fellings, external trade and wood working statistics, association statistics on recovered paper and change in stocks, and an empirical study on recovered wood (Weimar 2018).

In addition and within the Charter for Wood, a regular assessment of forestry and wood-based value chains was developed and implemented. As a result, cluster statistics for forest and timber have been providing annual data on number of enterprises, employment, turnover and value added since 2000 (Seintsch 2007; Becher and Weimar 2020). The cluster statistics as well are an important part of a future monitoring. Its relevance for sectoral monitoring is further explained in chapter 2.5.1.

The first Charter for Wood-process (2004 – 2014) was successful in increasing the per capita wood consumption from 1.1 m^3 (r) to 1.4 m^3 (r) (BMEL 2017; Deutscher Bundestag 2010). In the context of the National Climate Action Plan 2050, the second Charter for Wood (CfW 2.0) focuses on a qualitative growth of forestry and wood industry. Primary objectives are (i) climate protection through increased use of wood from sustainable managed forests, (ii) preservation and increase of value added and competitiveness of the forestry and wood industries cluster, and (iii) sustainable and efficient use of forests and wood (BMEL 2018a). Fields of activity are wood construction, wood-based bioeconomy, material and resource efficiency, forest management, value added and employment in forestry and wood industries, stakeholder communication and research and development (BMEL 2017). In order to see development towards reaching these goals, detailed information on supply and use is needed and the existing measures outlined above need to be improved and expanded (Purkus et al. 2019a; Purkus et al. 2019b).

A main pillar of quantifying wood flows in Germany is the wood resource monitoring: Due to considerable gaps of information on the use of roundwood in available statistics, the project was started in 1999. It has been continued and further developed over the years by the University of Hamburg under Prof. Udo Mantau, the company INFRO and the Thünen Institute. The main objective of the project is to gain information on production capacities and the raw material demand of

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[2] Cubic meters of roundwood equivalent (m^3(r)) is a theoretical figure which expresses how many units of roundwood have been used for the manufacturing of a unit of a specific wood-based product. Thus, losses of wood during processing are considered.

the wood processing industry in Germany (e.g. sawmill industry, panel mills, pulp mills). Additionally, all other areas of the sources (besides roundwood also wood processing residues, recovered wood short rotation coppice and others) and the uses (e.g. energy generation in private households or non-residential plants) are monitored regularly. To do so, several individual surveys are carried out on a regularly basis and summarized in several reports (Döring et al. 2018a; Döring et al. 2016, 2017a, 2017b; Döring et al. 2018b; Döring et al. 2018c).

Another important milestone in describing wood material flows was the development of the wood flow model (Weimar 2011). The wood flow model is a comprehensive graphical representation of the material flow of wood fibres in wood and wood-based products. It maps and quantifies wood fibre material flow from raw material to semi-finished products and energetic use as well as the respective external trade. The underlying method can be applied retrospectively and continuously.

Furthermore, a new reference unit was developed that allows for balancing only the wood contained in wood and paper products. Wood can be subject to manifold processing steps, resulting in a broad variety of products. Besides wood, the final products then contain other materials. Using units like cubic metre or ton that are customary to wood working industries does not allow the quantification of wood flow only. Furthermore, specific characteristics of wood, i.e. swelling and shrinking and the resulting change in volume cannot be considered. The proposed reference unit is the wood fibre equivalent which is defined as the equivalent volume of wood-based fibres at the fibre saturation point that are contained in a product (Weimar 2011).

To overcome the limitations of the official felling statistics that are in detail described in chapter 2.4.3.2, Jochem et al. (2015) developed a model for estimating wood removals and fellings based on the amount of used roundwood. The model includes (material and energetic) roundwood uses in industries and private households, changes of stocks of already felled roundwood in the forests (timber stacks at site) and in the forest-based industry (e.g. storage of roundwood by companies) as well as foreign trade. For quantification, all sectors that use roundwood, associated data sources and data gaps have to be identified in a first step. Relevant sources of information are official statistics, statistics of industry association and empirical studies (e.g. wood resource monitoring). In a second step, branch-specific models are used to close the identified data gaps on the use side. Based on that, wood removals can be calculated. Taking into account variables such as logging residues and unused coarse wood, the fellings in Germany can be determined finally. This estimation of wood removals and fellings in Germany is continuously updated and available to the interested public (TI-WF 2020d).

Further detail on the different types of data sources is provided in the following chapter. Against the background of emerging wood-based industries of the bioeconomy, the wood flow model and estimation of wood removals and fellings will be further developed as new wood-based products and processes are expected to evolve.

Despite the methodological development outlined here, the use of wood and wood-based products at the manifold processing stages, comprehensive data on covered amounts and on developments is still missing. Empirical analyses are and will be needed in the future to close these data gaps and to provide more comprehensive information on wood material flows.

2.4.3.2 Available Data

Official statistics: Felling Statistics and Wood Working Statistics

Official felling statistics cover roundwood fellings in forest operations (DESTATIS 2018e) but considerably underestimate the actual amount of total fellings. Numerous studies have investigated and explained this underestimation (see Jochem 2017). Main reasons are that for privately owned forests fellings are only estimated by the statistic agencies but without sound empirical database. Furthermore, fuelwood fellings are not reported properly (Jochem et al. 2015 and references therein).

Data on wood working industries is published annually and is based on a comprehensive survey with a cut-off threshold of 20 employees for wood working companies and 10 employees for saw mills (DESTATIS 2020b). Data gaps due to non-responses are filled with estimations by DESTATIS (Bösch et al. 2015; Weimar 2011). Basically, this survey provides important information on wood processing. Further data on the use of wood can be derived from production statistics (chapter 1.2.2).

Association Statistics and Market Studies

Association statistics can be used in addition to official statistics to close important data gaps. Important industry associations that provide relevant data on the use of wood resources are the German Paper Association (VDP) and the German Pellet Association (DEPV). These associations deliver data on the assortments of wood that are used, production quantities, trade quantities and wood flows. They also finance research on wood supply and use (Mantau and Bilitewski 2005) in order to provide their associated companies with information on supply and use of wood to support their business model development. Associations are important partners in conducting empirical studies like surveys among their associated members as they facilitate communication between research and economy.

Empirical Studies

For describing and monitoring wood flow, the empirical studies conducted within the frame work of the wood resource monitoring (see chapter 2.4.3.1) have been the indispensable foundation since 1999.

A broad variety of products contains wood or wood-based materials. For describing material flows, this variety has to be aggregated for which information on the wood content and on conversion factors between the different processing stages of wood and wood-based products are needed. In that context, Diestel and Weimar (2014) provided the first comprehensive compilation of carbon contents in wood and paper products and conversion factors.

For describing and quantifying material flows, also Life Cycle Assessment (LCA) studies are of use. LCA studies always refer to a defined functional unit and are in a strict sense only valid for the defined assessment goal, scope and system boundaries. However, they may provide detailed information on composition, used materials and consequently, biomass contents of end-products (Schweinle et al. 2020). In the context of wood material flow, we used information on flat pallets provided by Scholtes and Jansen (2014), but LCA studies with unambiguous references to official classifications of products are very rare. For applying LCA results to data from official statistics, assumptions that have to be backed up with additional data in a future monitoring have to be made.

In an evolving bioeconomy, fossil resources will be substituted by renewable resources and the variety of wood-based products will further increase. Against that background, empirical studies will also be needed in the future.

2.4.3.3 Results

Wood Flow Model

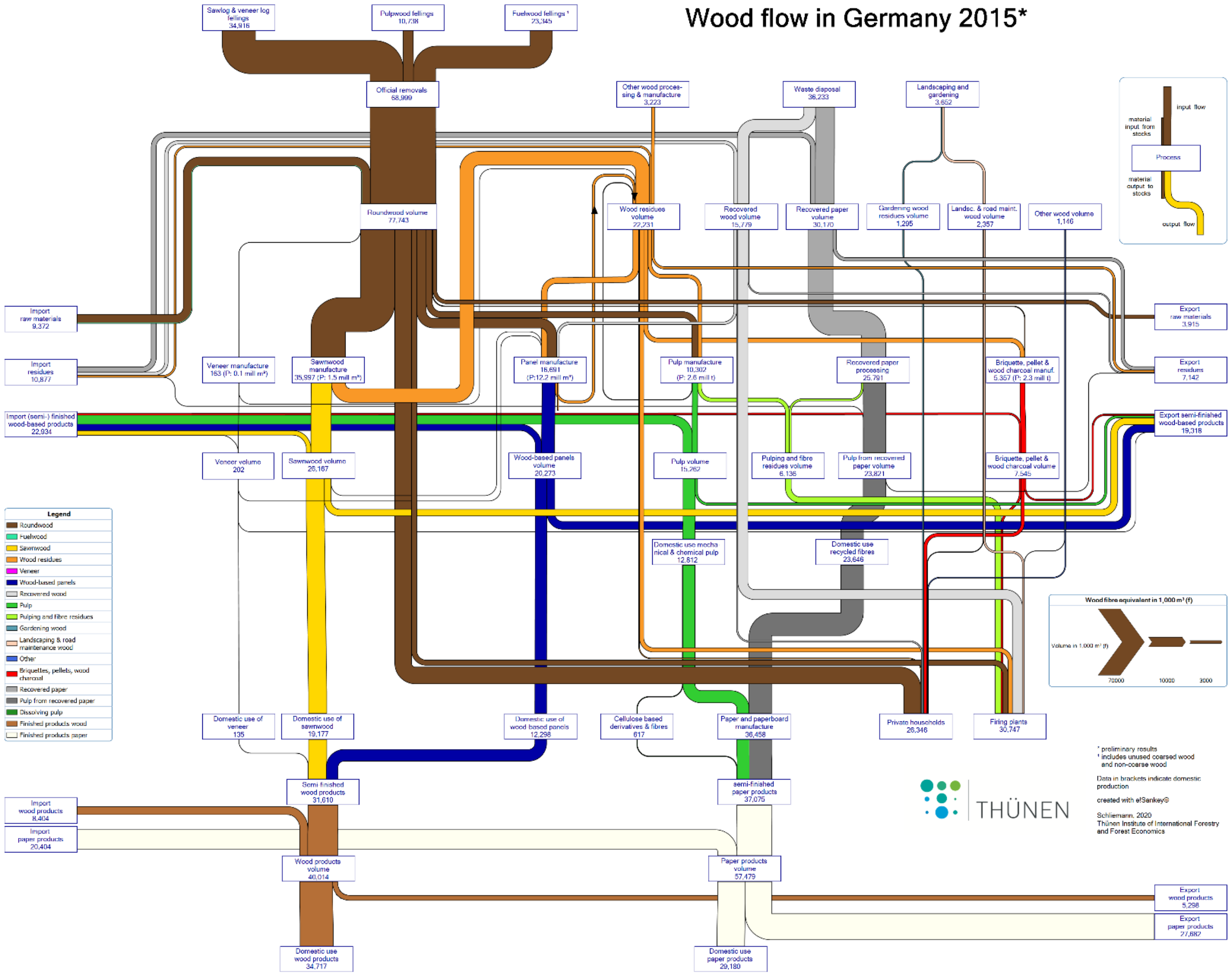
Figure 2.21 provides an update of the wood flow model by Weimar (2011) as a result of the development outlined in chapter 2.4.3.1, using the described data sources. It breaks down the wood flow shown in Figure 2.3 and shows supply and use of wood from raw material to semi-finished products and energetic use in Germany in much more detail. In the update of the model, external trade flows are now differentiated into raw materials, residues and recycling and semi-finished products. Due to their increasing importance, wood-based chemical derivatives and textile fibres are also mapped as an additional branch of wood pulp (in green).

Some selected findings for Germany are as follows. About two third of the wood that is removed from forests is used for material purposes. A major part of wood is further processed in saw mills (in yellow). Sawn wood is mostly domestically used in the construction sector, manufacture of furniture and wood packaging (Bösch et al. 2015, not shown in wood flow model). Residues from saw mills (in orange) are an important resource in the manufacture of panels and pulp, for energetic uses in dedicated firing plants and for manufacture of pellets. In energetic use of wood, private households play a major role, as they use a substantial part of fellings in Germany. About one third of wood removals from forests is directly used energetically.

In the context of recycling, the wood flow model shows the importance of recovered paper and recovered wood (in grey). Most of the recovered wood is burnt in firing plants for energy production. With regard to paper, the wood flow model shows that recovered paper and pulp are important resources for paper and paperboard manufacturing in Germany. However, it is also shown that this manufacturing also relies on imports of pulp (in green).

Finally, it can be stated that the domestic consumption of paper products (light yellow) is almost as high as the material domestic use of wood products (light brown). For paper products, external trade is higher and results in a net export of paper products. External trade of wood products is smaller, but more wood products are imported than exported (net import).

Figure 2.21: Wood Flow Model Germany 2015



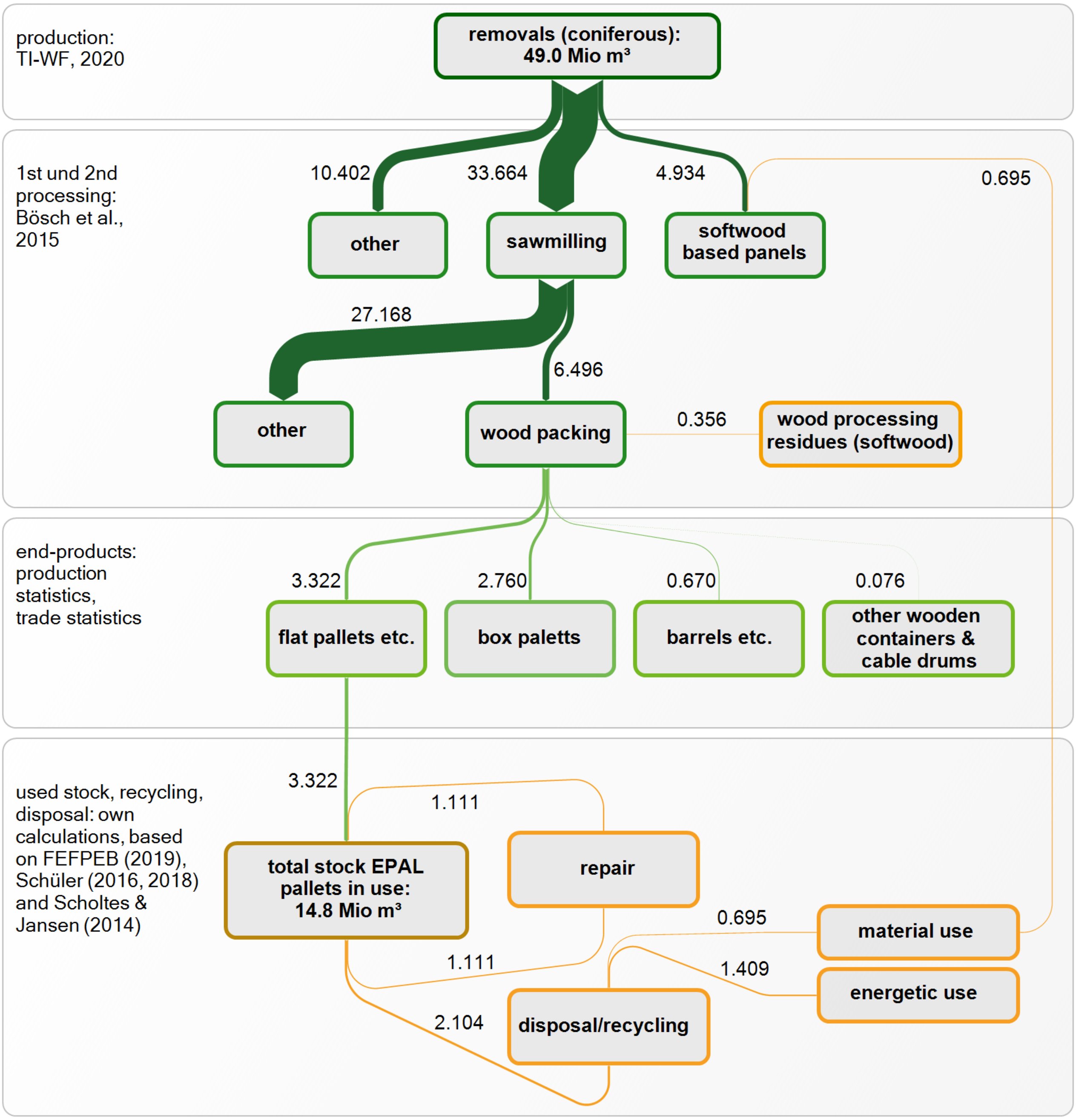
Source: own illustration

Core Product EPAL 1 flat pallet

A core product for softwood timber is the dominant type of flat pallet, i.e. EPAL type 1 (EPAL 1 pallet). EPAL stands for The European Pallet Association and represents a worldwide open pooling system for load carriers (EPAL 2019). In a pooling system, flat pallets are exchanged across sectors and branches. The circulating pallets are manufactured according to defined specifications and quality assurance is provided in production, repair and logistic services (FEFPEB 2020). Material flow and following sustainability assessment of this core product is comprehensively described by Schweinle et al. (2020). Here, we will give a short abstract of the material flow specifics for the reference year 2015 and present an updated version of the material flow chart in million m³, instead of in million t as presented in Schweinle et al. (2020). For quantifying EPAL 1 pallets, data from all of the described source types have been used (see Schweinle et al. 2020 and references therein). Still, as the GP09 code EPAL 1 pallets are covered by (i.e. 1624 11 330) does not only include this specific pallet, but all flat pallets and pallet collars, and no further information on product distribution within one product code is available, several assumptions were made: (i) 95 % of the products in 1624 11 330 are flat pallets, (ii) 95 % of (i) are EPAL 1 pallets. Another 95 % of those are made from softwood sawn wood, wood particle blocks and nails. The remaining 5 % of EPAL 1 pallets are made of softwood sawn wood, solid wood blocks and nails (for more detail see Schweinle et al. 2020). Based on the information given in Scholtes and Jansen (2014), for each pallet type and the respective components volumes and weights were calculated. Figure 2.22 shows that about 33.7 million m³ of softwood are further processed in sawmills. About 6.5 million m³ softwood sawn wood are used for manufacturing wood packaging. Main categories of wood packaging regarding the use of softwood are flat and box pallets that contained 3.32 and 2.76 million m³ softwood timber in 2015, respectively.

The end use of pallets is not only single consumption, but is characterized by an assumed lifespan of six years (Schweinle et al. 2020). Already used pallets may be repaired and re-enter the stock in use. On average, about 14 % of the softwood contained in a pallet are replaced by fresh softwood when pallets are repaired. Pallets that cannot be repaired are excluded from the pooling system but further used. Pallets made of untreated wood can be used as a resource in particle board manufacture. All other pallets are used for energy generation in biomass plants. The material flow of EPAL 1 pallets illustrates reuse and recycling options connected to wood use. It is remarkable that for this in global transport highly relevant product, reuse, repair and recycling already are essential. Thus, within bioeconomy, EPAL 1 and flat pallets in general are not only relevant in terms of wood use, but also as an example for the transition to a circular bioeconomy.

Figure 2.22: Material Flow Core Product EPAL 1 pallet



Source: own calculations based on Bösch et al. (2015), FEFPEB (2019), Scholtes and Jansen (2014), Schüler (2016, 2018) and TI-WF (2020b)

2.4.4 Aquatic Biomass

2.4.4.1 Introduction

The material flow analysis of aquatic biomass considers finfish, crustaceans, molluscs (mussels, snails and cuttlefish) and algae from marine and limnic waters (hereinafter, "fish and seafood"). The domestic production consists of sea fishery, aquaculture and freshwater fishery.

The yearly production of marine fisheries depends on the distribution of fishing quota for Germany. To ensure a sustainable fishery, the species-specific total allowable catch determines how much of each species can be caught in a certain area on a yearly or two-yearly basis. These quotas are adapted to the changes of the stocks of each fishing ground which is why they can change strongly. A large part of the landings (65 – 72 %) of Germany's fishing fleet takes place at international harbours as exports. In aquaculture, finfish, crustaceans, mussels and algae are cultivated under controlled conditions. Freshwater fishery considers the economic fishery in lakes and rivers, which can also have an artificial source like quarry ponds or dams.

The domestic production in Germany is not sufficient to satisfy the demand. The most important exporters to Germany are China, Denmark, Poland and Norway (BLE 2015a). Nevertheless, Germany also exports fish and seafood at different stages of processing (see Material flow of relevant commodity groups).

Fish and seafood are mainly used for human consumption (see Supply balance of fish and seafood). However, during the processing of these raw materials, by-products like fish heads, viscera and fish skin are generated partly not destined to human consumption. Together with further non-edible products, e.g. certain algae, fishmeal and fish oil as well as their raw material, they represent the non-food use products which are utilized for feed and material use (see Core product non-food use product).

2.4.4.2 Available Data

In addition to the already mentioned data sources (see chapters 1.2.2, 1.2.3), specific data sources considering aquatic biomass were used. The following data sources describe the domestic production of aquatic biomass:

The **landing statistics** provided by BLE consider all catches of species fished by the German fleets independently from fishing area or landings port. Within the statistic, it is distinguished between landings in German or international harbours. The landings are classified in "use for human consumption" and "waste/industrial use". Species of fish and seafood are classified by FAO code and by form of processing, e.g. fresh, frozen, whole, gutted and filleted. Volumes are available in weight of landing and live weight and values in Euro. The data are published monthly (with a delay of 3 to 4 month) and yearly (with a delay of 6 month maximum).

Information about the production of fish, mussels, crustaceans and algae in aquaculture are published in special series FS 3, R 4.6 **production in aquaculture plants** of DESTATIS. Units are live weight and values. Fish species are divided into 14 categories. Further categories depend on the aquaculture methods. Divisions based on local regions are also possible. Data are available yearly.

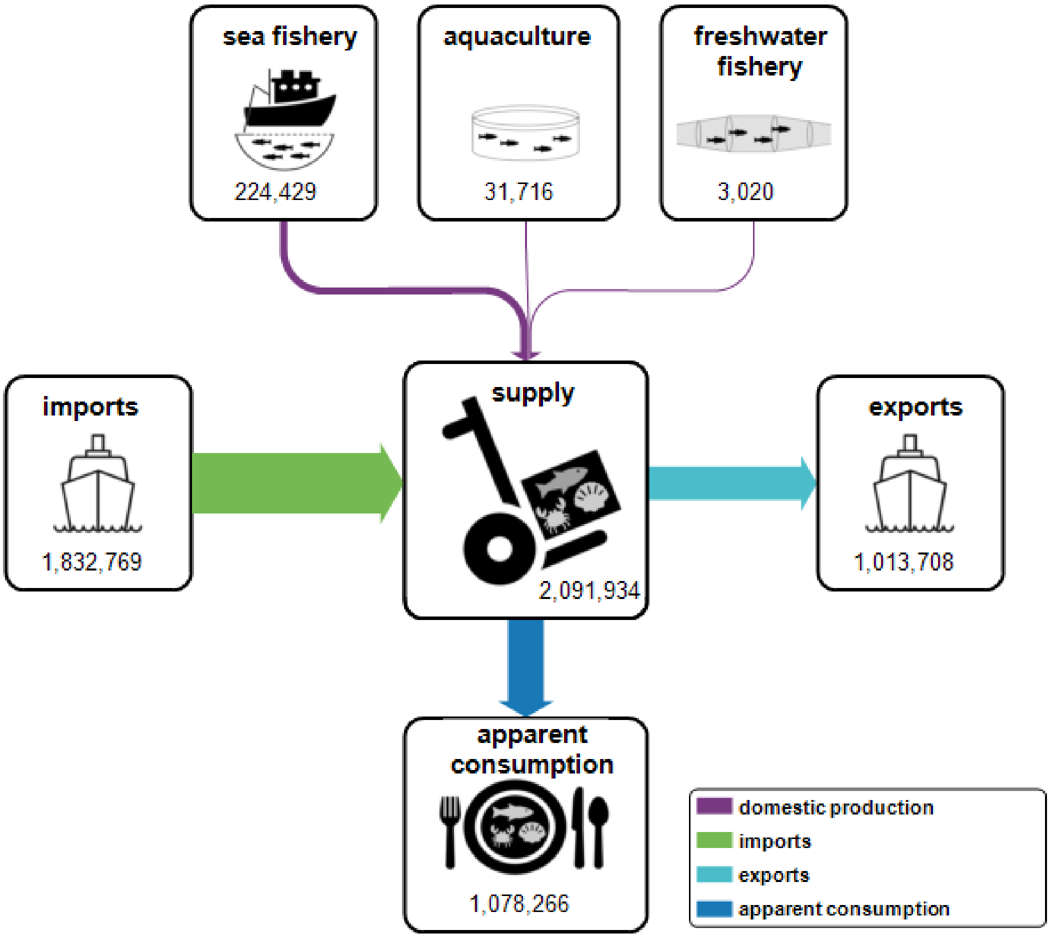
The **annual report of freshwater fishery and inland aquaculture** (Jahresbericht zur Deutschen Binnenfischerei und Binnenaquakultur), provided by the Institute of Inland Fisheries in Potsdam-Sacrow, contains information about the volume of commercial freshwater fishery in live weight. The data are published yearly with a delay of 10 to 12 months. The report distinguishes between fish species.

2.4.4.3 Results

Supply Balance of Fish and Seafood for Human Consumption

Figure 2.23 shows the supply balance of fish and seafood in Germany in 2015, only goods destined for human consumption are considered. The domestic production amounted to 259,165 t live weight equivalent, around 90 % of these originates from marine fishery. The aquaculture production contributed only 31,716 t and the freshwater fishery had the lowest share with 3,020 t. Considering an import of 1,832,769 t live weight equivalent, the German supply for human consumption amounted to 2,091,934 t. Taking into account an export of 1,013,708 t, the apparent consumption was calculated to be 1,078,226 t. The low domestic production leads to a level of self-sufficiency of around 24 %.

Figure 2.23: Supply balance of fish and seafood for human consumption in 2015 (volumes in t live weight)



Source: own illustration

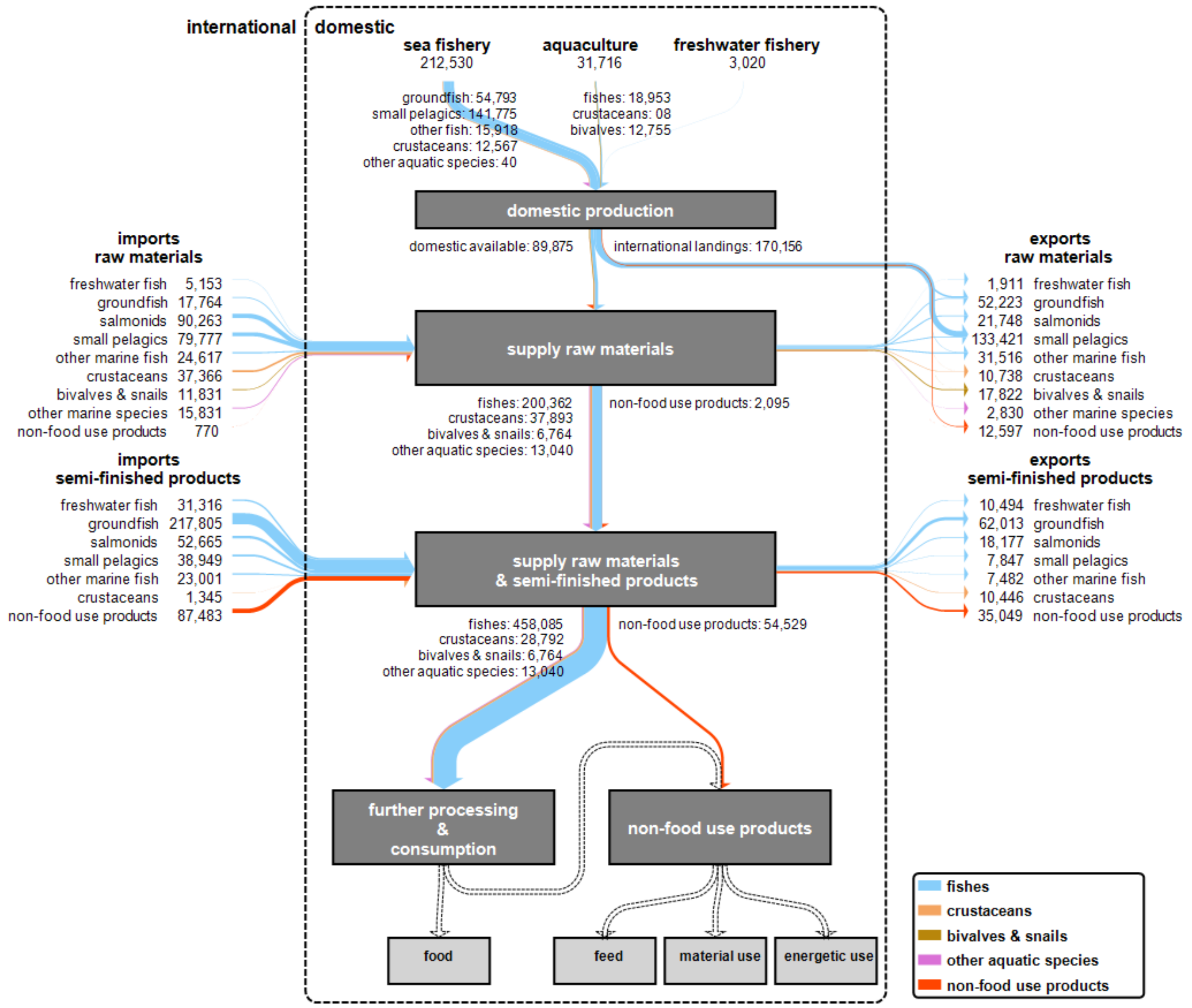
Material Flow of the most important Commodity Groups

Processing, trade and consumption take place at different levels of processed products. Figure 2.24 shows the material flow of fish and seafood considering the domestic production as well as import and export of raw materials and semi-finished products. Fish and Seafood is categorized into nine different commodity groups[3]. A closer look shows that the biggest flow of domestic production is the group “small pelagics” with the main species herring and mackerel. A small share of the fish from marine fishery is processed on board and therefore, counted as a semi-finished product. Furthermore, the majority of the catches of the German fishery was landed at international harbours. These amounts are not available for the German market if these goods are not imported afterwards. The import of raw material is dominated by the commodity groups “small pelagics” and “salmonids”. The species salmon and trout mainly represent the latter. On the export side of raw

[3] The groups rest on the commodity groups of EUMOFA. The groups “Flat Fish” and “Tuna and tuna-like species” were added to “Other marine fish”.

material, the commodity group “small pelagic” is the strongest due to the international landings, as mentioned before.

Figure 2.24: Material flow of relevant commodity groups of aquatic biomass in 2015 (in t product weight)



Source: own illustration; dashed arrows represent not quantifiable volumes

A comparison between imported raw material (282,602 t product weight for human consumption) and imported semi-finished products (365,081 t products weight for human consumption) shows that the main portion of imported goods was processed. Consequently, the section of the value chain where raw material is processed to semi-finished products for the German market takes mainly place abroad. For example, the products of the commodity group “groundfish”, such as Alaska pollock (*Theragra chalcogramma*), were mainly imported as frozen blocks and represented the largest share of imported semi-products. A further strongly represented commodity group in semi-finished products is the “non-food use products” with 87,483 t products weight, mainly non-edible by-products. On the other side, nearly half of this amount was exported.

The classification of products into commodity groups allows the calculation of the theoretically available amount of each group by balancing. Furthermore, the estimation of raw material for processing or consumption is possible. However, due to the lack of detailed domestic processing data and the trade with semi-processed products, a differentiation between these processing states is not possible. Therefore, only aggregations of raw material and semi-finished products for each commodity group can be calculated. In 2015, a total of 504,965 t product weight of raw material and semi-finished products for human consumption was available for further processing or final consumption. There is no information available at which state of processing the goods are consumed. For this reason, the quantification of the whole value chain is not possible with the available data. In addition to fish and seafood for consumption, 54,529 t of non-food use products, like non-edible algae or fish by-products, were available for feed or material use due to fisheries and international trade. Input of by-products based on domestic processing is not considered here but later on (for further information see Core product non-food use products).

Core Products

The analysis of core products enables the material flow from raw material to the use as a final product, as mentioned before. Within the analysis of aquatic biomass, products which show a quantitative relevance were chosen. Further selection criteria were the presentation of products with different locations of raw material sources and affiliation to commodity groups.

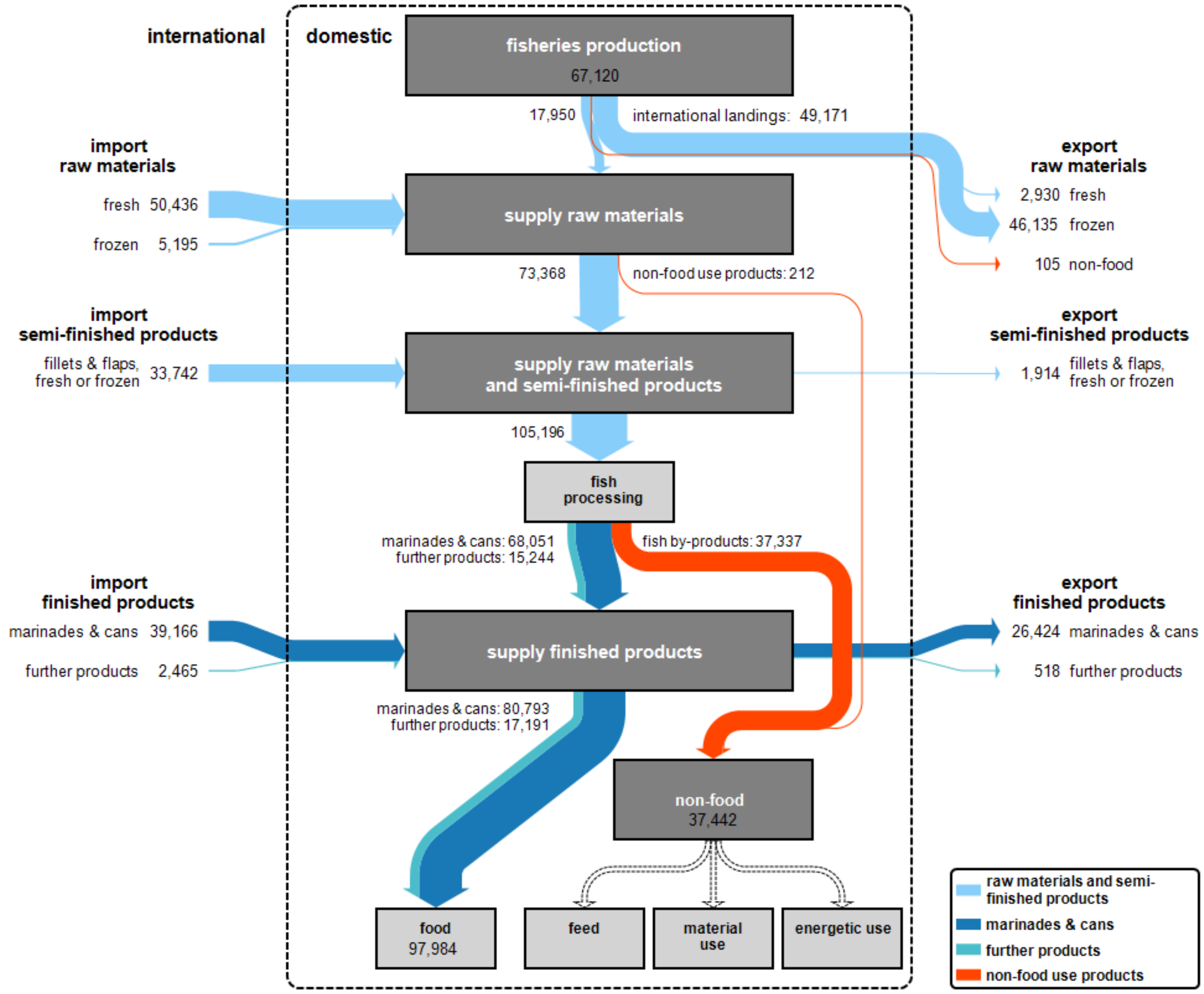
Based on the material flow of commodity groups, the following products were selected as core products:

- Marinades and cans based on herring (*Clupea harengus*): Herring is part of the commodity group “small pelagics” and caught by the German fleet as well as imported in large quantities. On the island of Rügen, a large processing plant for herring filleting is located. Marinades and cans based on herring are very popular in Germany, but are also exported to various countries.
- Fish fingers based on Alaska pollock (*Theragra chalcogramma*): The access to Alaska pollock is exclusively via import. The production of fish fingers is mainly located in Germany. During the process, frozen blocks in standardized size are used to produce fish fingers for the German and European market.
- Non-food use products: Non-food use products are a broadly based commodity group which requires an analysis due to the perspective increase of aquatic resources for material use.

Core Product Herring Marinades and Cans

In Germany, herring and its products play an important role in the fish processing industry and for final consumption. Finished products containing herring include different types of pickled and marinated herring. Figure 2.25 shows the material flow of marinades and cans based on herring, including imports and exports.

Figure 2.25: Material flow of the core product herring marinades and cans in Germany in 2015 (in t product weight)



Source: own illustration; dashed arrows represent not quantifiable volumes

German fishing vessels catch most of the herring in the North and Baltic Sea: the total catch amounted to 67,120 t in 2015. 73 % of it (49,171 t) was landed at international harbours, mainly as frozen fish. These landings are considered as exports. German production is not sufficient to meet the demand of the fish processing industry. 50,436 t of fresh herring were imported mainly by landings of foreign fleets in German harbours. This accounted to 39 % of the imported herring in total. Further 5,195 t of frozen herring were imported and the total supply of raw material amounted to 73,580 t. 33,742 t semi-finished products like filets or flaps were imported additionally. In total, 105,196 t of raw material and semi-finished products were available for further domestic processing and resulted in 68,051 t marinated and canned herring products, 15,244 t other herring products and 37,337 t fish by-products. The latter, together with herring not destined for human consumption constitutes an important source for fishmeal and fish oil production which is mainly used as feed. As for raw material and semi-finished products, imports also play an important role for the supply of finished products. Imported finished herring products amount to 41,631 t, about 94 % of these are marinated and canned. Exports of finished herring products amount to 26,424 t marinades and cans, and 518 t further products. Thus, the domestic consumption amounted to 80,793 t marinades and cans and 17,191 t further herring products.

During the quantification of this material flow, it became apparent that the official data were not sufficient to completely describe processing and the consumption. Some PRODCOM codes, e.g. frozen filets, are not species-specific and diverse fish species are contained. Therefore, assumptions have to be made to estimate the share of herring within these classifications. Furthermore, the estimation of the consumption of herring products could only be done by balancing. Finally, the household consumption and out of home consumption of raw material and semi-finished products could not be considered due to insufficient data.

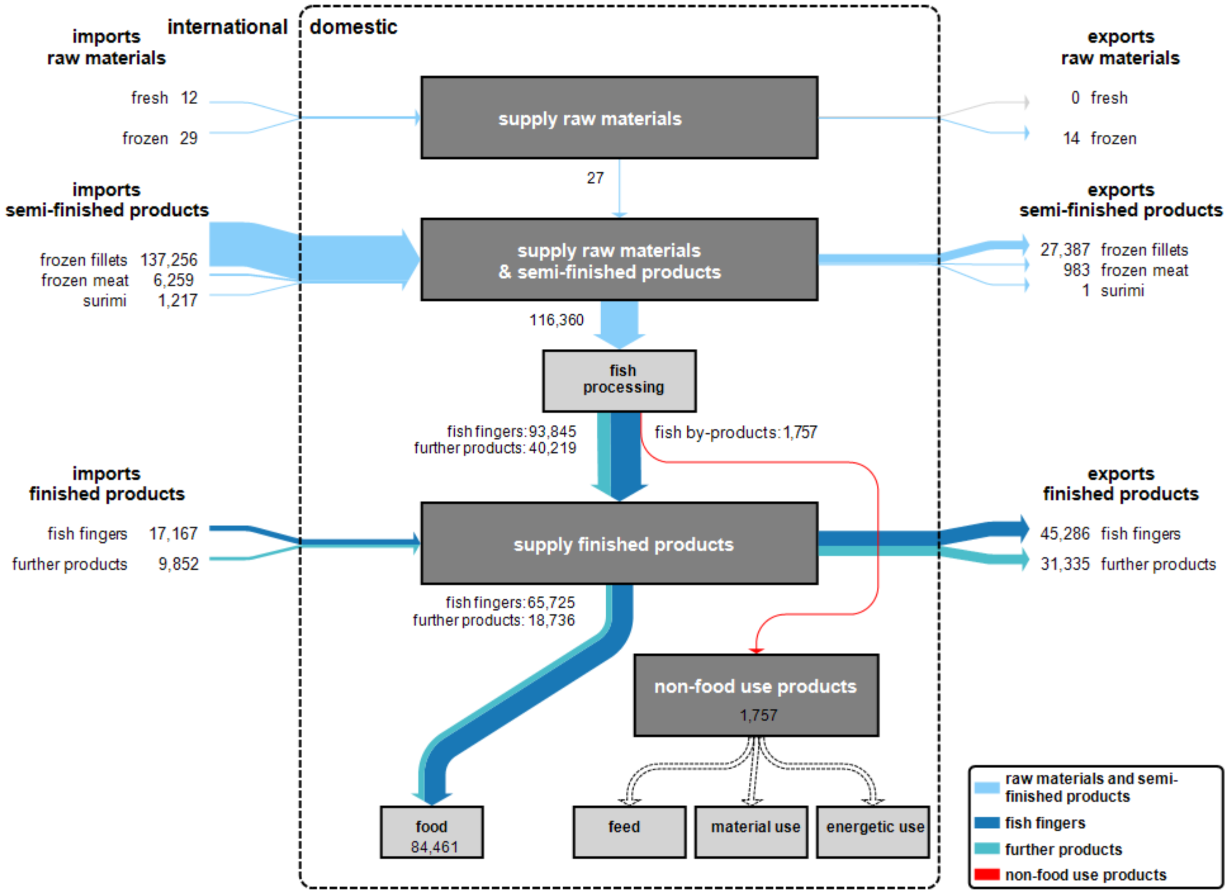
Changes in access to raw material, in this case due to changing fishing quota or even political events, e.g. Brexit, have a great impact on self-sufficiency and supply by third parties. These affect the domestic fish processing industry and consequently the added value.

Core Product Fish Fingers based on Alaska pollock

Alaska pollock (*Theragra chalcogramma*) is also a popular fish in Germany. Unlike herring, the access to Alaska pollock is solely by import. These were mainly caught in the Sea of Okhotsk and Bering Sea (FAO 2020) and imported from the USA, Russia and China (EUMOFA 2014) to Germany. Here, Alaska pollock is mainly processed to fish fingers. Figure 2.26 shows the material flow of this core product in 2015. It is notable that Alaska pollock is predominantly imported as frozen filets blocks, constituting 80 % (137,256 t) of the total import. The blocks are sawed to the required size; thereby, around 4 % sawing by-products arise. A part of these by-products is used for other fish products, e.g. fish cake or the fishmeal and fish oil production. The import of filet blocks implies that the majority of by-products are generated abroad.

In consideration of the export of unprocessed fish and semi-finished products, 116,360 t Alaska pollock are available for the fish processing industry. According to the production statistics, 166,403 t of products of the GP09 codes “Fish fillets in batter or breadcrumbs including fish fingers” were produced. The statistic does not consider which fish species is used. Besides Alaska pollock, further whitefish species like hoki, saithe, hake, cod or pangasius can be used (EUMOFA, 2014). Furthermore, no information about the amount of fish finger is available. Product research and expert interviews revealed that for the German market predominantly Alaska pollock is used and goods produced for the British and Italian market contain other fish species. Based on this information, it was estimated that 93,845 t fish fingers containing Alaska pollock were produced. 45,286 t of those were exported which makes Germany to a strong producer and exporter of fish fingers. In addition, 40,219 t of further Alaska pollock based products were produced and 31,355 t of those were exported. Taking into account the production and the international trade, a consumption of 65,725 t fish fingers and 18,736 t further Alaska pollock based products was calculated.

Figure 2.26: Material flow of the core product Alaska pollock fish fingers in Germany in 2015 (in t product weight)



Source: own illustration; dashed arrows represent not quantifiable volumes

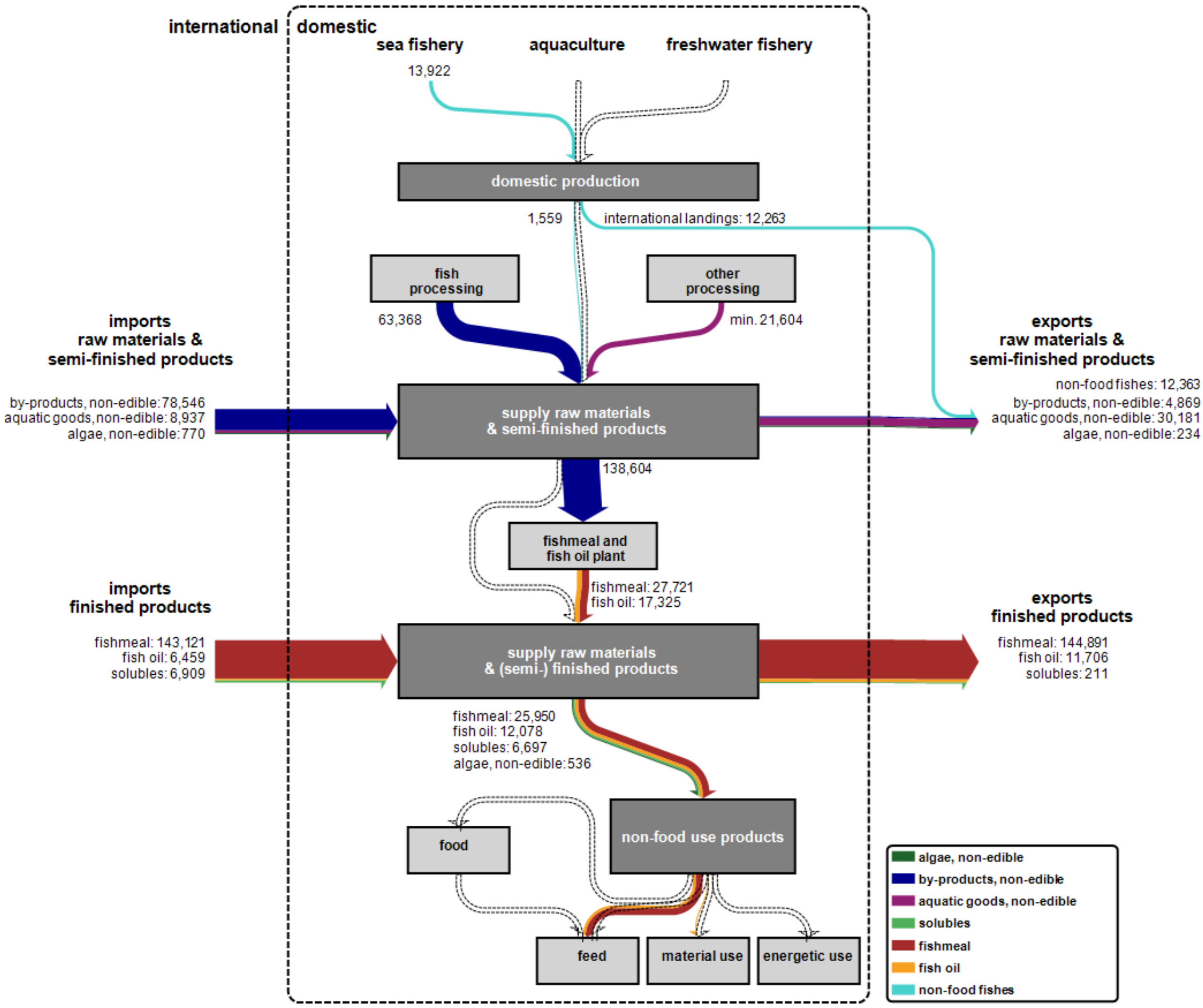
Similar to the core product herring marinades and canes, the allocation of the nomenclature of the international trade in goods statistic and production of manufactured goods statistic is not always explicit. Only with the help of market analysis and expert interviews proportions of GP09 codes were possible. These estimations require a regular update. Furthermore, the consumption of fish fingers could only be estimated by balancing the production and the international trade. However, the usage and consumption of semi-finished products like filets by restaurants, canteens or households could not be considered due to missing information.

Changes of access to the raw material are only indirectly depending on fishing quota. In fact, different countries compete for trade relations with the export countries and are dependent on political events. Both have a strong effect on the German processing industry and therefore, on the added value. Fortunately, the usage of standardized frozen blocks and standardized processes allows a simple substitute of Alaska pollock by other whitefish, if required.

Core Products Non-food use Products

Raw material for non-food use products like fishmeal and fish oil is mainly caught by specific fisheries targeting small pelagic species like sprat or sand eel. Another, though minor source is fish which is not useable for the consumer market, like undersized fish which is landed due to the discard ban. In 2015, the German fleet caught 13,922 t non-food fishes and 88 % of this amount was landed abroad (Figure 2.27). They were used for the production of fishmeal and fish oil.

Figure 2.27: Material flow of core product non-food use products in Germany in 2015 (in t product weight)



Source: own illustration; dashed arrows represent not quantifiable volumes

Some time ago, the fish processing industry recognized that by-products occurring during processing are no waste, instead they are valuable raw materials. The quantity of these by-products is not considered in the production statistic and data about fishmeal and fish oil production are declared as confidential. Based on expert interviews, the production of by-products is estimated to be around 63,000 t. Additionally, 78,546 t of fish waste were imported and both were used to produce approx. 28,000 t fishmeal and approx. 17,000 t fish oil (based on own estimations). In addition, 143,121 t fishmeal were imported and 144,891 t were exported. The largest part of the international trade takes place in Germany because fishmeal producing countries like Peru or Morocco supply the European market via Germany. The commodity group “aquatic goods, non-edible” (purple arrow) is insufficiently known but the negative external trade balance indicates that at least 21,600 t were produced in Germany. There is no information about the quantity and type of domestic utilization. Inedible algae, like seaweed, are also part of the non-food use products. Data about domestic algae production, edible or non-edible, are confidential but the positive external trade balance indicates a domestic utilization of at least 536 t. It is known that seaweed is used for production of hydrocolloids (alginate, agar-agar and carrageenan) and its application is in pharmacy, cosmetic industry and food additives industry (Netalgae 2012). Furthermore, a consumption of 26,000 t fishmeal and 12,000 t fish oil was calculated. All fishmeal was used as feed, in particular in pet food and aquaculture feed. Around 13 % of fish oil was used for material purposes, e.g. in the oleo-chemistry or as lubricating oil. The remaining fish oil was also used for feed production. Fish oil used for pharmaceutical purpose is not considered within this analysis because the raw material has to fulfill certain criteria and is part of other commodity groups.

By-products are also produced during preparation in fishmonger, canteens, restaurants and private households. These by-products are mainly not available for the fishmeal producers, instead they are disposed as residual waste or organic waste. The disposing enterprises use this waste to generate energy via biogas plants or waste incineration plants. The quantification of this usage was not possible.

The analysis of non-food use products is important because a large part is used as feed. Especially feed for aquaculture contains fishmeal and fish oil. These were mainly produced from captured fish for which there is little or no demand for human consumption. Globally, only 33 % of fishmeal and 26 % fish oil are based on by-products; in contrast the portion is 54 % of fishmeal and 47 % fish oil in Europe (Jackson and Newton 2016). Even though the used fish species have a low value, they can have a great effect on the ecosystem and food chain and the caught fishes originate mainly from sustainably managed stocks (SEAFISH 2018). Based on that and the scarcity of resources, it is expected that the sector of non-food use products will increase in future by expansion of industrial use of fish by-products as well as algae-based products.

The complete quantification of the material flow of non-food use products was not possible due to insufficient data information and data declared as confidential. Production volumes of fishmeal and fish oil for example could only be estimated after expert interviews. For a continuous monitoring, access to this information is required. However, expert interviews and market analyses need to be expanded in future to observe the changes within this sector, to identify new trends and to quantify and evaluate them.

2.5 Bio-based Shares of Sectors

2.5.1 Introduction

As outlined in chapter 2.4, material flows provide information on quantities of resources that are processed and used along processing and value chains. Such information provides insight into the efficiency of resource use and other indicators of sustainability. However, official, reliable data on material flows is scarce. On the level of economic sectors, more data is available. Official statistics have been developed focusing on comparisons on a monetary scale. Sectoral approaches use monetary information from official statistics for comparisons with other countries and for description of developments over time.

The sectoral approach to quantify bioeconomy uses the established system of economic classifications and the comprehensive data that is being published by statistical agencies. This approach uses the existing data that is traditionally and currently being used for description and evaluation of economic activities in the wider sense. Bioeconomy estimates based on sectoral data provide the basis for description of the development of bioeconomy over time and for comparisons between regions and countries (Ronzon and M'barek 2018).

A well-established example of a sectoral approach is the cluster of forestry and timber (TI-WF 2020a). The official definition of the cluster was elaborated in 1999 at European level (COM 1999) and provides the basis for collecting and analysing effects of wood use on the socio-economic parameters of turnover, value added, number of companies and number of jobs (Becher and Weimar 2020; Becher 2016). The definition of the cluster focuses on the value added across sectors that is derived from wood as a raw material. This resource-oriented definition of the cluster was built upon the challenges connected to strained supply situation for wood processing industries, the importance of wood-based value added in rural areas and the effects of wood use on the attainment of political goals regarding nature conservation, renewable energies and climate protection at the end of the 1990ies. The overall aim of establishing a cluster statistic was the identification of measures for increasing wood consumption as well as value added and competitiveness of wood use (Seintsch 2007).

Bioeconomy strategies follow this line of thinking and pick up on the idea of increasing use and consumption of wood and broaden the idea to all renewable biomasses. Underlying political objectives (see chapter 1) are very similar to the objectives the development of the cluster of forestry and timber was based upon. Sectoral approaches for defining and estimating bioeconomy can be divided into output- or input-based approaches. In both approaches, the first step of the analysis is the selection of relevant economic activities, i.e. those that are considered bio-based. However, the criteria for selection differ: criterion is either the content of renewable resources in the product, i.e. the OUTPUT of an economic activity (Piotrowski et al. 2016), or the share of renewable resources that is used for an economic activity, i.e. the INPUT (Efken et al. 2012; Efken et al. 2016; Aarne and Hautakangas 2018).

2.5.2 Data and Methods

The development of our sectoral approach premised on cluster statistics for forestry and timber, the output-based approach as described by Piotrowski et al. (2016) and the input-based estimates of Efken et al. (2016; 2012). Coming from a biomass production perspective and thinking along the lines of biomass processing, we focused on the input-based approach and extended it with information on biomass contents in products of NACE section C (manufacturing), if data of inputs into economic activities was not available or ambiguous. This extended input-based sectoral approach has been described in detail by Iost et al. (2019). After publication, the approach was refined to reduce the risk of overestimation of bio-based shares. In the following, the refined calculation methods for the relevant bioeconomy sectors are described for each sector. Resulting bio-based shares are then presented (chapter 2.5.3) and discussed (chapter 2.5.4)

2.5.2.1 Manufacturing

Manufacturing (NACE section C) comprises 24 divisions with a total of 260 subclasses. Therefore, it is the most differentiated section of NACE 2.0 classification. A large part of biomass is used for material purposes in these highly diverse economic activities of section C which makes them decisive for implementing bioeconomy. It can be expected that a major share of substitution of fossil with renewable materials and resources will be realized in manufacturing activities.

Basically, bio-based shares for manufacturing are estimated by evaluating material inputs into NACE classes (4 digits) of economic activities, i.e. following an input-based approach. Data is provided by the Material and Goods received Enquiry (MGrE). As described in chapter 1.2., inputs are categorized into raw materials and auxiliary materials (I), consumables including packaging (II) and fuels/combustibles (III). Category IV states the sum of all inputs (I − III). The applied calculation method (Iost et al. 2019) served as a basis for calculating bio-based shares in the years 2010 to 2017. However, we made some adjustments of the method that will be explained hereafter.

In a first step, Iost et al. (2019) classified all inputs of category I either as fully, partially or non-bio-based. For partially bio-based inputs, detailed production statistics data was used to calculate the bio-based share of an input of category I (Iost et al. 2019, Equation 2.5.1).

$$\boldsymbol{bbs} = \frac{\sum_i \boldsymbol{pv9_i}}{\boldsymbol{pv4}} \qquad \text{Equation 2.5.1}$$

where

bbs	bio-based share of input
i	number of bio-based products (at 9-digit level) of respective goods class (4 digits)

$pv9$	production value (at 9-digit level) of fully and/or partly bio-based products
$pv4$	total production value (at 4-digit level)

Production statistics provide an indication of the monetary value of products, consequently this calculation follows an output-based approach. Due to data and information restraints, we decided to calculate minimum and maximum bio-based shares of inputs in order to give a span of bio-based shares rather than less reliable fixed results (Iost et al. 2019, Eq. 2.5.2).

$$\boldsymbol{bbs_{min}} = \frac{\sum_j \boldsymbol{pv9_j^{min}}}{\boldsymbol{pv4}};\ \boldsymbol{bbs_{max}} = \frac{\sum_k \boldsymbol{pv9_k^{max}}}{\boldsymbol{pv4}} \qquad \text{Equation 2.5.2}$$

where

bbs_{min}	minimum bio-based share of a product (at 9-digit-level)
j	products (at 9-digit level) with full bio-based products value
bbs_{max}	maximum bio-based share of a product (at 9-digit-level)
k	products (at 9-digit level) with full or partial bio-based products value

In the second step, minimum and maximum bio-based shares of economic activity classes (i.e. NACE classes) were calculated (Iost et al. 2019, Equations 2.5.3 & 2.5.4) as the share of bio-based material inputs of all inputs (MGrE code 990).

$$\boldsymbol{bbNACE}_{min} = \frac{\sum_p ac_{\boldsymbol{input}_p} * bbs_{min}}{total\_inputs} \qquad \text{Equation 2.5.3}$$

where

$bbNACE_{min}$	minimum bio-based share of economic activity as expressed by 4-digits NACE code
ac_input	acquisition costs of inputs into economic activity in EUR (MGrE)
$total\_inputs$	total acquisition costs of economic activity in EUR (position **990** MGrE)
p	inputs

$$\boldsymbol{bbNACE}_{max} = \frac{\sum_p ac\_input_p * bbs_{max}}{total\_inputs} \qquad \text{Equation 2.5.4}$$

where

$bbNACE_{max}$ maximum bio-based share of economic activity as expressed by 4-digits NACE code

In evaluating the published method, it became evident that it neglects possible bio-based shares of input categories II and III. For example, wooden or paper packaging (category II) can be considered bio-based, goods used in canteens cover food and electricity (category III), which is in part generated from biomass. In order to take this into account and to estimate bio-based shares of economic activities more accurately, two approaches were considered: (i) estimating the bio-based share of the inputs in categories II and III and (ii) calculating bio-based shares based only on inputs of category I.

Following the first approach, it becomes apparent that the coding of the inputs in categories II and III is the same for all economic activities surveyed by MGrE. Bio-based shares of inputs of categories II and III would then be the same for all surveyed economic activities. The underlying assumption would then be that all economic activities use the same amount of, for example, wooden packaging or biomass-generated electricity. This assumption is very likely to be invalid and data to calculate economic activity-specific bio-based shares for these inputs is lacking. Furthermore, integrating bio-based shares of categories II and III includes the possibility of double counting as the inputs of categories II and III are also outputs of economic activities included in MGrE.

Consequently, we chose the second approach and calculated bio-based shares as the relation of bio-based inputs of category I to the sum of category I, leaving out inputs of categories II and III. Inputs of category II can be considered as outputs of economic activities of which material inputs (category I) are covered by this calculation. Energy and fuel inputs (cat. III) are covered by calculating the bio-based shares of NACE section D (chapter 2.5.2.2). Consequently, Equations 3 and 4 in Iost et al. (2019) are adjusted as total inputs are no longer referenced to MGrE code 990, but to MGrE code 910 (Equations 2.5.5 and 2.5.6):

$$\boldsymbol{bbNACE}_{min} = \frac{\sum_p ac_{input_p} * bbs_{min}}{total\_inputs} \qquad \text{Equation 2.5.5}$$

where

$bbNACE_{min}$ minimum bio-based share of economic activity as expressed by 4-digits NACE code

ac_input acquisition costs of inputs into economic activity in EUR (MGrE)

$total\_inputs$ total acquisition costs of economic activity in EUR (position **910** MGrE)

p inputs

$$\boldsymbol{bbNACE}_{max} = \frac{\sum_p ac\_input_p * bbs_{max}}{total\_inputs}$$ Equation 2.5.6

where

$bbNACE_{max}$ maximum bio-based share of economic activity as expressed by 4-digits NACE code

As noted in Iost et al. (2019), the Material and Goods received Enquiry (MGrE) is provided only every four years and we used data on 2010 and 2014. In a continued monitoring, annual estimates are of interest and importance to describe bioeconomy development and to elaborate political steering measures. The methods described above provide several starting points for updating interpolation of MGrE results in combination with further statistics and data:

Classification of MGrE category I inputs as either fully, partially or non-bio-based must be updated regularly based on information on substitution of fossil resources. As noted above, increased material use of biomass is expected to occur in products assigned to economic activities of NACE section C. Expert opinions, market and empirical studies on material biomass use (e.g. Dammer et al. 2017; Lammens et al. 2017) as well as information provided by economic associations are used in updating bio-based products. This update should be done as soon as new information is available or new studies are published.

The second starting point for updating bio-based shares are annual production statistics. Bio-based shares of MGrE inputs are calculated as the share of production value of partially or fully bio-based products (Iost et al. 2019, Eq. 2.5.1). This calculation can be done annually. In combination with an updated classification of bio-based products, an increased share indicates either increased production of a product, more bio-based products or just increased prices of the product or increased production costs. Thus, changed bio-based shares must be evaluated carefully.

For the annual estimation of bio-based shares, MGrE data is extended with annual data from cost structure statistics. Cost structure statistics and MGrE base on the same sample of companies and are interconnected. Both survey total acquisition costs. As noted above, this indicator is coded 990 in MGrE. The amount given there equals the sum of inputs and traded goods as stated in cost structure statistics and provides numbers on total inputs ("Eingänge an Rohstoffen und sonstigen Vorprodukten, Hilfs- und Betriebsstoffen") and traded goods ("Eingänge an Handelsware") for the respective company and economic activity (DESTATIS 2020d). Thus, total acquisition costs for economic activities are available annually. Further information on the composition of these inputs is provided every four years by MGrE. Based on the annually available data on total acquisition costs, we calculated annual bio-based shares.

We made two assumptions: First, the distribution of acquisition costs into categories I – III remains unchanged within one MGrE period (4 years) and second, the distribution of MGrE category I inputs remains unchanged. The distribution of inputs of MGrE 2010 is transferred to cost structure data of the years 2011 – 2013 and of MGrE 2014 to cost structure of 2015 to 2017. MGrE data of 2018 will be available in 2020 and the distribution of inputs reported there will be used on cost structure data of 2021 to 2023.

2.5.2.2 Electricity, Gas, Steam and Air Conditioning Supply

Bio-based share of NACE code 35 is derived from the ratio of conversion input of biomass to conversion input of all energy carriers. Main data source is the energy balance for Germany and its satellite balance (AGEB 2015). This energy balance provides information on all energy that is converted and includes energy conversion from different economic activities. This balance is used for calculating the bio-based share of NACE division 35. For this, we will later select only the energy conversion that happens in economic activities of the selected division.

The energy balance annually documents supply, conversion and use of energy carriers in Germany in form of a matrix. Columns represent energy carriers that may be used for energy generation but also for material uses. An energy carrier is a source or substance in which energy may be stored in mechanical, thermal, chemical or physical form (AGEB 2015). Rows differentiate the balance into three main parts: primary energy balance, conversion balance and consumption. Primary energy balance is further differentiated into supply types like domestic production or imports. The conversion balance is divided into conversion in- and output. Each is further differentiated in types of conversion, i.e. type of energy generation or asset type. Consumption is disaggregated according to economic activities. Energy balance is provided in different units: joule, coal equivalent, and natural units.

For calculation of bio-based shares, we use the conversion balance data, as only for energy conversion detailed information of used energy carriers (biomass) and the asset type is available. Bio-based shares can only be calculated for those asset types that can be assigned to economic activity codes. We use energy balance data in joule, as joule is commonly used and energy balance data can be easily compared to other data sources.

In detail, in a first step, we sum up total conversion input (column AI “Summe”) for rows 11 – 16 (row number is indicated in column B) (Equation 2.5.7). These rows represent conversion or asset types that can be assigned to economic activities of NACE code 35.

$$\boldsymbol{conversion\ input}_{total} = \sum_{r=11}^{16} column\ AI\ ("Summe") \qquad \text{Equation 2.5.7}$$

where

r	rows of conversion balance
AI (Summe)	total conversion input

In a second step, conversion input from biomass in column AA is summed up for the same rows of the conversion balance (Equation 2.5.8).

$$\boldsymbol{conversion\ input}_{biomass} = \sum_{r=11}^{16} column\ AA \qquad \text{Equation 2.5.8}$$

where

AA biomass conversion input

Finally, the bio-based share of NACE code 35 (bb_share(35)) is calculated as the ratio of biomass and total conversion input (Equation 2.5.9).

$$\boldsymbol{bb\_share}(\mathbf{35}) = \frac{biomass\ conversion\ input}{total\ conversion\ input} \qquad \text{Equation 2.5.9}$$

When applying the described method, it must be considered that energy is also generated in other economic activities besides those in division 35 that are included in the conversion balance. Companies are assigned to NACE categories according to their activities that generate the highest share of value added (DESTATIS 2008). However, the company may also produce energy or heat besides their major activity. One example is the heat generation out of wood processing residues in sawmilling. In the conversion balance, this type of energy production is represented by row 12 (industrial power stations, electricity only). This amount of energy converted here should be excluded from calculations of the bio-based share of division 35, because actually this type of energy conversion occurs in economic activity division C (Manufacturing) and cannot be used for calculating bio-based shares of division D.

Also, conversion of gas from purification plants should not be assigned to division 35. As of today, purification gas is produced in water purification plants and used for energy production at site. Consequently, purification gas is part of division 37. In the satellite balance of the energy balance, renewable energy carriers are covered in more detail, but gas from purification plants is included in biogas, but its share cannot be determined. We are expecting methodological advancement for the satellite balance and will adjust our method in a future monitoring accordingly. Furthermore, there are approaches to use purification gas more flexible and also as energy carrier in power plants of division 35 (Obermaier et al. 2018). Consequently, the calculation method will be updated in a future monitoring.

A substantial number of farmers operate biogas plants as sideline businesses. These companies are assigned to NACE section A. Biogas documented in the energy balance refers to biogas converted in companies of section A and E (division 35). Consequently, the share of biogas attributed to companies of division 35 is lower than documented in the energy balance. This issue will possibly be addressed in a next step of the monitoring.

2.5.2.3 Construction

In construction (NACE section F), four economic activities are relevant within bioeconomy (see Table 2.1). While joinery installation (43.32.0) and roofing activities (43.91.2) are fully included in our bioeconomy definition, for construction of residential and non-residential buildings (41.20) bio-based shares are calculated based on official data on construction permits (DESTATIS 2018b), which provide information on cubic content of buildings differentiated into mainly used building material. Based on this, timber construction rate is calculated as the relation of cubic content of buildings mainly made of wood to the cubic content of all buildings.

2.5.2.4 Professional, scientific and technical Activities

NACE section M summarizes different professional, scientific and technical activities. As noted in our definition, bio-based services are a relevant part of bioeconomy. However, consistent methodology for estimating bio-based shares of services is still not established and data seems to be lacking. Referring to the example of forest-based bioeconomy, Pelli et al. (2017) point out that the role of services in the context of bioeconomy is just evolving.

Pelli et al. (2017) state that in literature, the role of knowledge-intensive business services such as research & development are important for growth and innovation in other sectors. Consequently, research in bioeconomy-related sectors must be included in bioeconomy estimates. Due to its high relevance for developing bioeconomy (BIOCOM AG 2013), we fully included NACE code 72.11.0, i.e. research and experimental development on biotechnology (NACE section M). NACE code 72.19.0 (Other research and experimental development on natural sciences and engineering) was partially included (Aarne and Hautakangas 2018).

We estimated the bio-based share of NACE code 72.19.0 using official statistics on public sector expenses (DESTATIS 2016a). From the variety of data and disaggregation this survey provides, we used internal expenses for research and development of public sector scientific institutions, differentiated into science fields (Table 3.2 of the survey). Public sector scientific institutions include national, federal and municipal Research Institutions, Helmholtz Centers, Max-Planck Society, Fraunhofer research organization, Leibniz Association, other publicly funded organisations in science and research like universities, scientific libraries, archives and museums. These research institution categories reflect the structure of public research in the German research and innovation system (BMBF 2018a, Fig. II.1).The data refers only to expenses directly related to research and development. Expenses related to administration and IT infrastructure are excluded. We used expenses for personnel as public sector institutions usually pay similar wages according to the public wage agreement which allows for comparison of the institutions.

Disaggregation into science fields of the used data does not directly reflect NACE categories. According to EUROSTAT, NACE Rev. 2 code 72.19.0 includes research and engineering on natural sciences, engineering and technology, medical sciences, agricultural sciences and interdisciplinary research with focus on fields listed above. Thus, we assign the following categories of Table 3.2 in DESTATIS (2016a): mathematics and natural sciences; medical sciences and humanities; agricultural, forest and nutritional sciences; engineering sciences. These categories are further divided. From these subcategories, we selected those with high relevance for bioeconomy. The assigned subcategories are chemistry, pharmaceutics, biology, geoscience, agricultural, forest and nutritional sciences and also engineering sciences.

In engineering sciences, research in architecture and construction engineering is relevant for bioeconomy when it comes to wood construction. Here, especially in multi-storey wood construction, advances are currently made. Thus, we calculated the contribution of this science field in relation to wood construction share (chapter 2.5.2.3).

We calculated the bio-based share as the sum of personnel costs of all selected subcategories in relation to the sum of personnel costs for all categories assigned to NACE code 72.19.0. As we fully attributed NACE code 72.11.0 to bioeconomy, we calculated a weighted mean of 72.11.0 and 72.19.0, using turnover data from structural statistics in the service sector (DESTATIS 2020c, 47415-0009). Data on value added is not available for this NACE section.

2.5.3 Results

Table 2.2 summarizes bio-based shares of all sectors assigned to bioeconomy for the years 2010 to 2017. For section C (manufacturing), minimum and maximum bio-based shares of sub-sections are displayed. As described in chapter 2.5.2.1, bio-based shares were calculated for selected NACE classes (4-digit level). In order to give a better overview, we aggregated this data on the level of NACE divisions (2-digit level) using turnover data provided by EUROSTAT (2018e). For aggregation, NACE classes with bio-based shares ≥ 10 % were selected. As discussed in Iost et al. (2019), such a cut-off allows for neglecting minor biomass flows, especially, if these cannot be quantified reliably. Thus, Table 2.2 shows manufacturing divisions that include NACE classes having a bio-based share of at least 10 %. For sections other than C, Table 2.2 displays class and division bio-based shares.

Table 2.2: Bio-based shares of selected NACE codes

Section	Sub-section	Description	2010		2011		2012		2013		2014		2015		2016		2017	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
C	10	Manufacture of food products	0.96	0.97	0.96	0.97	0.96	0.97	0.96	0.96	0.96	0.97	0.96	0.97	0.96	0.97	0.96	0.97
C	11	Manufacture of beverages	0.89	0.90	0.89	0.90	0.89	0.90	0.89	0.90	0.90	0.90	0.90	0.91	0.90	0.91	0.90	0.91
C	13	Manufacture of textiles	0.19	0.38	0.17	0.36	0.18	0.37	0.17	0.36	0.14	0.35	0.12	0.33	0.12	0.33	0.12	0.34
C	14	Manufacture of wearing apparel	0.21	0.56	0.19	0.55	0.20	0.56	0.18	0.55	0.17	0.57	0.16	0.56	0.17	0.56	0.14	0.51
C	15	Manufacture of leather and related products	0.49	0.73	0.49	0.72	0.49	0.72	0.48	0.73	0.47	0.85	0.38	0.75	0.38	0.76	0.48	0.86
C	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.81	0.84	0.82	0.84	0.82	0.84	0.82	0.85	0.77	0.80	0.77	0.80	0.77	0.80	0.77	0.82
C	17	Manufacture of paper and paper products	0.73	0.78	0.72	0.78	0.73	0.78	0.73	0.79	0.78	0.83	0.78	0.83	0.78	0.83	0.78	0.86
C	18	Printing and reproduction of recorded media	0.73	0.79	0.73	0.79	0.73	0.79	0.73	0.79	0.75	0.79	0.75	0.79	0.75	0.80	0.75	0.83
C	20	Manufacture of chemicals and chemical products	0.06	0.11	0.06	0.11	0.06	0.10	0.06	0.10	0.04	0.09	0.04	0.09	0.05	0.10	0.04	0.11
C	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.11	0.42	0.11	0.40	0.01	0.01	0.01	0.01	0.12	0.42	0.13	0.39	0.13	0.41	0.13	0.42
C	22	Manufacture of rubber and plastic products	0.08	0.09	0.08	0.09	0.08	0.09	0.08	0.09	0.09	0.10	0.08	0.09	0.09	0.10	0.10	0.11
C	23	Manufacture of other non-metallic mineral products	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
C	30	Manufacture of other transport equipment	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03
C	31	Manufacture of furniture	0.39	0.46	0.39	0.46	0.39	0.46	0.39	0.46	0.34	0.42	0.34	0.42	0.34	0.42	0.34	0.43
C	32	Other manufacturing	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02
D	35	Electricity, Steam and air conditioning supply	0.09		0.10		0.08		0.08		0.09		0.09		0.09		0.10	
D	41	Construction of buildings	0.08		0.07		0.06		0.06		0.06		0.06		0.06		0.06	
F	41.20	Construction of residential and non-residential buildings	0.10		0.09		0.09		0.08		0.08		0.08		0.07		0.08	
F	43	Specialised construction activities	0.12		0.12		0.11		0.12		0.12		0.12		0.12		0.13	
F	43.32.0	Joinery installation	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
F	43.91.2	Roofing activities	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
I	56	Food and beverage service activities	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
M	72	Scientific research and development	0.38		0.38		0.37		0.37		0.36		0.37		0.35		0.35	
M	72.11.0	Research and experimental development on biotechnology	1.00		1.00		1.00		1.00		1.00		1.00		1.00		1.00	
M	72.19.0	Other research and experimental development on natural s	0.31		0.32		0.31		0.31		0.30		0.32		0.29		0.30	

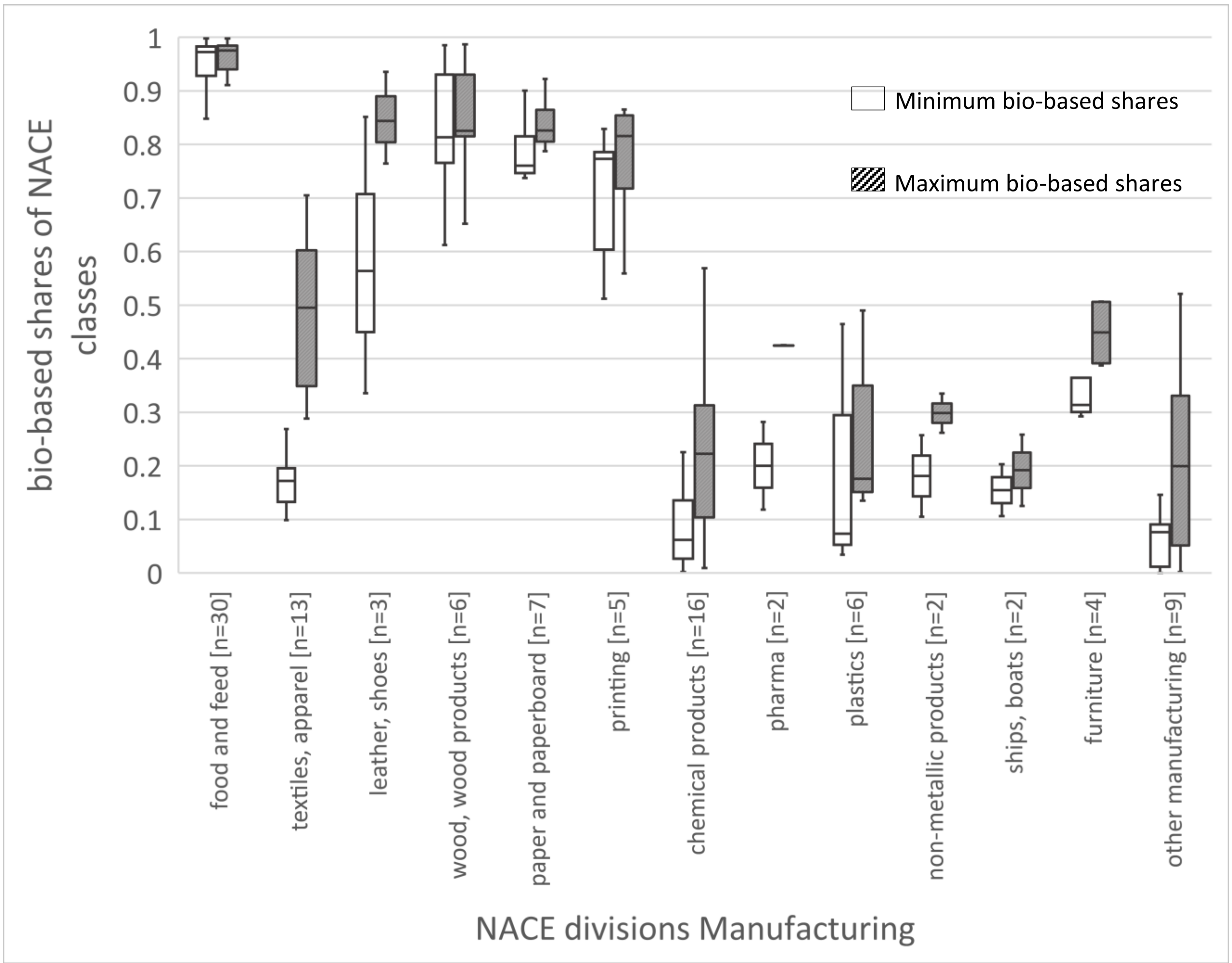
Source: own calculations

In manufacturing, economic activities related to food and beverages have the highest bio-based shares, which range between 0.89 and 0.97 in the years 2010 to 2017. Manufacture of wood and wooden products, paper and paper products and also printings show stable bio-based shares during the selected time period. Production of textiles and wearing apparel, leather products and manufacturing of furniture also use considerable amounts of biomass which is reflected in bio-based shares ranging from 0.39 to 0.79. These economic activities traditionally use and process biomass. In division 21, the bio-based shares in 2012 and 2013 are surprisingly low, which can be explained with the application of a 10 % cut-off threshold we applied (Iost et al. 2019). In 2012 and 2013, the bio-based share of NACE class 21.20 (manufacture of pharmaceutical preparations) was below 10 %. Thus, turnover of this class was excluded from calculating the bio-based share of division 21 which resulted in a considerably decrease of the bio-based share.

However, in an evolving bioeconomy, fossil resources are expected to be increasingly substituted by renewable resources, for example in manufacture of chemicals and chemical products which also includes plastics. At the highly aggregated level, no trend of increasing bio-based shares can be detected. The maximum shares are quite stable over the examined years and range between 0.10 and 0.11. Minimum bio-based shares are even declining from 0.06 to 0.04. Substitution has only taken place during the last years and the time period covered in our study may just not include years where substitution gained detectable impact. Furthermore, bio-based shares are calculated based upon official statistics that are structured according to internationally harmonized classifications. These classifications represent a certain status quo of economic activities and their outputs. New processes and products that we expect from bioeconomy must be included or visible in these classifications in order to be detected using the method presented here. Consequently, with upcoming changes in classifications, we expect to see trends in bio-based shares in the coming years.

Figure 2.28 shows bio-based shares of NACE classes of section C (manufacturing) in more detail. As described by Iost et al. (2019), NACE classes with bio-based shares of less than 10 % were excluded from the estimation. In Figure 2.28, the bio-based shares of selected NACE classes are grouped according to their NACE division. Relevant divisions and numbers of respectively included NACE classes are displayed on the x-axis. For each division, the box-whisker plot shows minimum and maximum (whiskers), first and third quartile (box) and the median (line in the box) of bio-based shares of corresponding NACE classes. For each division, results for minimum and maximum bio-based shares are given. The variation of the bio-based shares of food and feed is smallest, the shares range from 0.9 to 0.99. Economic activities involving wood, wooden products, paper and paperboard and printings also have high bio-based shares.

Figure 2.28: Bio-based shares of selected NACE divisions in 2014 (classes with bio-based shares >=10 %)



Source: own calculations based on Iost et al. (2019)

Medium bio-based shares occur in textiles and apparel, leather and shoes, chemical products and plastics. These divisions show high variation which indicates higher uncertainties in the applied method like smaller degree of detail in the official statistics, high heterogeneity within classification units and lack of data on biomass contents in products.

When we assigned economic activities to bioeconomy in the first place (see chapter 2.3), we did not consider manufacture of non-metallic products (NACE division 23) as well as manufacture of ships and boats (NACE division 30) as bio-based. However, our results show that in each of these divisions, two NACE classes have bio-based shares of at least 10 %. For manufacture of non-metallic products, maximum bio-based shares are estimated to reach more than 30 %. In division 23, bio-based economic activities are the manufacture of ready-mixed concrete (23.62) and manufacture of fibre cement (23.65). In both activities, cellulose is used as an additive. In division 30, building of ships and floating structures (30.11) and of pleasure and sporting boats (30.12) is bio-based.

Consequently, the applied method using official statistics is able to detect bio-based economic activities and can be used in the future for detecting also new bio-based activities.

2.5.4 Discussion and Conclusions

Bio-based shares are the result of tracing biomass and its processing within the economic system, but they refer to aggregated economic categories and lay the foundation for indicator application and sectoral sustainability assessment.

Methods for estimating bio-based shares in economic sectors that use biomass either as a raw material, semi-finished or finished product face certain uncertainties. First of all, if we rely on official statistics, the degree of differentiation in the underlying official classifications determines to a large degree the level of differentiation in bioeconomy estimates. From official statistics, we can only detect what is reflected in statistical classifications. If bio-based and non-bio-based economic activities are not differentiated, additional data, studies or expert opinions are needed to define reliable bio-based shares. The same is true for classification units that include a high variety of products or economic activities. In the future, adjustments of classifications may provide a better basis for estimating bio-based shares of economic activities based on official statistics.

The method presented here determines bio-based shares by using information of production from official statistics on the least aggregated level that this statistic provides. Products are classified as bio-based, non-bio-based or mixed. This distinction often cannot be made unambiguously. Secondly, production statistics often miss production value for single product codes due to the non-disclosure policy of the Federal Statistics Agency that we use for calculating bio-based shares. Furthermore, the official data sources used here, i.e. production statistics and MGrE, only cover companies having 20 or more employees. Consequently, new bio-based products that are produced by smaller companies are not covered. This may constitute a major data gap, as SMEs are key actors in the transition to a circular bioeconomy (Hansen 2016; D'Amato et al. 2020) and are able to commercialize product innovations (Andries and Faems 2013).

This required the use of secondary statistics, empirical studies and expert estimates. From this we conclude that a future bioeconomy monitoring must include constant market observation and consultation of experts in order to take bioeconomy-related innovations in processes and products into account. Expert opinions and estimates will remain an important source of information needed to quantify bioeconomy, even if official statistic classifications will be adjusted to the information needs of an economic system that uses more renewable resources and is more circular (see also Iost et al. 2019).

The applied 10 % cut-off has a large impact on socio-economic indicators of bioeconomy (Iost et al. 2019), as NACE classes are excluded from bioeconomy estimates. The 10 % cut-off initially was chosen to have an operational basis for developing the estimation method. Due to the broad variety of biomass uses, bio-based products and processes and the fast progress in substitution that is made in certain parts of the economy, small bio-based shares often cannot be determined reliably, especially not based on official classifications and data. Thus, the 10 % cut-off deliberately neglected these small biomass flows. Results in Iost et al. (2019) show, however, that smaller cut-off percentages must be tested and adjusted continuously in order to give reliable estimates of the bioeconomy.

In comparison to bio-based shares published by Iost et al. (2019), the bio-based shares presented here range slightly lower. This is a result of the adjusted method, which calculates shares based on all material inputs instead of all inputs (see chapter 2.5.2.1).

The result of our calculations is a time series for 2010 to 2017 that can be updated. For updating, data of different periodicity is used. First, we use annual production statistics data on production value for calculating bio-based shares of product groups. This data is available annually and fits methodological standards that allow for comparison between years and therefore, also for time series estimation. Secondly, we use data on inputs into economic activities that is updated every four years (MGrE). This data provides information on the distribution of all inputs which are considered stable during the survey period. The underlying assumption is that during four years, sudden innovations or a change in technology that causes a change in the distribution of inputs into an economic activity is not very likely. This assumption may not be accurate, but any other assumptions about possible changes of the input distribution may also be inaccurate as there is no data. Thus, data from one survey referring to one year is used for all years until the next survey. Changes of input distribution can therefore only be detected every four years which may result in sudden changes of the time series. Furthermore, sudden changes may be caused by empirical study results that help classifying product codes into bio-based or non-bio-based (like Lammens et al. 2017). Due to innovation, bio-based products may become relevant at the market and then have an effect on bio-based shares of product groups and on the time series. However, the dynamics of bio-based innovation and market penetration cannot be estimated. Consequently, we decided to use only actual data without inter- or extrapolation of data points. In a future monitoring and with more information on innovation, market penetration and consumer's acceptance of bio-based products will be available, calculation methods can be adjusted or even calculation models developed in order to inter- or even extrapolate the available empirical data or revise the whole time series.

As described in Iost et al. (2019) using the same bio-based shares of bioeconomy sectors for calculating different socio-economic indicators (chapter 3.4) assumes that "all inputs equally contribute to" the selected indicators. This neglects that the use of renewable resources might contribute differently to the chosen indicators and the fact that sectors are more labour- and/or capital-intensive as others. In that context, Iost et al. (2019) point out that similar assumptions are used in Life Cycle Assessments (Weidema 2014; Weidema and Schmidt 2010). More importantly, the major part of official statistics in Germany, but also on the EU level that allows differentiation of economic activities focuses on monetary indicators. For example, one of our major data sources that provides data on inputs in economic activities, refers to acquisition costs (in €) and not to amounts.

3 Sustainability Assessment

3.1 Concept & Indicators

In line with the two bioeconomy monitoring scopes, our suggested assessment of sustainability effects foresees two complimentary levels of evaluation: the level of material flows and the economy-wide sectoral level. Sustainability assessment on the sectoral level quantifies the total effects of bioeconomy in a country and puts them into perspective with the whole economy or parts of it. Deeper analysis of biomass flows within the national bioeconomy, its sources, respective value chains, products and caused sustainability effects are quantified by the material flow-based approach.

Thus, the assessment of sustainability effects on the sectoral level allows

- to quantify the size and importance of bioeconomy on the national level for key economic, social and environmental indicators
- to assess the contribution of bioeconomy in achieving selected SDGs
- to analyse the structure and importance of the respective economic sectors within bioeconomy, their performance and hot spots
- to compare bioeconomy with other branches or group of branches (e.g. bioeconomy versus processing industry or fossil-based industry)

Measuring sustainability effects of material flows, on the other side, is aiming at

- Providing detailed information about the sustainability effects of biomass resources and their processing steps up until the level of particular products including recycling and disposal.
- Assessing environmental, economic and social effects of different bio-resources and thus identify hot spots, potentials for improvement, such as e.g. increasing efficiency, reducing waste, cascade using.
- A comparison of bio-based products with fossil or bio-based references.

The starting point for assessments of sustainability effects under both concepts is the operational definition of the bioeconomy as described in chapter 2.3 ”Definition and Operationalisation“. This definition is the basis for determining the scope and system boundaries of the assessment of sustainability effects.

Since sustainability is a normative term, it leaves room for interpretation and, hence, for selection of topics reflecting the societal sustainability discourse. As a result, the key step of any assessment of sustainability effects is the selection of the effects and indicators to be measured. With regard to bioeconomy, different stakeholder groups have different claims with respect to the desirable sustainable development and achievements. Thus, an approach collecting, weighing off, consolidating and prioritizing expected sustainability aspects with regard to bioeconomy from different societal groups needs to take place. The Sustainable Development Goals (SDGs) including its targets developed by the UN is an example of such a process on the international level. In Germany, SDGs are implemented in the German Sustainable Development Strategy (Deutsche Nachhaltigkeitsstrategie, DNS), their achievement is monitored by a set of indicators which were elaborated in an iterative participative process (Bundesregierung 2016). However, such a process did not take place for bioeconomy, neither in Germany nor in the EU. In general, we expect a wide range of environmental, social and economic aspects and indicators to be the outcome of such a process, which would vary in course of time due to changing societal preferences. Therefore, the goal of our project at this very early conception stage was to develop and test a general approach for sustainability measurement of bioeconomy which is not bound to a particular set of indicators, but is flexible for application to a wide range of indicators.

However, selection of sustainability indicators might be significantly limited by data availability. Verifying a range of potentially available data sources for economic, social and environmental assessment was an inherent part of our conceptual work and is one of the key deliverables of its outcome. Since many of the indicators in the DNS are relevant for bioeconomy, we used them as proxy-indicators for an exemplary assessment of bioeconomy performance on the sectoral level. Also, for material flow-based assessment, some of the most common economic, social and ecological aggregates contained in the DNS were used as exemplary indicators. In the future, a process elaborating sustainability aspects considered important for various stakeholders and indicators addressing them under consideration of data availability has to take place. In particular, we suggest to use the methodology called ‚Logical Framework for a Sustainability Assessment' (LOFASA) (Meier 2015). It is a multiple step, holistic approach of indicator-based sustainability assessment, which is briefly described below[4].

'LOFASA foresees the selection of the relevant sustainability aspects based on a thorough qualitative content analysis (Mayring 2015) of the current societal discourse in public, stakeholder groups, media and politics. As a result, relevant sustainability aspects and indicators related to bioeconomy would be identified and structured. Qualitative content analysis is a common methodology in socio-empirical studies to systematically structure any kind of communication about a distinct topic. To structure the different kinds of communications, a database is set up with information about the communications' content, sources, search terms used to find them, etc. Next, the communications are structured based on key words or phrases. Content represented by the key phrases is

[4] The following text is essentially based on the article by Schweinle et al. which provides a detailed methodology for the developed material flow-based sustainability approach (Schweinle et al. 2020).

paraphrased and assigned to so-called semantic analytical units. The semantic analytical units are text modules that represent sustainability aspects such as criteria or indicators. As a result, complex communications are narrowed down to a few essential attributes. Finally, the semantic analytical units are assigned to sustainability themes such as health, resources, standard of living, climate change, economic competitiveness, and international responsibility. Coding rules make sure that the assignment process is reproducible and subjective choices of the encoder are minimized' (Schweinle et al. 2020).

'In the next step of LOFASA those sustainability aspects, that are not relevant for the assessment object, are eliminated in a valuation analysis. The valuation analysis is a heuristic process based on logical and comprehensible causal interrelations. The valuation analysis is a tool to eliminate those analytical units that do not address the object of the assessment. The resulting list of sustainability aspects relevant for the object of assessment is one of the bases for the selection of indictors that are required for the quantification of sustainability effects. Finally, the indicators are selected regarding the specific assessment goals and the sustainability aspects identified as being relevant for bioeconomy monitoring in the content and valuation analysis of LOFASA. According to LOFASA, the indicators should be checked by experts in a verification analysis for redundancy, adequateness, efficiency, and detail. To limit the efforts for data acquisition, redundant indicators must be eliminated. Indicators should adequately address the relevant sustainability aspects. At the same time, they should as comprehensively as possible assess and quantify the cause or causes of the respective sustainability effects. Finally, the indicators that pass the verification analysis are from a scientific point of view suitable for the assessment and should be put up for discussion and final selection among stakeholders' (Schweinle et.al. 2020).

Overall, the proposed sustainability assessment approach alike the whole bioeconomy monitoring concept is designed to be:

- Predominantly based on periodically updated and reliable information,
- Transparent,
- Efficient,
- Goal oriented,
- Flexible enough to cover altered and new material flows and products of an evolving bioeconomy.

A periodical update of information in data sources is a prerequisite to monitor changes of the bioeconomy. Quality insured data guarantee reliability of monitoring results. Hence, official statistics are due to their periodicity and quality assurance a preferred source of information. Transparency is also a key point in monitoring since any monitoring step and any calculation must be reproducible and comprehensible. Efficient in the context of bioeconomy monitoring means that the goals of the monitoring should be met in a cost and time efficient way. In addition, the monitoring itself should focus only on relevant aspects of bioeconomy. Relevance must be defined by the user groups of the monitoring and is part of the LOFASA. The setup of the monitoring should address the monitoring goals. Any effort that is not goal-oriented must be avoided. Finally, the monitoring system should be flexible enough to cover altered and new material flows and economic activities (Schweinle et al. 2020).

3.2 General Data Availability

Data availability and efforts for its collection are crucial for a monitoring and can significantly influence its feasibility. Although some selected sustainability aspects may be very important for the evaluation of bioeconomy's sustainability, missing data sources or high efforts for data collection can prevent their assessment. Thus, data gaps are a big challenge. They can even lead to an inappropriate indicator selection and indirectly change the goal and scope (Hák et al. 2016; Obenland 2018; Sustainable Development Solutions Network 2015). Hence, verification of data availability was one of the key tasks when developing the concept for the assessment of sustainability effects.

Bioeconomy covers very different economic sectors: agriculture, forestry, manufacturing, energy etc. Therefore, data sources for the assessment of its economic, ecological and social effects should deliver information from these very heterogenic economic sectors on an unified methodological basis. Only this allows for comparisons among sectors and in relation to the national economy. In addition, selected data sources should be (at best) suitable for comparisons of results with other European and non-European countries, notably at the sectoral level. While the deepest possible breakdown of data for the economic activities is desirable for the sectoral approach, it is absolutely essential for the material flow-based approach. These as well as general data monitoring requirements (comp. chapter 1.2) reduce the number of suitable data sources.

As described in the chapter 3.1 "Concept & Indicators", we largely used the indicators of the German Sustainable Development Strategy (Deutsche Nachhaltigkeitsstrategie, DNS) to test data availability and thus, the feasibility of our methodological approach. DNS includes 65 indicators, 27 of them were considered to be bioeconomy relevant. By investigating data sources for these 27 selected indicators, we gained a broad understanding of available data sources across social, environmental and economic aspects for the assessment of bioeconomy. Hereby, we also considered other potentially suitable indictors for sectoral and material flow-based assessments. Our main findings are described in the following sub-chapters. In addition, a detailed list of all used data sources for each indicator that was quantified by us within the project is listed in the respective chapters (cf. chapters 3.3.2 "Case Study of Softwood Lumber and its Core Product EPAL 1 Pallet" and 3.4.2 "Indicator Results").

3.2.1 Economic Dimension

3.2.1.1 Data Sources

National accounts

Economic strength of national economies is measured by national accounts (DESTATIS 2016e; EUROSTAT 2013). They reflect a range of common economic indicators such as value added, investments, exports, labour productivity. National accounts are compiled in accordance with the internationally common accounting rules and thus, deliver a consistent and comparable description of German economy. They derive their variables from various sources, notably statistical sources and administrative data, which are then thoroughly analysed, completed and adjusted to achieve methodological consistency. It is the only data source which allows for quantification of the bioeconomy's size in relation to the economy-wide performance of Germany as well as for its comparison with the bioeconomy in other countries. Due to a comprehensive data validation and various adjustments for completeness and methodological coherence, national accounts perform the most comprehensive and uniform quantification of different economic sectors which is important for an accurate quantification and structural analyses. Thus, it considers the value added generated in German economy and households within the relevant economic activities[5], value added by black economy and other informal economic activities as well as gratuities and other items, not covered by any other statistical sources. The overall adjustments value is quite significant and varies from sector to sector. Table 3.1 shows the size of the adjustments for German economy and the bioeconomy relevant sectors on the example of value added in 2010.

Table 3.1: Overview over the absolute and relative value of adjustment in national accounts on the basis of underlying statistics

	All sectors	Agriculture, forestry & fisheries (A)	Manu-facturing (C)	thereof: Manufacture of chemicals (CE)	Manufacture of motor vehicles and other transport equipment (CL)	Construction (F)	Food Service (I)	Scientific research & development (MB)	Energy (D)
Value added in the underlying statistics in billion €	1 771	18	500	36	77	86	11	5	55
Adjustments in billion €	551	-1	15	5	20	14	1	11	1
Adjustements in % of the underlying statistics	0	0	0	0	0	0	0	2	0
Value added in the national accounts in billion €	2 322	17	515	41	97	100	12	16	56

Source: based on DESTATIS (2016e)

[5] which is especially material in research and development

For the reasons mentioned above, national accounts represent the only data source suitable for sectoral assessment of sustainability effects. Using national accounts for the assessment of sustainability effects of bioeconomy is, however, at the same time problematic due to its high aggregation. It is restricted to 63 economic sectors only. To overcome this hurdle, we suggest to apply a combination of national accounts and the respective underlying statistical sources when quantifying bio-based economic metrics. The underlying statistical sources like structural business statistics or value added tax statistics are much more disaggregated than national accounts. Hence, in a first step, they are used to quantify the respective bio-based values. In a second step, the amount of adjustments made within national accounts, is split on the lowest possible aggregation level to a bio-based and non-based value. The final bioeconomy value is thus, a sum of bio-based values of the underlying statistical sources and of the related adjustments. The exact quantification equation is given in chapter 3.4.1 “Methodological Approach”. Due to a very high aggregation level, national accounts are not suitable for material flow-based assessment.

Structural business statistics

As mentioned before, the main underlying statistical source of national accounts used for bioeconomy-relevant economic sectors is the structural business statistics (DESTATIS 2018h; EUROSTAT 2018c, 2018d, 2019d). SBS contain a range of indicators for all bioeconomy-relevant economic sectors with the exception of agriculture, forestry and fisheries. Thanks to the high level of detail and a wide range of economic metrics included, SBS represent an important data source for both, the sectoral and the material flow-based approach. We used SBS for quantification of production value, intermediate consumption, value added and investments in tangible assets in sectoral approach as well as of production value and value added in material flow-based case study. In general, SBS data is available on the detailed 4-digit level. However, some economic activities can only be retrieved on a more aggregated level due to data protection reasons or an insufficient sample size.

Value added tax statistics

In line with national accounts, we used value added tax statistics as underlying data source for quantification of production value for economic activity F 43 “Specialized construction activities” and business register for economic activity I 56 “Food Service” when quantifying indicators in the sectoral approach (DESTATIS 2017e). The related intermediate consumption was calculated by application of an intermediate consumption ratio from SBS to the amount of revenue in respectively value added tax statistics or business register. Both statistical sources have a very deep level of disaggregation (5-digit level) and thus, can also be used for revenue/production value quantification in material flow-based assessment.

Since agriculture and forestry are not covered by SBS, the German National Economic Accounts for Agriculture and the German National Economic Accounts for Forestry can be used as data sources for quantification of economic indicators within material flow-based assessment. They contain a split of production value into different products. However, Economic Accounts for Agriculture do not contain information about the related intermediate consumption, which is why it is not possible to calculate value added for different product types. This is due to the fact that intermediate consumption in agricultural entities is booked by cost type and not by product group.

Table 3.2 gives an overview of statistical sources which can be used for quantification of economic indicators production value, added value and investments in sectoral and material flow-based assessment.

Table 3.2: Overview of the main data sources for economic indicators by sector for sectoral (S) and material flow-based (MF) approach

Economic Sector /Data Source	Agriculture, forestry & fisheries	Manufacturing	Construction	Food service	Scientific research and development	Energy
National Accounts	S	S	S	S	S	S
Economic Accounts for Agriculture	MF					
Economic Accounts for Forestry	MF					
Structural Business Statistics (SBS)		S/MF	S/MF	S/MF	S/MF	
Business Register				S/MF		
Value Added Tax Statistics			S/MF			

Source: Own compilation

3.2.1.2 Data Gaps

Overall, we consider the data situation to be sufficiently good for economic indicators. Nevertheless, there are some data gaps which are listed below. In the majority of cases, these gaps arise from the inaccessibility of existing data. For this reason, we strongly recommend to involve DESTATIS when implementing a bioeconomy monitoring.

Since national accounts are published on the highly aggregated level of 63 economic activities, their allocation to bio-based and non-bio-based economic activities leads to an increased uncertainty of results. However, as described in the methodological guidance published by DESTATIS (2016e), information is available on a more detailed level. This information, however, is only used internally and not shared with interested stakeholders. Having this level of detail readily available would help to decrease the range of results.

SBS for entities with less than 20 employees are neither published by DESTATIS nor made available upon request. Although EUROSTAT publishes key variables from this survey as part of consolidated figures, it does not cover a full range of information available in the survey. For example, it does not publish data on intermediate consumption, excise duty and other taxes and subsidies. This information, however, would help to achieve more precise calculation results.

For the analysis of bioeconomy over time, it is essential to quantify price adjusted values. For that, production specific deflators per economic activity on a 4-digit level for each specific variable (production value, intermediate consumption etc.) are needed. Although such deflators are calculated by DESTATIS, they are not made publicly available. Instead, highly aggregated deflators for 63 economic sectors are published. Without a detailed information on deflators, however, it is not possible to perform a sufficiently precise calculation of price adjusted bioeconomy development. Thus, we could only carry out a rather rough estimation based on the assumption that all deflators of the underlying economic activities within the 63 officially published economic sectors equal to the deflator of the respective overarching sectors (for detailed approach see chapter 3.4.2.1)

There is currently no underlying statistical source for investments in intangible assets. Thus, quantification of bio-based values for the sectoral approach was based on the data of national accounts broken down into 63 economic sectors only. This enlarges significantly the minimum-maximum range of results (see chapter 3.4.2.2). Due to complex calculations of this variable by DESTATIS, it was not possible to find any approach for a more detailed split.

To assess innovation potential and thus, the economic strength and competitiveness of bioeconomy in the future, expenditures invested for bioeconomy-related research & development need to be quantified. While this is possible for public research entities based on statistical data (chapter 2.5.2.4 “Professional, scientific and technical Activities”), no sufficient data is available for research expenditures of businesses. The Stifterverband regularly conducts surveys on research and development expenses in private businesses. However, the survey structure regarding research topics is neither suitable to quantify shares of bioeconomy nor is it comparable with the structure of statistics for public research institutions which is essential to ensure a coherent approach. Hence, it is currently impossible to quantify the indicator of the DNS “Private and public expenditure on research and development in relation to GDP”. To overcome this gap, changes in the structure of the survey for private businesses is required.

Missing data on the intermediate consumption and thus, value added for different product groups in agriculture impede the quantification of this important economic metric for agricultural material flows. Approaches should be elaborated for dealing with this gap.

Detailed results of environmental accounts are published with a delay of 2 years after the reference year. Hence, assessment of sustainability effects of bioeconomy can be made available only with an even bigger time lag. This, however, delays timely delivery of information.

3.2.2 Environmental Dimension

3.2.2.1 Data Sources

Due to a broad variety of environmental aspects, available data sources are also manifold. On the national level, these various data sources are collected, analysed and consolidated to economy-wide indicators by the German Federal Environmental Agency. Unlike economic data, impacts on the environment are not extensively accounted and reported by companies and other entities, making it very difficult to precisely attribute environmental impacts to a particular economic sector.

Table 3.3 gives an overview of the main environmental data sources available to quantify energy and air-emission-related indicators.

Table 3.3: Main data sources for quantification of energy and air-emission-related indicators[6] at the sectoral level by sector (S)

Economic Sector /Data Source	Agriculture, forestry & fisheries	Manufacturing	Construction	Food service	Scientific research and development	Energy
Environmental Accounts	S	S	S	S	S	S
Annual survey on energy use in manufacturing, mining and quarrying		S				
Annual survey of electricity generation plants of enterprises in manufacturing mining and quarrying		S				
Energy Balances		S				S
Satellite Balances						S
NIR		S				S

Source: Own compilation

Environmental accounts

One of the central tasks of environmental accounts as a statistical system is to allocate ecological impacts to the respective polluting economic sectors and private households (DESTATIS 2014). En-

[6] Examples of such indicators in the DNS are: “primary energy use”, “final energy productivity”, “greenhouse gas emissions”, “air emissions” and “energy consumption and CO_2-emissions by households”

vironmental accounts use a wide range of underlying data sources for its analysis, e.g. energy statistics, data of the German Federal Environmental Agency (UBA 2017, 4/18/2018, 2019a, 2019b), data of the Energy Balances Group (AG Energiebilanzen) (AGEE-Stat 9/2/2019, 2019, 2020), which are then validated, adjusted and organised in a coherent way. They structure environmental data in line with the methodological system of national accounts, thus, building its pendant from an environmental point of view. This allows to make a range of eco-efficiency analysis as well as to compare the performance of different economic sectors and of national economies. Similar to the national accounts, environmental accounts deliver its output on a very high aggregation level of 55 emitting sectors/homogeneous branches which makes it unsuitable for material flow-based environmental assessment. However, they represent a very important data source for environmental assessment at sectoral level. As in the case of national accounts, we propose to use the respective more disaggregated underlying statistical data sources of economic activities where applicable. The amount of adjustments is then split on the lowest possible aggregation level to a bio-based and non-based value and added up to the bio-based values calculated using the underlying statistical sources (see chapter 3.4.1 “Methodological Approach” for details). When using environmental accounts, the specificities of this statistical source should be kept in mind which are explained in more detail below.

To enable a coherent analysis of environmental impacts, the environmental accounts use a functional breakdown of economic processes into homogeneous branches in accordance with CPA. Homogeneous branches are defined by purely functional criteria that only include production processes of a certain commodity group. This classification not only better suits for economic-environmental analysis but also allows for using the input-output-tables of national accounts for further input-output analysis of environmental variables. Hence, only very few outputs of environmental accounts are classified into economic activities. Since the quantification of bio-based shares is valid for economic activities, this poses additional hurdles on quantification of environmental indicators at sectoral level, requiring extra reconciliation steps. In addition, the homogeneous branches for energy and air emission variables in the environmental accounts are not fully identical in their structure which should be further taken into consideration when quantifying bio-based values.

In order to ensure consistency with national accounts, environmental accounts follow the resident concept. It considers environmental effects (for example energy use, air emissions) of domestic units on German territory and abroad. Environmental impacts of non-domestic units on German territory are excluded. However, many of the related environmental data sources (such as the National Inventory Report for the German Green House Gas Inventory (NIR) or Energy Balances) follow the domestic concept. This concept only includes environmental effects arising within the German territory without further differentiation by domestic and non-domestic units. These two different concepts should be beard in mind, when quantifying bio-based values. The difference between the two concepts mainly concerns the transport sector that is according to our definition currently not included as part of bioeconomy. The impact in other economic activities is minor and was therefore, not considered in our calculations (pers. comm DESTATIS 2018f).

The main underlying statistical sources of environmental accounts for energy- and air-emission-related aggregates are as follows:

- The annual survey on energy use in manufacturing, mining and quarrying[7] (DESTATIS 2018a)
- The annual survey of electricity generation plants of enterprises in manufacturing mining and quarrying[8] (DESTATIS 2017d, 2019d)
- Energy balances, satellite balances for renewable energy and energy use balances for final consumption of the Energy Balances Group (AGEB 2020a, 2020b)
- National Inventory Report for the German Green House Gas Inventory (NIR) (UBA 2019a)
- Central system of emissions database (EEA 2019)

Annual survey on energy use in manufacturing, mining and quarrying

While all of these sources deliver some specific useful information, only the annual survey on energy use in manufacturing contains detailed data per economic activity at 4-digit level, allowing detailed quantification of bioeconomy values per economic activity. The remaining sources can only be used as additional supporting data for particular economic activities. In the following, short information about the underlying data sources and their use for quantification of bio-based indicators at sectoral level is laid down.

The annual survey on energy use in manufacturing, mining and quarrying contains data on energy use in the manufacturing sector broken down by 35 energy sources and economic activities at a 4-digit level (DESTATIS 2018a). It is a full survey of manufacturing companies with more than 20 employees[9]. This survey allows for quantification of bio-based values on a detailed level per energy source and thus, represents a very useful data source for quantification of energy-related indicators. However, due to data protection issues many data sets are published only at a higher aggregation level. Furthermore, it includes a double-counting of energy used in economic activities with own industrial power stations (DESTATIS 2019d). This should be taken into consideration and adjusted when quantifying energy-related indicators. Due to the breakdown into different energy sources, these statistics allow to estimate not only the energy use but also the energy-related CO_2-emissions per detailed economic activity in bioeconomy.

Annual survey of electricity generation plants of enterprises in manufacturing mining and quarrying

The annual survey of electricity generation plants of enterprises in manufacturing, mining and quarrying helps to take account of energy conversion in the manufacturing sector (DESTATIS

7 This survey is also often referred to as “Energy statistics”

8 This survey is also often referred to as “Energy statistics”

9 With the exception of certain economic activities, for which all companies with more than 10 employees are surveyed

2019d). It provides data about conversion input broken down by energy source and the amount of generated power and heat. Although data is collected on a 4-digit level per economy activity, it is available only at 2-digit level due to data protection reasons that impede the quantification of bio-based indicators.

Energy balances

Energy balances of the Energy Balances Group (Arbeitsgruppe Energiebilanzen, AGEB) document the supply, conversion and use of energy sources in Germany (AGEB 2020a, 2020b). A distinction is made between the primary energy balance, the transformation balance and the final energy consumption which is broken down by 13 manufacturing sectors, transport, commercial, trade and service sectors as well as the households. The Energy Balances Group processes different statistical and other energy-related data sources, evaluates and adjusts them in order to achieve a coherent and comprehensive figure. Energy balances along with their satellite balances for renewable energy and energy use balances for final consumption represent an important data basis for environmental accounts. They can be used as an additional information source of energy data for verification and quantification of selected bio-based indicators, notably the estimation of energy use in food services and in energy sector.

National Inventory Report for the German Green House Gas Inventory

The National Inventory Report for the German Greenhouse Gas Inventory (NIR) including the accompanying Common Reporting Format (CRF) under the UN Framework Convention on Climate Change provides comprehensive data on sources and volume of the German greenhouse gas emissions (UBA 2019a). It also includes a detailed methodology for data collection, evaluation and undertaken estimations. NIR is based on the “Central Emissions System" (EEA 2019) which is also used by the environmental accounts for its air emission reporting. Although NIR includes a very rough breakdown of economic sectors, its detailed descriptive explanations about the process-related greenhouse gas emissions can be used for their allocation to particular economic activities on a detailed level. Furthermore, it contains emission factors for different energy sources which can be utilized for estimations of energy-related greenhouse gas emissions.

Central Emissions System Database

The Central Emissions System database of the German Federal Environmental Agency is a central instrument for calculation and reporting of emissions in Germany (EEA 2019). It contains all air emission related information. Although it does not include a detail split into economic activities, its information is broken down into different source groups with different specifications such as "application", "product", "technology" or "material”. This information could serve as an additional source for a breakdown of highly aggregated data of environmental accounts, notably for process related emissions. However, its data use is restricted due to data protection issues. Therefore, it was unavailable for this project.

Renewable Energy Statistics

Indicators, reflecting the share of biomass for electricity generation and energy consumption at the sectoral level ("share of biomass in gross final energy consumption" and "share of electricity from biomass in electricity consumption") can be quantified based on the regularly published data of Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien, AGEE-Stat) of the German Federal Environmental Agency (AGEE-Stat 9/2/2019, 2019, 2020). These statistics provide comprehensive data for energy use of biomass. Additional breakdown for different types of biomass can be made available upon request.

None of the above listed data sources suitable for quantification of environmental indicators at the sectoral level can be used in the material flow-based approach. This is because environmental assessment of material flows and their products requires much differentiated material- and process-specific information. So far, no statistical sources providing such specific environmental information exist. Hence, we suggest using Life Cycle Assessments (LCA) for environmental assessment of core products of the bio-based material flows. Due to the flexibility of the approach, different products and services with the same function can be compared to each other. Several LCA-based environmental assessment databases are available as a data source, comprising data on a high number of environmental products and processes (e.g. Ecoinvent, Gabi). To make the assessment as precise as possible, only geographically, technologically and timely representative LCA-studies with system boundaries exactly matching the selected core products are needed. Such studies should be based on average data from a representative sample of producing companies. However, the number of available studies matching these criteria is very limited.

3.2.2.2 Data Gaps and Limitations

(1) The high aggregation level of environmental accounts complicates to achieve precise results. For energy use metrics and the fuel combustion-related CO_2-emissions, energy statistics are a source of information. However, there is no source for other air emissions. We expect that data from the Central Emissions System Database could possibly help to reduce the fluctuation range of results, especially for process-related air emissions. Although not available for public use, access is granted for scientific institutions on request. However, in order to be consistent with classification in national accounts, a concurrent support of DESTATIS is required for bioeconomy related assessments.

(2) Environmental accounts are disaggregated into homogenous branches instead of economic activities. This causes some uncertainty of results that, notably in case of air emissions, neither can be quantified nor reduced.

(3) Due to data protection reasons, detailed data at 4-digit level is in many cases not published in energy statistics (the annual survey on energy use by manufacturing and the annual survey of electricity generation plants of enterprises in manufacturing), thus, causing a higher fluctuation range of achieved results.

(4) Similar to the national accounts, environmental accounts use various underlying statistical and non-statistical sources and conduct methodological adjustments to calculate the output values. The landscape and variety of used data sources as well as their complexity, however, is significantly higher as compared to the national accounts. Thus, energy balances used by environmental accounts are in turn also based on other underlying sources and include methodological adjustments. While national accounts provide a detailed methodological description with an extensive example for the year 2010, the methodological publications of national accounts are rather brief. This significantly impedes a more precise allocation of the adjustments made as well as plausibility checks of own calculations. Therefore, close cooperation with DESTATIS is essential to overcome this hurdle and to assure a high quality of calculations.

(5) The rather high level of aggregation of homogeneous branches/economic activities impedes to calculate the indicator “raw material input productivity”. This data gap needs to be closed by extension of existing calculations based on input-output tables by DESTATIS.

(6) Data of environmental accounts is published 2 years after the end of the reference year (DESTATIS 2019h, 2019i). Hence, assessment of environmental sustainability effects of bioeconomy on sectoral level lags more than 2 years behind.

(7) A systematic material-flow-based assessment of core products is currently impossible based on official and non-official statistics. Currently, the only available data source is LCA-studies. However, being set up for different purposes than monitoring environmental sustainability effects of bioeconomy, each available study has its specific goal and scope, system boundaries, cut-off criteria, etc. Thus, the number of studies matching the key parameters (scope, used technology etc.) of the core products is limited. Consequentially, they are a no viable basis for a frequent bioeconomy monitoring. To address this gap, frequently updated LCA-studies specifically designed for selected material flows and their core products are an option.

3.2.3 Social Dimension

3.2.3.1 Data Sources

In this initial attempt to monitor bioeconomy and assess its social effects, the focus was on employment and employment condition-related indicators. As with environmental and economic aspects, also for social issues data is needed that allow to uniformly evaluate different economic sectors. Social indicators, however, can often not be calculated as a simple sum of individual values per economic activity, but use average values or ratios of two bio-based variables (e.g. average salaries in bioeconomy or the share of employees with precarious conditions in bioeconomy).

In case of average metrics, to quantify bio-based indicators, a detailed breakdown of data at 4-digit level is needed. This is true for both, the material flow-based and the sectoral approach, since quantification of bio-based indicators by extending the minimum-maximum range at the sectoral level (as described in chapter 3.4.1 “Methodological Approach”) is not possible in this case. On the aggregated level, one cannot use average values, since they may be not representative for the respective underlying bioeconomy-relevant economic activities.

At the sectoral level, it is possible to calculate ratios of two bio-based variables with a minimum-maximum range by finding a minimum and maximum for the respective ratio function (as stated in chapter 3.4.1 “Methodological Approach”) However, using two variables with a range of results consequently further widens the range of the resulting ratio-based indicators. At the same time, judgements about social conditions are only valid if the range of results is sufficiently narrow. Thus, detailed disaggregation of the economic activities is usually essential for social indicators. For a material-based approach, a 4-digit level is absolutely necessary. Also, the sectoral approach requires detailed sector disaggregation to allow meaningful conclusions.

Thus, although a range of employment-related statistical sources exist, only few of them are useful to quantify bioeconomy-relevant indicators. The main reason for this is insufficient breakdown of economic activities or an incomplete scope of many statistical sources. In the following, a brief description of the principally available employment related data sources, their advantages, limitations and suitability for quantification of social indicators for bioeconomy is given. For the sectoral level, we notably examined the indicators of DNS “the number of persons employed aged 20 – 64”, “the number of persons employed aged 60 – 64” and ”gender pay gap”. In line with these indicators, the focus was directed towards quantification of the number of persons employed and the average salaries at the level of material-flows and at the sectoral level.

Labour Force Survey of Eurostat

The Labour Force Survey of EUROSTAT (LFS) (EUROSTAT 2018a, 2019b, 2019c) is a large household survey providing a wide range of person and employment related data such as age, employment status, working time, permanency of the job, professional status, etc. Annual values are calculated as an average of the results from quarterly surveys. The advantage of the Labour Force Survey lies in its comprehensive scope. It includes all persons aged 15 years and over and considers all kinds of employment: short term contracts, freelancers, trainees. A breakdown of economic activities is available, its level of detail, however, depends on the specific indicator to be quantified. The deepest breakdown is the 3-digit level. Hence, LFS is not suitable for a material flow-based approach. Nevertheless, this survey is applicable for indicators at sectoral level, requiring a simple summing up of one variable per economic activity. It was used to quantify the indicators “number of persons employed aged 20 – 64” and “number of persons employed aged 60 – 64”. However, due to an insufficient level of detail for indicators requiring average values or a ratio of more than one value, LFS is not suitable. Since LFS does not contain data at the 4-digit level, the total number of persons employed in bioeconomy has a relatively high minimum-maximum range (see chapter 3.4.2.3). To reduce the range of results, different statistics with partly deviating scopes and concepts need to be combined. Thus, data of LFS could be broken down into economic activities at 4-digit level using ratios of SBS or Employment statistics of the Federal Employment Agency or both. Although this would result in some inaccuracy of results, it could be a reasonable approach to further narrow the minimum-maximum range.

Employment Accounts of DESTATIS

The employment accounts of DESTATIS is an integrated part of national accounts (DESTATIS 2016e). It quantifies employment by economic sector, reflecting both, the number of persons employed and the number of hours worked. Employment accounts use around 60 different underlying data sources and make additional adjustments to achieve a comprehensive and coherent result. Similar to the national accounts, employment accounts could be principally used for quantification of the total number of employed persons in bioeconomy at the sectoral level using Eq. 3.4.3 and Eq. 3.4.4 in chapter 3.4.1 “Methodological Approach”. However, no detailed methodological description, exactly explaining what underlying statistical sources are used for different variables and economic sectors is available. Hence, support from DESTATIS is needed.

Structure of Earnings Survey

The Structure of Earnings Survey (SES) (DESTATIS 2018i) is a sample survey of companies. It records data on earnings and other characteristics of the employment relationships and the persons surveyed. The SES gives information on distribution of employee earnings and on the influence of important factors that determine individual earnings. It has a comprehensive scope which covers all economic sectors and all company sizes. The level of detail depends on data category and economic sector. Thus, the average earnings are mostly available at a 4-digit level, however, the respective number of employees per economic activity only at a 2 – 3-digit level (pers. comm. DESTATIS 2019b). This is insufficient to quantify average earnings in bioeconomy at the sectoral level. Applicability in the material flow-based approach is also limited. Another drawback of this statistical source is the 4-yearly frequency of the survey, not allowing comparisons on a yearly or biennial basis.

Earnings Survey

The earning survey (ES) (DESTATIS 2018c, 2018d) is another sample survey of companies, recording data on employees’ earnings. Its main purpose, however, is the monitoring of gross earnings development. It is carried out more frequently on a quarterly basis. However, ES has a reduced scope not including agriculture, forestry and fishery, small entities with less than 10 employees[10] as well as trainees and part-time retirement employees. The level of detail varies depending on the particular economic activity and the related variable. Mostly, data is available only at a 3-digit level. Due to a limited scope and the missing level of detail, also this statistical source does not provide sufficiently comprehensive data to quantify average gross earnings in bioeconomy.

[10] In some sectors also smaller enterprises with more than 5 employees are surveyed.

Employment Statistics

Employment statistics of the Federal Employment Agency record the number of employees that are subject to social insurance contributions and marginally employed persons as well as their employment relationships including annual salaries. It also provides information on the employing companies. Employment statistics are based on legally binding data input from all employers. Hence, it has a very comprehensive scope, including entities of all sizes and contains data at a 5-digit level. Data provided allow to quantify the number of employees and marginally employed persons in bioeconomy as well as some other employment related characterises. However, the total number of persons employed is not available, since data on self-employment is missing. Due to the annual upper earnings limit relevant for social insurance payments, employment statistics only provide data on a median of annual earnings.

Structural Business Statistics

Structural business statistics (SBS) as an economic statistical source has been described in the previous chapters. Besides a range of economic variables, SBS provide information at a 4-digit level about the number of employed persons (divided by employees, self-employed and unpaid persons employed), the number of persons in full time equivalents as well as personnel expenses (divided by wages and social security costs). No additional personal-related information is recorded. The number of employees, however, does not reflect the average annual values but the state as of 30.09 of the respective year, which may lead to seasonal deviations and thus, inaccuracy when used to quantify average salaries.

3.2.3.2 Data Gaps

(1) The lack of detail of the existing statistical sources significantly limits the number of indicators to be quantified in the material flow-based and sectoral approach. Thus, due to the insufficient data breakdown of the respective statistical sources, it is neither possible to quantify the Gender Pay Gap nor the overall average annual earnings in bioeconomy. There are two options to overcome this shortcoming. First, the scope of existing statistical surveys could be extended. Second, different statistical sources with partly deviating scopes and survey methodologies could be blended[11]. The latter, however, leads to a reduced accuracy of results. If "blending" of different statistical sources is applied, an explanation of deviating scopes and methodologies should be given.

(2) To achieve coherency of results with economic and environmental dimension, it would be useful to calculate the total number of persons employed in bioeconomy using employment accounts. This would allow to conduct a coherent analysis of ratios of economic, social and environmental variables and put them into perspective to the national economy as a whole.

[11] Thus, we mixed different statistical sources with partly deviating scopes for quantification of social indicators in the material flow-based approach (see chapter 3.3.2).

However, missing detailed methodological description impedes such quantification and requires support from DESTATIS.

(3) Overall, data availability for social indicators for bioeconomy assessment can be seen as poor which significantly reduce the number of potential indicators for monitoring.

3.3 Material flow-based Sustainability Assessment

3.3.1 Methodological Approach

The following chapter's text is based on an article published by Schweinle et al. (2020) and in many parts quoted verbatim.

'To understand how and how much biomass and bio-based materials are produced, how interlinked the bio-based value chains are, which sustainability effects bio-based value chains or products have, a good understanding of the material and energy flows of the bioeconomy is essential. Since bio-based materials in general are versatile resources, the variety of uses and products from bio-based materials is numerous. Official statistics on production and processing of bio-based materials and manufacture of bio-based products are available, but the indicators provided do not necessarily allow for the calculation of flows of bio-based materials processed at different stages of the value chain. Hence, we propose to use sound Material Flow Analysis (MFA) tracing bio-based products from growing and harvesting of biomass until final disposal or incineration for monitoring of sustainability impacts.' (Schweinle et al. 2020)

'Due to the high number of material flows and products of the bioeconomy, a total coverage of all material flows is not feasible. Hence, the approach is developed to assess core products that represent the major material flows of the bioeconomy. Regarding a bi- or triannual monitoring, the selection of core products limits data collection and analytical efforts. It reduces complexity to an acceptable level and at the same time covers major sustainability effects of bio-based material flows. In addition, the selection of core products allows comparing sustainability effects of bio-based with other bio-based or fossil products or substitutes.' (Schweinle et al. 2020)

'The selection of core products is based on the results of an MFA for a certain bio-based material. Typically, the core product is produced using the biggest share of a bio-based material flow and shows a high degree of homogeneity. It represents the material flow by means of quantity. Due to the large quantity produced, recycling and waste streams of the core product are also significant. Since many sustainability effects are related to mass, by selecting a core product, consequentially, also a large proportion of the sustainability effects of the material flow is covered.' (Schweinle et al. 2020)

‘Our approach combines MFA and LCA with regard to a functional unit, system boundaries, and cut-off criteria. We propose to select the amount of a core product produced repaired, recycled, and disposed in one year as the functional unit. The technical system boundary is set by delimiting the assessed material flow and core product from other material flows and products. This is a requirement for MFA to prevent from overlapping and double counting. Geographically, the system covers a country. To assess the sustainability effects associated with the core product all steps of production, use, recycling, and disposal are assessed. Sustainability effects associated with services, ancillary materials, and means of production required to produce a core product are in general cut-off from the assessment. However, for components of a core product that do not belong to the material flow, a common understanding is needed whether these should be included in the assessment or not.’ (Schweinle et al. 2020)

‘Sustainability indicators are quantified by combining statistical and non-statistical information with the results of the MFA. In general, indicators should be quantified for each processing, use, recycling, and final disposal step of the material flow in order to show how much a certain step contributes to the sustainability impact quantified by the indicator. However, if information is not available yet, the approach allows for quantification of only some steps or as a total for the entire material flow and its core product.’ (Schweinle et al. 2020)

Currently, no applicable environmental statistical data is available for material flows in Germany. And it is not likely that such statistics will appear in the near future. Hence, we suggest to use life cycle assessment studies to assess environmental effects (see chapter 3.2.2 “Environmental Dimension”). By mapping processing stages to the related material flow, cumulated environmental impacts for the respective material flow are calculated. First, however, it must be checked whether the functional unit of the respective LCA study is consistent with the selected material flow and the respective core product. Second, goal and scope as well as system boundary should be checked to ensure compatibility. This cross-checking is a very helpful procedure to identify implausibility and fill data gaps. Hence, a combination of LCA and MFA is a useful tool for the assessment of material flow-based sustainability effects. Since material flow analysis provides a cumulative value for all processing entities of a particular material flow, a complementary LCA should reflect the entities covered by the material flow (see chapter 3.2.2 “Environmental Dimension”).

Since the data availability is very good up to the first processing step, the combination of MFA and LCA is feasible. Environmental effects of further processing steps need to be quantified using the example of core products as described at the beginning of this chapter.

When quantifying environmental effects of the use phase of a core product, one should keep in mind that the respective data should be sufficiently comprehensive for a potential comparison with the reference products or services. Therefore, we suggest to monitor all product-related specific usage data (such as average life time, recycling quote, average washing cycles and etc.). Any assumptions should be made transparent, since this is essential for comparisons with reference products. When conducting comparisons, it might be necessary to change the respective functional unit.

End of life phase is often missing in MFA. However, it is important for a holistic monitoring of environmental effects resulting from bio-based products. Hence, bio-based waste streams should be an integrated part of bioeconomy monitoring in the future. Besides environmental impacts resulting from post-use phase, it is inevitable for estimations of recycling potential and resource efficiency that are essential for the achievement of the SDGs.

Contrary to environmental effects where data from official statistics is not available, for economic and social effects data availability from official statistical data sources is good. The structure of the economic activities used in official statistics within the European Union (NACE) covers the steps of a material flow. This allows to quantify economic and social effects of a core product. One can quantify the share of a core product in a related economic activity as the proportion of the respective bio-based material used for its production to the total amount of bio-based material used in the relevant economic activities. Regarding the economic and social effects, it is assumed that these are proportional to the respective calculated share of bio-based material. Although this assumption might not fully reflect reality, a more precise approach to determine the proportion of the economic and social effect of bio-based materials within an economic activity is currently not feasible.

For more details on the proposed material flow-based methodology, please refer to Schweinle et al. 2020.

It is conceivable that, due to possible data gaps, the presented method will not be applicable for certain material flows or core products. In these cases, assumption based on empirical studies or other secondary literature might be necessary.

3.3.2 Case Study of Softwood Lumber and its Core Product EPAL 1 Pallet

The following chapter's text is essentially based on the article published by Schweinle et al. (2020) and is quoted verbatim in many parts.

3.3.2.1 Goal and Scope

In the following, the applicability of the proposed approach is demonstrated on the example of softwood lumber material flow and its core product EPAL 1 pallet. EPAL 1 pallet is a representative of wooden package goods, covering a significant part of the softwood lumber material flow. Sustainability aspects were quantified using a combination of MFA, LCA and statistical data sources.

As mentioned in the chapter 3.1 “Concept & Indicators”, indicator selection process for bioeconomy was not in the focus of our project. Hence, several proxy indicators reflecting some of the goals and metrics of the DNS were used. These selected indicators are well established and often applied to assess environmental, economic and social sustainability aspects of products and services (Schweinle et al. 2020).

The assessment goal was formulated as follows:

- Relevant environmental, economic, and social effects of a material flow and its core product shall be assessed and quantified.
- The assessment is set up for comparisons with reference material flows and core products (Schweinle et al. 2020).

The first goal reflects the common understanding that all three pillars of sustainability (environmental, economic and social) should be reflected in a sustainability assessment. The second goal considers that bio-based products must proof that they are more sustainable than other non-renewable products or bio-based alternative products with the same function (Schweinle et al. 2020).

3.3.2.2 Material Flow Analysis

General methodological approach for quantification of the softwood material flow and its core product EPAL 1 pallets is presented in the chapter 2.4.3. Table 3.4 shows key aggregates of the analysis for the years 2010 and 2015. In 2010, approximately 2.128 million t and in 2015 approximately 2.624 million t wood was used in Germany for the manufacturing of packaging products. 1.048 million t in 2010 and 1.316 million t in 2015 of softwood was used for EPAL 1 pallet production. This amount is equivalent to 35 % in 2010 and 36 % in 2015 of softwood used for manufacturing of packaging. The produced EPAL 1 pallets (softwood and wood particle blocks), contained 0.978 million t softwood in 2010 and 1.228 million t in 2015. For EPAL 1 pallets made of softwood lumber and nails only, 0.07 million t (2010) and 0.088 million t (2015) softwood were used. In 2010, about 5.7 million t and in 2015 7.08 million t softwood lumber was stored in both EPAL type 1 pallets. For repair of pallets, approximately 0.07 million t (2010) and 0.08 million t (2015) softwood lumber was used. In 2010, about 0.272 million t and in 2015 0.270 million t softwood lumber that originated from packaging was used as post-consumer wood for particleboard production (Schweinle et al. 2020).

Table 3.4: Material flow of softwood lumber in pallet manufacturing

processing steps		Year	softwood weight million t 2010	2015
Forest production	softwood removals		20.686	19.061
1st processing	sawmilling		13.609	13.095
2nd processing	wood packaging		2.128	2.624
	flat pallets (EPAL 1)		1.048	1.316
End product	EPAL 1 (softwood & wood particle blocks)		0.978	1.228
	EPAL 1 (softwood only)		0.070	0.088
Stock in use	EPAL 1 (softwood & wood particle blocks)		5.349	6.605
	EPAL 1 (softwood only)		0.385	0.475
Repair	EPAL 1 (softwood & wood particle blocks)		0.175	0.217
	EPAL 1 (softwood only)		0.009	0.011
Post-use (material)	EPAL 1 (softwood & wood particle blocks)		0.253	0.252
	EPAL 1 (softwood only)		0.018	0.019
Post-use (energy)	EPAL 1 (softwood & wood particle blocks)		0.515	0.511
	EPAL 1 (softwood only)		0.037	0.037

Source: own calculations based on Bösch et al. (2015), FEFPEB (2020), Scholtes and Jansen (2014), Schüler (2016, 2018) and TI-WF (2020b)

3.3.2.3 Environmental Indicators

Two examples for indicators assessing and quantifying environmental sustainability effects of the EPAL 1 pallets Global Warming Potential (GWP100) and Eutrophication Potential (EP) are selected. Both indicators address so-called midpoint environmental impact categories (Guinée 2002). Midpoint because they do not directly quantify impacts on human health, social assets, biodiversity and primary plant production. These are the so-called impact endpoints LCAs try to characterize to give a comprehensive environmental impact profile of the system assessed. GWP100 quantifies the impact on radiative forcing of the studied system whereas EP quantifies impacts of nitrogen and phosphorous on waters and soil. Hence, both indicators address two important sustainability aspects: Climate change and protection of waters and soil which are also manifested in the DNS indicators 13.1a, 6.1a and b, 14.1a and 15.2 (Schweinle et al. 2020).

Data Sources

To our very best knowledge, no representative LCA study for EPAL 1 pallets produced, used and disposed in Germany has been made so far. Consequently, GWP and EP are calculated based on a LCA study made by the Dutch Institute for Building Biology and Ecology (Scholtes and Jansen 2014). The study covers the complete life cycle of EPAL 1 pallets including use and disposal. Both indicators are quantified according to the CML-2 method, developed at the Centre of Environmental Science at Leiden University (Guinée 2002) and described in Scholtes and Jansen (2014). More details on the main underlying data and assumptions made can be found in Schweinle et al. (2020). Since the study does not contain information about the individual contributions of softwood lumber, wood particle blocks and nails, GWP and EP have to be related to EPAL 1 pallets instead of softwood used in EPAL 1 pallets (Schweinle et al. 2020).

Results for environmental Dimension

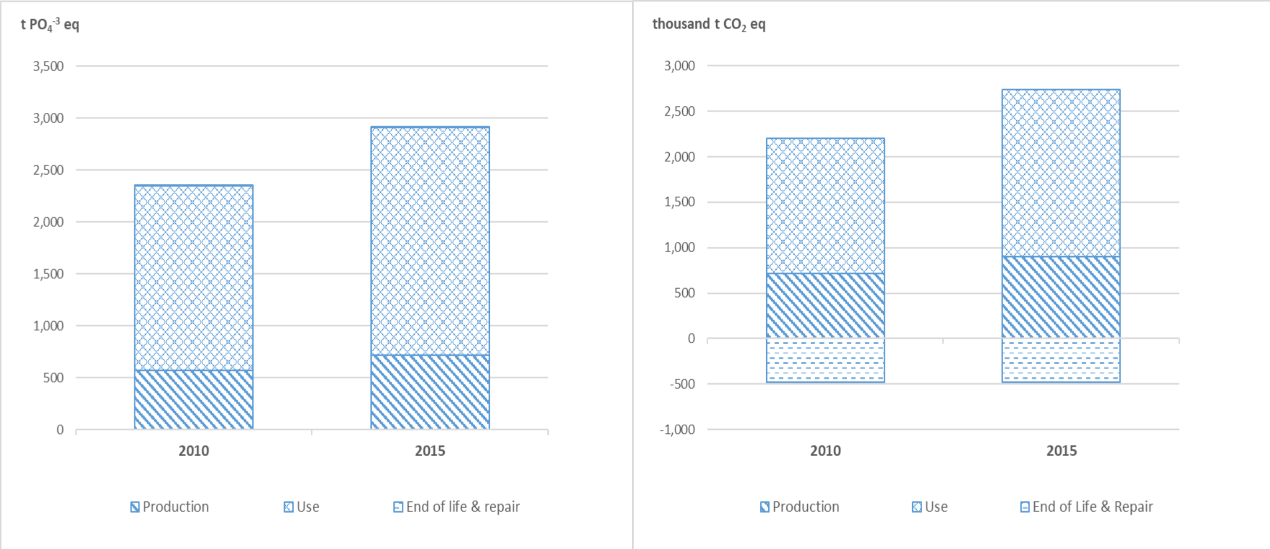
Table 3.5: Cumulated environmental impacts resulting from the production, use and disposal of the EPAL 1 pallets in Germany

EPAL 1 pallet type	Impact of production, use and disposal per t EPAL 1 pallet		Impact of production, use and disposal of the total amount of EPAL 1 pallets in Germany			
	GWP t CO_2 eq.	Eutrophication kg PO^{4-}_3 eq.	GWP thousand t CO_2 eq.		Eutrophication t PO^{4-}_3 eq.	
Year			2010	2015	2010	2015
EPAL 1 (softwood lumber only)	1.06	1.68	76	100	112	138
EPAL 1 (softwood and wood particle blocks)	1.21	1.76	1,648	2,160	2,237	2,774
Total			**1,724**	**2,261**	**2,349**	**2,912**

Source: Scholtes & Jansen (2014) and own calculations

Table 3.5 shows the cumulated global warming and eutrophication potential resulting from the entire life cycle of EPAL 1 pallets. GWP as well as EP do not differ much between the two EPAL 1 types when related to 1 metric ton of EPAL 1 pallets. EPAL 1 pallets made with wood particle blocks have a slightly higher GWP and EP per t of product. This is caused by a higher energy demand to produce the wood particle blocks as compared to softwood lumber. However, EPAL 1 pallets with wood particle blocks are the most commonly produced type since it has lower production cost and the same level of quality. Due to the significantly higher production amount of EPAL 1 pallets with wood particle blocks in 2010 and 2015, GWP and EP are significantly higher. Total GWP for the EPAL 1 (softwood and wood particle blocks) was 1.724 million t CO_2 eq. in 2010 and 2.261 million t CO_2 eq. in 2015. The EP was 2,349 t PO^{4-}_3 eq. in 2010 and 2,912 t PO^{4-}_3 eq. in 2015.

Figure 3.1: Breakdown of Global Warming Potential (GWP) and Eutrophication Potential (EP) into the process steps of softwood lumber material flow and its core product EPAL 1 pallets in 2010 and 2015



Source: Scholtes & Jansen (2014) and own calculations

A breakdown of the respective environmental effects into different life cycle phases can be seen in Figure 3.1. They show that the use phase contributes most significantly to the environmental impacts. This is caused by fossil fuel combustion during the transportation of loaded pallets. Also, production has a significant share in the total amount of GWP and EP in the respective years, mainly due to the energy use during the processing of wood and nails. End-of-life phase partly offsets the global warming impact since both, wood combustion and wood recycling save CO_2-emissions either for energy generation or production of new wood particle blocks. More details on the underlying calculation data and assumptions can be found in Schweinle et al. (2020).

Based on the currently available data, a more differentiated breakdown into processing steps like in the MFA or for the economic and social indicators is currently impossible. For a frequent monitoring, this data gap needs to be filled. Since GWP and EP are standard LCA impact categories, the results can be compared to other material flows of core products or non-bio-based substitutes (such as plastic pallets) provided that assessment goal and scope as well as the system boundaries are identical.

3.3.2.4 Economic Indicators

'Production value' and 'value added at factor costs' are the two indicators selected to estimate economic effects associated with EPAL 1 pallets. They are the most commonly used indicators to measure the economic strength and are used as economic aggregates in several sustainability indicators of the DNS (e.g. 8.3, 8.4, 7.1a). Ronzon and M'barek (2018) for example propose value added to be one of the socioeconomic indicators to assess bioeconomy on EU level. Production value is the total value of all economic activities generated along the assessed material flow. In this case study, softwood harvesting, pallet production and repair are covered. Disposal and/or incineration is not covered, yet. Production value is defined as turnover, plus or minus the changes in stocks of finished products, work in progress and goods and services purchased for resale, minus the purchases of goods and services for resale, plus capitalised production, plus other operating income (excluding subsidies). Income and expenditure classified as financial or extra-ordinary in company accounts are excluded from production value (EUROSTAT 2018c). Value added at factor costs is the gross income from operating activities after adjusting for operating subsidies and indirect taxes. Value adjustments (such as depreciation) are not subtracted (EUROSTAT 2018c).

Both values indicate the economic strength and relevance of the material flow and 'core product' as such and in relation with the production value and value added of the German economy. In comparison to the production value, the value added at factor costs indicates the depth of value creation within the material flow since the intermediate consumption is subtracted from the production value.

Data Sources

- Structural Business Statistics (EUROSTAT 2018c, 2018d, 2018e)
- German National Economic Accounts for Forestry (EUROSTAT 2020c)

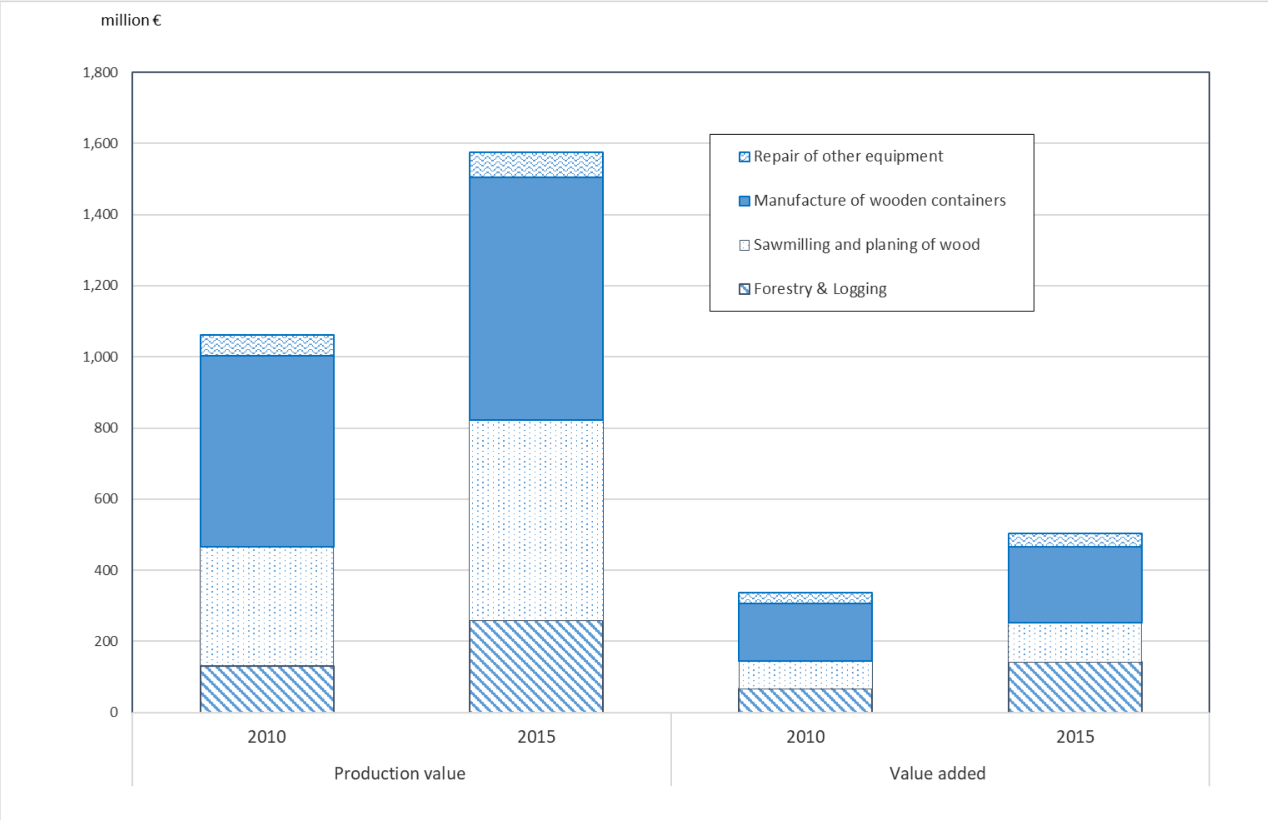
Results for economic Dimension

As indicated in Figure 3.2, the production value related to the softwood lumber material flow and its core product EPAL 1 pallet was 1,060 million € in 2010 and 1,574 million € in 2015. In 2010, this was equivalent to 10 % of the total production value generated in the economic activities forestry & logging, sawmilling, manufacture of wooden containers and repair of other equipment, whereas in 2015 it was equivalent to 11 %.

The added value generated in the process steps of softwood lumber and its core product EPAL 1 pallets was 336 million € in 2010 and 503 million € in 2015. This equated 9 % of the total value added generated in 2010 in the related economic activities of forestry, sawmilling, manufacture of wooden containers and repair. In 2015, it was 10 %.

Looking at the distribution of production value and value added, it shows that assembling EPAL 1 pallets in the economic activity manufacture of wooden containers generate the highest values in the entire material flow. However, it is a common observation that the last processing step in a production value chain generates the highest production value and value added. In line with the higher production value and value added generated in the relevant economic activities of the material flow in 2015 as compared to 2010, also the production value and value added of the EPAL 1 pallets increased significantly. The share of EPAL 1 pallets in the relevant economic activities remained almost unchanged. Compared to the economic activities sawmilling and planing of wood and manufacture of wooden containers, the difference between production value and value added is rather small in forestry & logging. This is because in the first processing step, the connections to other economic activities are low and as a result the amount of intermediate consumption is rather small.

Figure 3.2: Production value and value added at factor cost of the process steps of softwood lumber material flow and its core product EPAL 1 pallets



Source: EUROSTAT (2018c-e, 2020c) and own calculations; Production value and value added at factor costs associated with the production of nails and wood particle blocks are not included.

3.3.2.5 Social Indicators

To exemplify the quantification of social effects, the ‘number of persons employed’ as well as the ‘average annual earnings’ of fulltime employees associated with EPAL 1 pallets were selected. Both metrics are directly or indirectly reflected in the DNS (indicators 8.5a and 5.1a). The number of persons employed is also proposed by Ronzon and M’barek (2018) to monitor bioeconomy on EU level.

Data sources for indicator ‘number of persons employed’:

- Structural Business Statistics (for manufacturing) (EUROSTAT 2018c, 2018d, 2018e, 2019d)
- Labour Force Survey (for forestry & logging) (EUROSTAT 2018a, 2019b)

Data sources for indicator ‘average annual earnings’:

- Earnings Survey (for manufacturing) (DESTATIS 2018c, 2018d)
- Structural Earnings Survey (for forestry & logging) (DESTATIS 2018i)

Alike production costs and value added, the production of EPAL 1 pallets as part of the economic activity manufacture of wooden containers accounts for the highest employment share of the entire material flow, as can be seen in Table 3.6. In line with the increased use of softwood and softwood lumber for the increased EPAL 1 pallet production between 2010 and 2015, the number of persons employed also increased from 7,500 persons in 2010 up to 8,900 persons in 2015. Within the economic activities the percentage of persons employed for the material flow increases from 3 % in forestry & logging to 7 % in sawmilling and planing of wood, 30 % in repair of other equipment and to 35 % in manufacture of wooden containers in 2010. In 2015, the numbers differ only slightly.

Table 3.6: Number of persons employed in production and repair of EPAL 1 pallets in Germany in the year 2010 and 2015 excluding nails and wood particle blocks

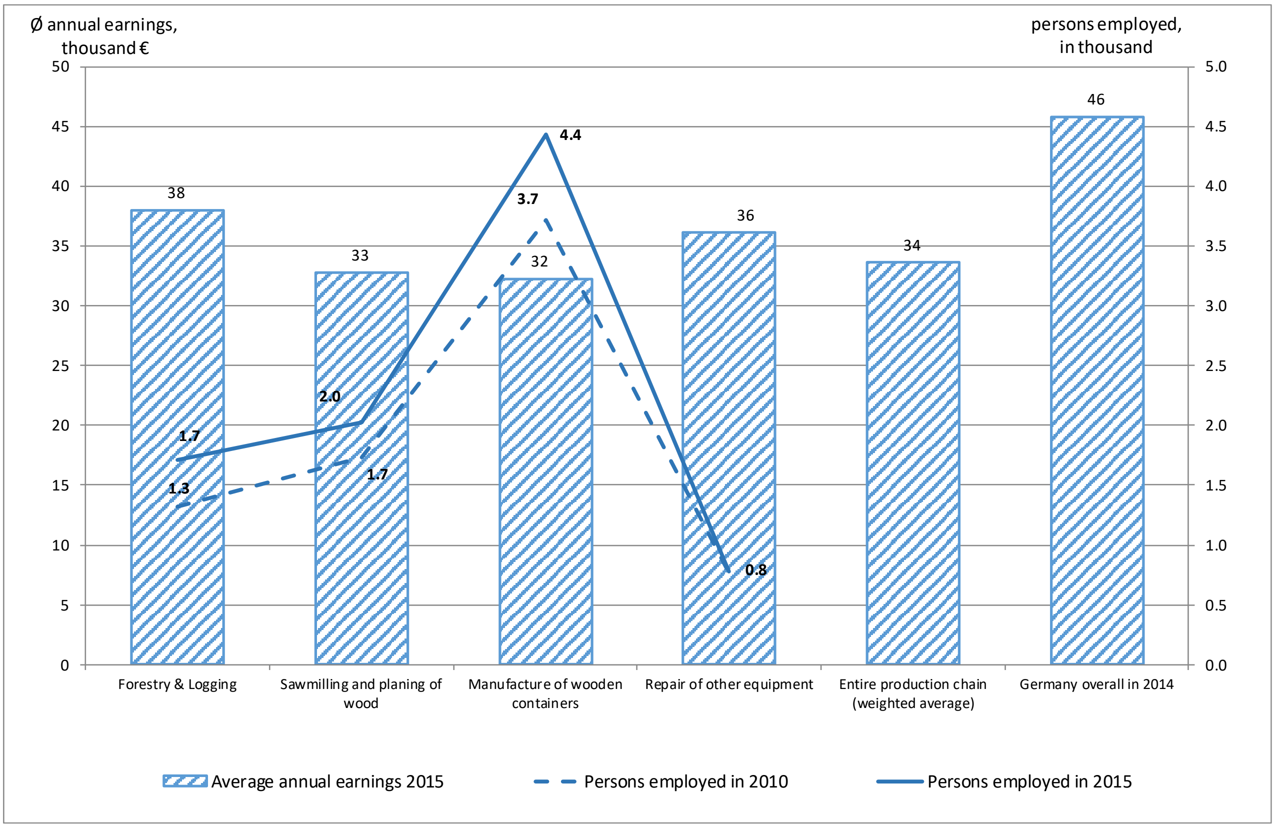
	Persons employed		**Calculated share of EPAL 1 pallets in the related economic activity**		**Persons employed in the production of EPAL 1 pallets**	
	thousand		%		thousand	
Economic activity/Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
Forestry & Logging	38	37	3 %	5 %	1.3	1.7
Sawmilling and planing of wood	25	23	7 %	9 %	1.7	2.0
Manufacture of wooden containers	11	12	35 %	36 %	3.7	4.4
Repair of other equipment	3	3	30 %	30 %	0.8	0.8
Total	76	74			7.5	8.9

Source: EUROSTAT (2018a, c-e, 2019 b,c) and own calculations

Manufacture of wooden containers has, however, compared to the other economic activities the lowest average annual earnings (see Figure 3.3). While in forestry & logging the average annual earnings are 38,000 € and in sawmilling and planing of wood 33,000 €, it is only 32,000 € in manufacture of wooden containers. Compared to the average annual earnings in Germany of 46,000 € in 2014[12], the average annual earnings of persons working in the entire material flow for EPA 1 production is with 34,000 € significantly lower.

12 Since only the Earnings Survey provides comprehensive statistical data for average annual earnings including all economic activities (and agriculture, forestry and fisheries), the average annual earnings in forestry and logging and in Germany overall are only available for 2014. For 2015, no data is available.

Figure 3.3: Persons employed and average annual earnings of full-time employees associated with the process steps of softwood lumber material flow and its core product EPAL 1 pallets for 2010 and 2015



Source: DESTATIS (2018c, 2018i), EUROSTAT (2018a, 2019b, 2019c), own calculations; Production of nails and wood particle blocks are not included

3.4 Sectoral Sustainability Assessment

3.4.1 Methodological Approach

The approach for sectoral assessment of sustainability effects of bioeconomy is based on the quantification of bio-based shares per economic activity. How the bio-based shares are calculated is explained in chapter 2.5 “Bio-based Shares of Sectors”. The approach allows to quantify sustainability effects caused by these bio-based shares for different levels of economic activities (1-, 2-, 3- or 4-digit level). The total for all economic activities with bio-based shares represent bioeconomy’s effect on a national scale. In contrast to the material flow-based approach, the sectoral approach currently assesses sustainability effects related to production only. Effects arising from use and disposal of bio-based products and services (as for example greenhouse gas savings resulting from the harvested wood products or energy use of biomass by private households) are currently not included. However, this is subject for future development of the bioeconomy monitoring concept.

The main underlying assumption of the approach is that the size of bio-based shares per economic activity calculated as a ratio of bio-based material inputs to the total material inputs in monetary values is also valid for different environmental, social and economic sustainability effects quantified by indicators, such as added value, employed persons or air emissions. Although this assumption may not always be true, we argue that a more precise calculation specifically tailored for various economic, social and environmental indicators is currently not feasible.

As described in chapter 2.5 “Bio-based Shares of Sectors”, bio-based shares per economic activity are calculated on the 4-digit level[13], which includes 615 economic activities. Based on the assumption described above, effects of bioeconomy on economic, social and environmental indicators is calculated by multiplying bio-based shares per economic activity with the respective economic, environmental and social indicator values per economic activity. As will be explained in the course of this chapter, the bio-based shares per economic activity are in most cases quantified as a minimum-maximum range. A minimum and maximum range reflects that for some economic activities it is not possible to exactly determine a bio-based share. Hence, a minimum and maximum value is quantified. Consequently, minimum and maximum values also need to be calculated for economic, social and environmental indicators.

However, none of the data sources suitable for sectoral assessment of sustainability effects provide data fully covering all economic activities on a 4-digit level. In many cases, data is available only on a higher level of aggregation (3-, 2- or 1-digit level). This mismatch of data aggregation is addressed in the following three ways:

(1) Using average bio-based shares on a higher aggregation level matching the level of aggregation of the relevant data source.

(2) Applying the minimum and maximum bio-based shares for the respective economic activities on a higher aggregation level (broadening the minimum-maximum range).

(3) Using additional (underlying) statistical sources.

The first approach would require a calculation of the average bio-based shares on a higher aggregation level than a 4-digit level, matching the aggregation level of the respective statistical data source. However, such average shares on a higher aggregation level would lead to a significant loss of accuracy, which is hard to quantify exactly. Therefore, we decided not to follow this approach.

Applying the minimum and maximum bio-based shares for the respective economic activities on a higher aggregation level (second approach) allows for achieving more accurate results by enlarging the range between the minimum and maximum value. That is why we used this method explained in detail below.

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[13] For construction activities, a 5-digit level is used.

The minimum bio-based value of an indicator on any higher aggregated level than a 4-digit level IND $_{\text{bb min NACE (1,2,3-digit level)}}$ is calculated by multiplying the lowest minimum bio-based share of all underlying NACE economic activities on the 4-digit level with the indicator value on the aggregated level (1-, 2- or 3-digit level)

$$\boldsymbol{IND_{bb\,\min NACE\,(1,2,3-digit)}} = \boldsymbol{IND_{NACE\,(1,2,3-digit)}} * \boldsymbol{min(bb_{\min 1}; bb_{\min 2}; \ldots; bb_{\min n})}$$

Equation 3.4.1

where

$IND_{bb\,\min NACE\,(1,2,3-digit)}$	minimum bio-based value of an indicator on a 1-, 2- or 3-digit level
$IND_{NACE\,(1,2,3-digit)}$	respective indicator value on a 1-, 2- or 3-digit level
bb_{min}	minimum bio-based share of all underlying economic activities on the 4-digit level
n	number of the underlying economic activities on the 4-digit level

Accordingly, the maximum bio-based value for an indicator on any higher aggregated level than a 4-digit level IND $_{\text{bb max NACE (1,2,3-digit level)}}$ is calculated by multiplying the highest maximum bio-based share of all underlying NACE economic activities on the 4-digit level with the indicator value on the aggregated level (1-, 2- or 3-digit level)

$$\boldsymbol{IND_{bb\,\max NACE\,(1,2,3-digit)}} = \boldsymbol{IND_{NACE\,(1,2,3-digit)}} * \boldsymbol{max(bb_{\max 1}; bb_{\max 2}; \ldots; bb_{\max n})}$$

Equation 3.4.2

where

$IND_{bb\,\max NACE\,(1,2,3-digit)}$	maximum bio-based value of an indicator on a 1-, 2- or 3-digit level
$IND_{NACE\,(1,2,3-digit)}$	indicator value on a 1-, 2- or 3–digit level
bb_{max}	maximum bio-based share of all economic activities on the 4-digit level
n	number of the underlying economic activities on the 4-digit level

The described approach allows to delimit the range of possible bioeconomy sustainability effects. The higher the aggregation level of the available data sources, the larger is the minimum-maximum range of the results and accordingly the uncertainty regarding bioeconomy performance. We applied this method for any cases of missing data on a 4-digit level, including gaps in statistical data due to non-disclosure policy of DESTATIS. However, this method is not applicable if only average values of the respective economic activities are available (for example average salaries). In this case, indicator values are calculated on a 4-digit level if a breakdown for all economic activities is available.

Where applicable, we also use additional statistical sources underlying national and environmental accounts in order to further reduce the minimum – maximum range (third approach). They are often available on a 4-digit level and are adjusted to match the highly aggregated economic sectors of the national accounts. Hence, for the different indicators and economic sectors adjustment values from 4-digit level to higher aggregates are provided in supplementary material to national accounts. How indicator values are calculated based on the underlying statistics is explained in the following:

$$\boldsymbol{IND_{bb\,min\,NACE\,(1,2,3-digit)} = \sum_{i=1}^{n} IND_{NACE\,(4-digit)i} * bb_{min\,i} + IND\ adj._{NACE\,(1,2,3-digit)} * min(bb_{min\,1}; bb_{min\,2}; \dots; bb_{min\,n})}$$

Equation 3.4.3

where

$IND_{bb\,\min NACE\,(1,2,3-\mathrm{digit})}$	minimum bio-based value of an indicator on a 1-, 2- or 3-digit level
$IND_{NACE\,(4-digit)\,i}$	indicator value in the underlying statistical source on the 4-digit level for economic activity i
$bb_{\min i}$	bio-based share of the economic activity i on the 4-digit level
i	underlying economic activity on the 4-digit level
n	number of the underlying economic activities on the 4-digit level
$IND\ adj._{NACE\,(1,2,3-digit)}$	adjustment term in the main statistical source on a 1-, 2- or 3-digit level

$$\boldsymbol{IND_{bb\,\max NACE\,(1,2,3-digit)} = \sum_{i=1}^{n} IND_{NACE\,(4-digit)i} * bb_{\max i} + IND\ adj._{NACE\,(1,2,3-digit)} * max(bb_{\max 1}; bb_{\max 2}; \dots; bb_{\max n})}$$

Equation 3.4.4

where

$IND_{bb\,\max NACE\,(1,2,3-digit)}$	maximum bio-based value of an indicator on a 1-, 2- or 3-digit level
$IND_{NACE\,(4-digit)\,i}$	indicator value in the underlying statistical source on the 4-digit level for economic activity i
$bb_{\min i}$	bio-based share of the economic activity i on the 4 –digit level
i	underlying economic activity on the 4-digit level
n	number of the underlying economic activities on the 4-digit level
$IND\ adj._{NACE\,(1,2,3-digit)}$	adjustment term in the main statistical source on a 1-, 2- or 3-digit level

Table 3.7 illustrates the quantification of an indicator based on underlying statistical sources using the example of the minimum bio-based production value for economic activity 21 "Manufacture of pharmaceutical products and preparations".

Table 3.7: Quantification of minimum bio-based production value using approach 3 for economic activity 21 "Manufacture of pharmaceutical products and preparations"

NACE Nr.	Name	Indicator value on a 4-digit level ($IND_{NACE\ (4\text{-}digit)}$) Million €	Adjustment in national accounts ($IND\ adj._{NACE(1,2,3\text{-}digit)}$) Million €	Min. bio-based share (bb_{min}) %	Min. bio-based indicator value on a 4-digit level ($IND_{NACE\ (4\text{-}digit)}*bb_{min}$) Million €	Min. bio-based indicator value of adjustment ($IND\ adj._{NACE(1,2,3\text{-}digit)} * bb_{min}$) Million €	Min bio-based indicator value total ($IND_{bb\ min\ NACE\ (1,2,3\text{-}digit)}$) Million €
2110	Manufacture of basic pharmaceutical products	1,233.50	2,472.60	31.1	383.15	252.43	4,181.77
2120	Manufacture of pharmaceutical preparations	34,735.90		10.2	3.546.19		

Source: Own calculations based on EUROSTAT (2019d)

Eq. 3.4.3 and Eq. 3.4.4 are applicable to any indicator, that is based on a single value, e.g. value added, green-house gas emissions etc. and thus, requires only a summing up of all quantified bio-based values per economic activity on a 1-, 2-, 3- or 4-digit level. For indicators representing a ratio of two variables (e.g. labour productivity), additional calculation steps are required. For any two variables A_{bb} and B_{bb}, the resulting bio-based indicator value represents a function

$$\boldsymbol{f(x) = \frac{A_{bb}(x)}{B_{bb}(x)} = \frac{\sum_{i=1}^{N} x_i * a_{NACE\ (1,2,3,4-digit)i}}{\sum_{i=1}^{N} x_i * b_{NACE\ (1,2,3,4-digit)i}}} \qquad \text{Equation 3.4.5}$$

where

$$bb_{\min i} \le x_i \le bb_{\max i};$$

$$bb_{\min i} = min(bb_{\min 1}; bb_{\min 2}; \dots; bb_{\min n});$$

$$bb_{\max i} = max(bb_{\max 1}; bb_{\max 2}; \dots; bb_{\max n});$$

and

$a_{NACE\ (1,2,3,4-digit)i}$ value of indicator A per economic activity i on a 1-, 2-, 3- or 4-digit level;

$b_{NACE\ (1,2,3,4-digit)i}$ value of indicator B per economic activity i on a 1-, 2-, 3- or 4-digit level;

x_i bio-based share per economic activity i;

i economic activity on a 1-, 2-, 3- or 4-digit level;

N number of data sets to be added up;

$bb_{\min i}$	minimum bio-based share on the 4-digit level for the respective economic activity i;
$bb_{\max i}$	maximum bio-based share on the 4-digit level for the respective economic activity i;
n	number of any underlying economic activities on the 4-digit level for economic activity i.

Unfortunately, the minimum-maximum range of the two bio-based variables used to calculate ratio indicator also increases the resulting ratio. Thus, a more detailed breakdown level is usually required to achieve meaningful results for ratio-based indicators.

We tested the applicability of the sectoral approach with 27 bioeconomy-relevant indicators of the DNS. Overall, data was principally available for 23 of 27 indicators. Among these, 8 indicators do not require any additional calculations. The remaining 15 indicators need to be quantified based on the equations explained above. Although data is available to quantify the indicators, the level of detail varies significantly, thus, leading to inhomogeneous results. While some indicator values have a relatively narrow range, for others the range is quite wide. In some cases, one can quantify only minimum indicator values.

Each indicator is different, which often requires a specifically tailored quantification method. Although the above described approach allows to quantify a wide range of sustainability indicators, it is not applicable to all of them. Hence, an additional brief description of the methods used for each indicator is provided in chapter 3.4.2 “Indicator results”. Due to time restrictions and data unavailability, results are presented for 10 indicators. However, we attached an overview of all 27 DNS indicators identified as being relevant for the bioeconomy in Annex 1.

3.4.2 Indicator Results

In order to give an idea on some of bioeconomy’s sustainability effects on a national scale, 10 indicators have been quantified and put into perspective with the total figures for Germany. As described in the previous chapters, the indicators origin from the German Sustainable Development Strategy (Deutsche Nachhaltigkeitsstrategie, DNS). When necessary, some of the indicators have been slightly adjusted. In addition, we used calculated results to analyse eco- and labour-efficiency with two additional indicators. Although not a part of the DNS, we consider them very helpful for understanding and interpreting the bioeconomy’s performance and development. A brief description of methods and data used is given for each specific indicator. To achieve coherent results, we only used data sources applied in the DNS. Since there are no official goals defined for the (sustainable) development of German bioeconomy yet, there are no targets the indicator values could be compared with. Instead, they are compared with the development in Germany as a whole or parts of the economy. However, the national targets for Germany should not be understood as targets for German bioeconomy.

3.4.2.1 Gross Value Added (SDG 8, Sub-indicator for indicator 8.3)

This indicator aims to measure the achievement of SDG 8 “Decent Work and Economic Growth”. Gross value added is a sub-indicator to DNS indicator 8.3 “Gross fixed capital investment in relation to GDP”. Due to missing data, we had to modify the indictor to “Gross fixed capital investment in relation to value added”. Value added is one of the most important metrics measuring economic performance of a company, sector or a country. Value added is the value of all products and services less intermediate consumption. Due to the significance of this economic metric, we made a dedicated analysis chapter for its value and development in bioeconomy.

Data Sources

- National Accounts, production accounts (DESTATIS 2018k)
- Structural Business Statistics (SBS) (EUROSTAT 2019d)
- Turnover Tax Statistics (DESTATIS 2017e)
- Business Register (pers. comm. DESTATIS 2020a)

Methodological Approach

Gross value added is calculated based on the production accounts of national accounts. Gross value added at basic prices is used since it is the basis for GDP calculation. As described in chapter 3.4.1 “Methodological Approach” Eq. 3.4.3 and Eq. 3.4.4 are applied to calculate the indicator values. However, due to a very high level of aggregation of the construction sector in national accounts and its small share in bioeconomy, SBS were used to allocate the share of the adjustments made in national accounts for this sector.

Due to the missing data for deflators of economic activities on the 4-digit level (as described in chapter 3.2.1), the price adjusted values were calculated based on the weighted average results for economic activities on the aggregation level of 63 economic sectors. This may lead to inaccurate results. However, as presented in Figure 3.4, more than 70 % of the entire value added of bioeconomy is generated in the sectors:

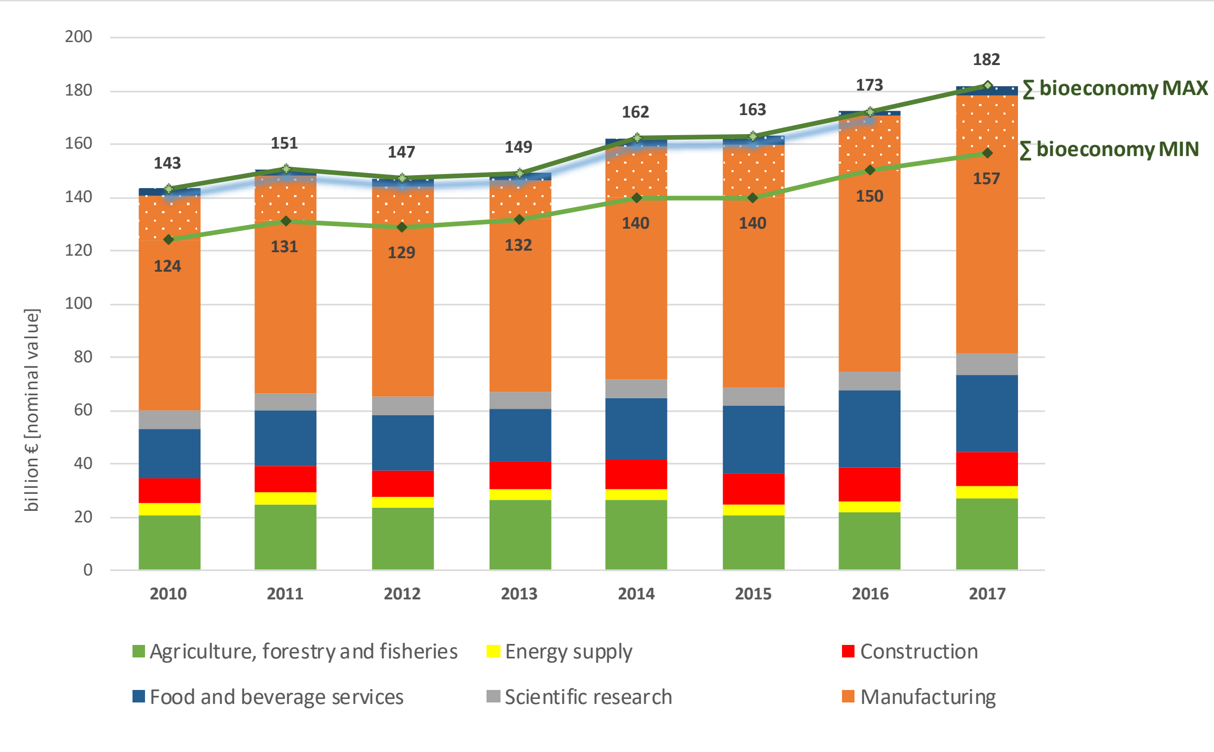
- agriculture, forestry & fisheries,
- food, feed and beverage industry,
- manufacture of wood, paper, printing and reproduction as well as
- food services.

Bio-based shares on the 4-digit level within these economic sectors are relatively homogeneously spread and on a constantly high level. Therefore, we expect the estimations to be a good proxy for a price-adjusted development of bioeconomy despite some uncertainty of results due to missing data for deflators.

Results for the years 2010 – 2017

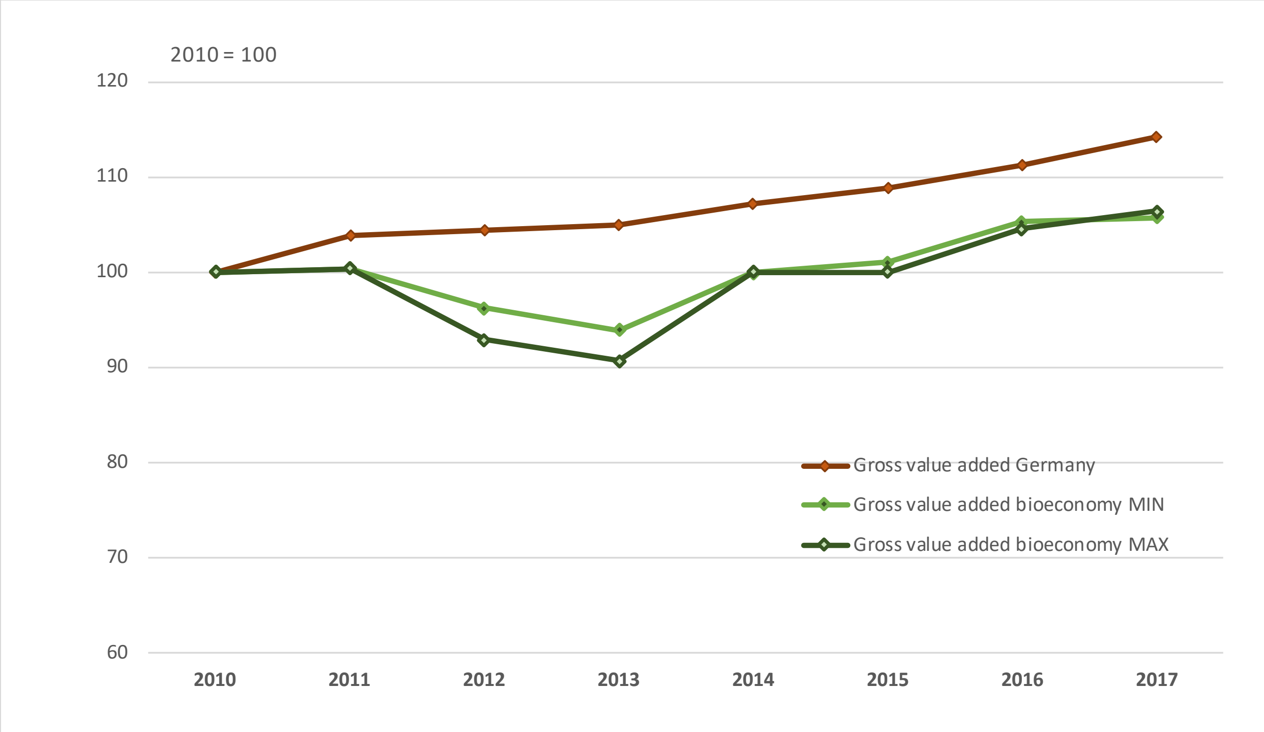
The share of bioeconomy in the total gross value added in Germany is 5 – 6 %. In 2017, about half of the gross value added was generated in the manufacturing sector, followed by food and beverage services (17 – 18 %) and agriculture, forestry & fisheries (15 – 17 %). Construction accounted for 7 – 8 %. The contribution of the energy sector and scientific research together amounted to 8 %. By far the largest share of gross value added within the manufacturing industry was accounted for by food, feed and beverage manufacturing (46 – 58 %). Paper production accounted for approx. 10 – 11 %. The remaining shares were distributed among different economic sectors and did not exceed 10 % per sector. As shown in Figure 3.4, the structural composition of bioeconomy remained essentially unchanged over the period considered.

Figure 3.4: Gross value added of bioeconomy in Germany in the years 2010 to 2017 (nominal values).



Source: Own calculation based on DESTATIS (2017e, 2018k, 2020a), EUROSTAT (2019d)

Figure 3.5: Development of the price-adjusted gross value added in Germany and in bio-economy in the years 2010 to 2017



Source: Own calculation based on DESTATIS (2017e, 2018k, 2020a), EUROSTAT (2019d)

The price-adjusted gross value added in bioeconomy has increased by 6 – 7 % over the observed period (Figure 3.5). This increase is mainly caused by growth in the food and beverage services (+18 to 19 % compared to 2010), in the food and beverage manufacturing (+4 % compared to 2010), in forestry (+82 % compared to 2010) and in paper production (+17 to 18 % compared to 2010). The decline in agriculture (-17 % compared to 2010) had the opposite effect. The change of added value over time is a result of growth or decline in the respective bioeconomy-relevant economic activities. Changes of bio-based shares per economic activity had only minor effects. The overall increase of the price-adjusted gross value added in bioeconomy remained significantly below the growth rate of the German economy as a whole.

3.4.2.2 Gross fixed Capital Investment in relation to Gross Value Added (SDG 8, indicator 8.3)

This indicator, which is also called investment rate, aims to measure the achievement of the SDG 8 “Decent Work and Economic Growth”. Investments made by companies and the state are essential for future economic strength and competitiveness. Thus, the German Federal Government aspires to ensure an appropriate relation of gross capital investment to GDP. However, no specific interpretation of the term “appropriate relation” is given. The indicator measures the share of the gross capital investment in relation to the GDP in nominal values. Since GDP is an economic aggregate of national accounts, it is not calculated for economic sectors. Therefore, in national accounts, the share of economic sectors in GDP is displayed in terms of gross value added (GVA). Hence, we modified the indicator. Instead of GDP, gross value added is used to calculate the investment rate in bioeconomy.

Gross fixed capital formation is measured by the total value of economic units' acquisitions, less disposals of fixed assets during the accounting period plus certain additions to the value of non-produced assets (such as subsoil assets or major improvements in the quantity, quality or productivity of land). Fixed assets are produced assets that are designed for repeated or continuous use in production processes for longer than a year. These include buildings and structures (dwellings, other buildings and structures), machinery and equipment (machinery, vehicles, tools) and other assets, mainly including intangible assets such as investments in research and development, computer software and databases, entertainment, literary or artistic originals). Also included are improvements on existing stocks of fixed assets that lead to a significant increase in the value of an asset and/or prolong its useful life (DESTATIS 2018g).

Data Sources

- National Accounts, production accounts (DESTATIS 2018k)
- Structural Business Statistics (SBS) (EUROSTAT 2019d)

Methodological Approach

Quantification of gross value added is described in the chapter 3.4.2.1. In line with GVA, also gross fixed capital investment is calculated based on the production accounts of national accounts, allowing its comparison with German economy as well as with other sectors and countries.

We applied approach 3 (Eq. 3.4.4 and Eq. 3.4.4) described in chapter 3.4.1 "Methodological Approach" to quantify bio-based values for gross investments in new buildings and machinery & equipment. Investments in "other assets" which include investments in intangible assets were allocated to bioeconomy according to Eq. 3.4.1 and Eq. 3.4.2. This is due to the missing data for intangible assets on the 4-digit level (as described in the chapter 3.2.1)[14]. Another statistical data gap concerns investments in used assets which are only available at the national level. They account for 3 % of the investments in new assets and have remained almost unchanged since 2010. To cover them in bioeconomy, an assumption was made, that investments in used assets have the same share in all economic activities. Hence, a mark-up of 3 % was made for each economic activity. Any further data gaps for specific economic activities in SBS were dealt with according to Eq. 3.4.1 and 3.4.2.

[14] With the exception of the economic activity 72 "Scientific research and development". For this economic activity, we distributed the amount of intangible assets in relation to the personnel costs in the underlying economic activities. This is due to the fact that intangible assets in scientific research are mainly generated by own employees.

A simplified method was applied to quantify the minimum and maximum ratio of gross fixed capital formation and GVA. In particular the following equations were applied:

$$bioeconomy \min\left(\frac{Gross\ fixed\ capital\ formation}{Gross\ value\ added}\right) = \frac{\min Gross\ fixed\ capital\ formation\ in\ bioeconomy}{\max Gross\ value\ added\ in\ bioeconomy}$$

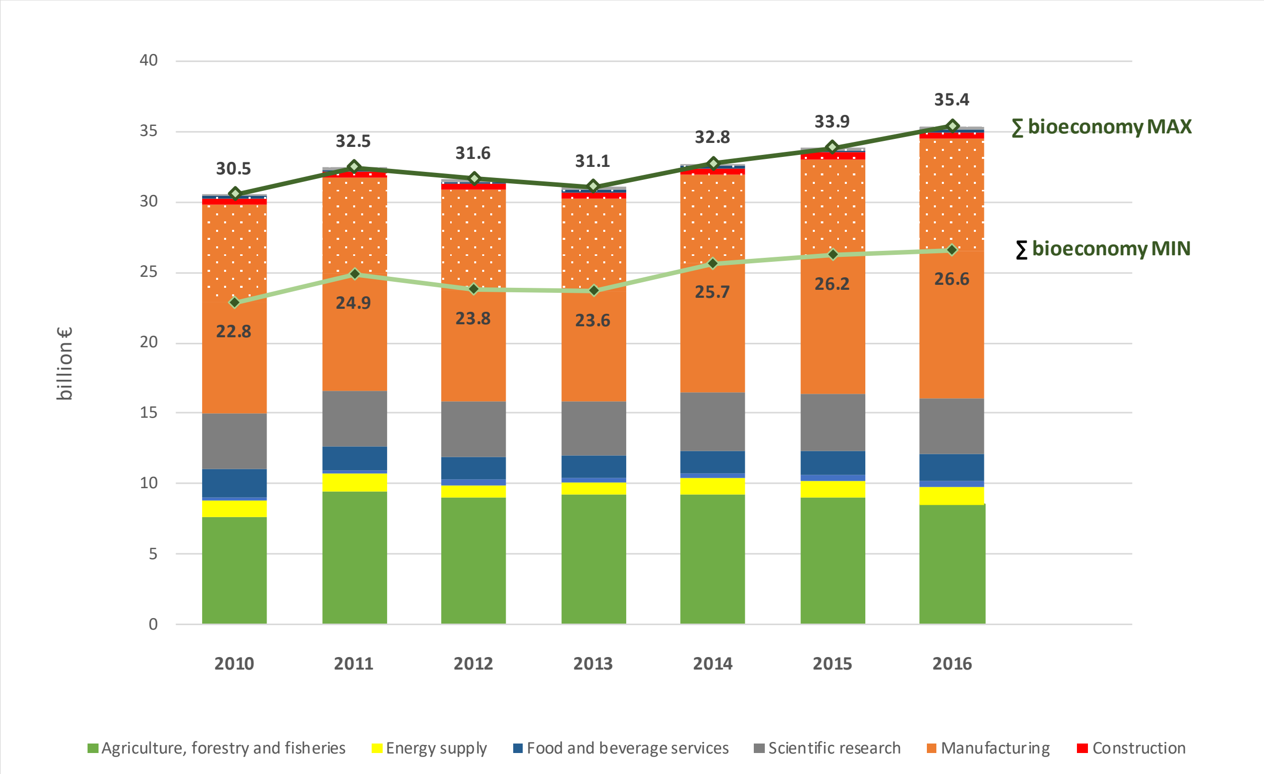
$$bioeconomy \max\left(\frac{Gross\ fixed\ capital\ formation}{Gross\ value\ added}\right) = \frac{\max Gross\ fixed\ capital\ formation\ in\ bioeconomy}{\min Gross\ value\ added\ in\ bioeconomy}$$

This simplified method, however, results in an enlarged range between minimum and maximum. In future, a more accurate calculation might reduce the minimum – maximum range.

Results

Figure 3.6 shows structure and development of investments in bioeconomy. Due to the missing data about investments in intangible assets per economic activity at a detailed level, the minimum-maximum span of the results for investments made in bioeconomy is higher than for the gross value added. Investments in bioeconomy account for 4 to 5 % of the total investments in Germany and thus, are on the same level as the share of gross value added. However, looking at the structure reveals a higher share of agriculture, forestry and fisheries as well as of scientific research & development as compared to the structure of gross value added. Agriculture, forestry and fisheries account for 24 to 33 % and scientific research & development for 10 to 13 % of the total investments in bioeconomy. This goes along with the lower shares of investments in food and beverage services (7 to 6 %) and construction (2 to 3 %). More than half of the investments across all economic sectors besides scientific research was made in machinery & equipment. Investments in the economic sector scientific research & development were dominated by intangible assets, accounting for roughly three quarters of the total invested amount.

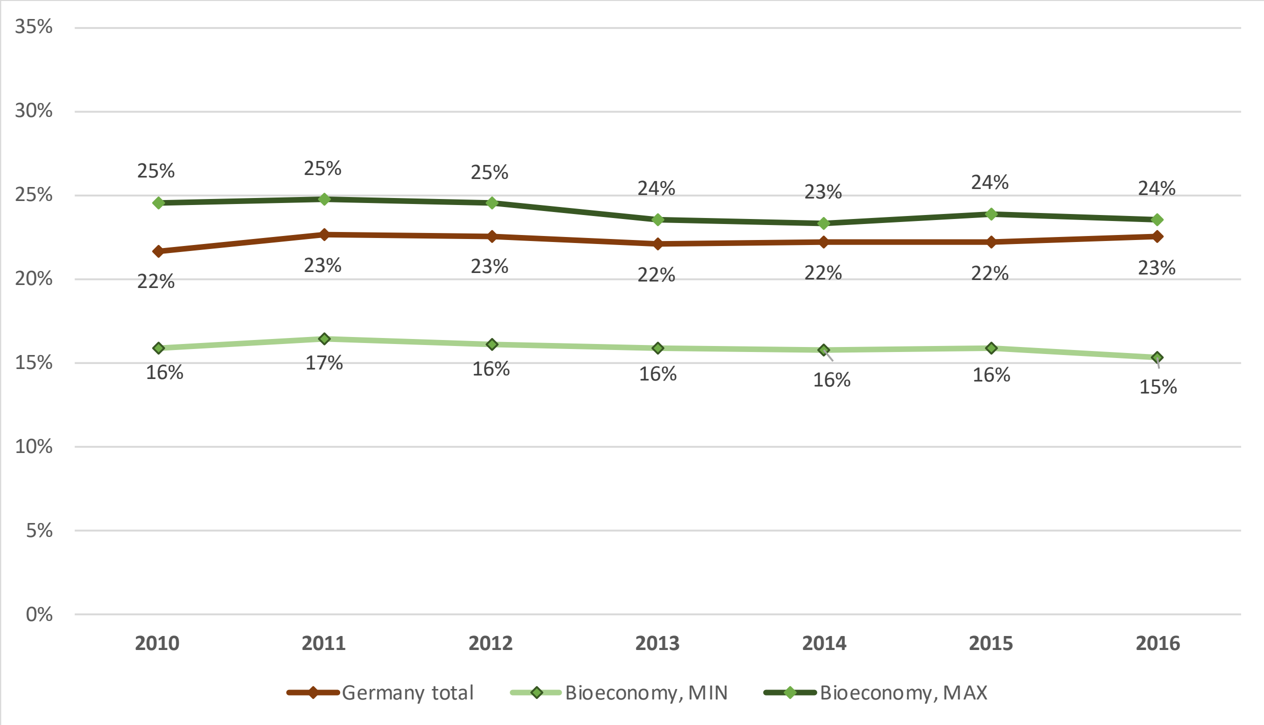
Figure 3.6: Structure and development of gross fixed capital investments in bioeconomy



Source: Own calculation based on DESTATIS (2018k), EUROSTAT (2019d)

The investment ratio of bioeconomy is between 15 to 24 % (cf. Figure 3.7). Similar to the investment ratio for German economy as a whole, bioeconomy values show slight increases and decreases with no clear development trend since 2010. Investment rates vary significantly in the different sectors due to underlying business specifics. Although the minimum-maximum range of investments ratio is rather wide, the average ratio is well below the overall rate in Germany. However, the latter is significantly determined by a very high investment ratio in the economic sector "real estate activities", accounting for more than 30 % of all new fixed assets in German economy. Without the real estate sector, the investment rate of Germany amounts to 1 % and is thus, comparable with the average value of bioeconomy.

Figure 3.7: Development of gross fixed capital investment in bioeconomy and in Germany



Source: Own calculation based on DESTATIS (2018k), EUROSTAT (2019d)

3.4.2.3 Employment Rate (SDG 8, indicators 8.5a and 8.5b)

A high employment rate of working-age population is important for social stability, maintenance of social security systems and a stable economic development. Increasing the labour force participation of all age groups and especially of older people is, therefore, a declared goal of German government. In accordance with the set goal, two indicators measure its achievement: employment rate of persons aged 20 – 64 (total persons in working age) and employment rate of persons aged 60 – 64. Employed persons are defined as all persons who have worked for at least 1 hour during the week as employees or self-employed persons against payment of remuneration as well as unpaid family workers (DESTATIS 2018g).

Data Sources

- Labour Force Survey (LFS) (EUROSTAT 2019b; pers. comm. EUROSTAT 2019c)
- Structural Business Statistics (SBS) (EUROSTAT 2019d)

Methodology

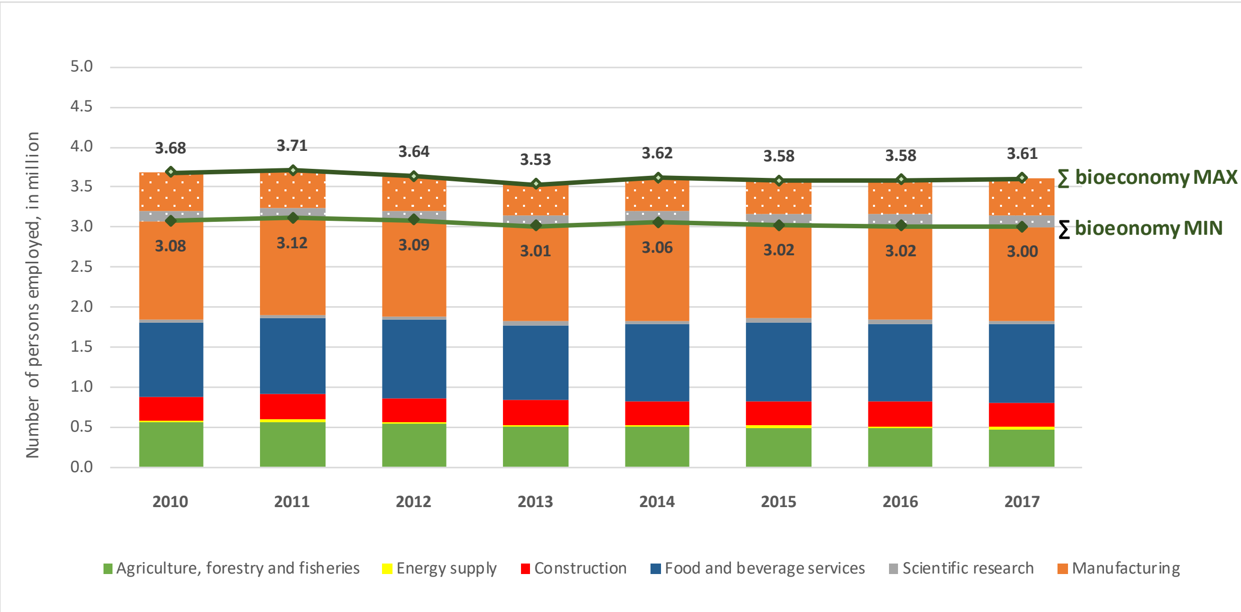
Following the methodological approach applied in the DNS, employed persons in bioeconomy were calculated for the age groups 20 – 64 and 60 – 64 years. Since data is available only at a 3- to 2-digit level, Equation 3.4.1 and

Equation 3.4.2 were used to quantify the respective bio-based values. Due to a very wide range of results in construction industry, we additionally used SBS for this sector. The respective values of the economic activities in the LFS at the 3-digit level were broken down into the values at the 4- and 5-digit level applying respective relations of the indicator "persons employed" in the SBS. We refer to our explanations in chapter 3.2.3 for deviations of scope and methodology between these two statistical sources.

A smaller sample size for persons aged 60 – 64 results in higher aggregated data as compared to age group 20 – 64 and thus, to a wider range of results. Any additional split of data (as for example into male and female persons or employees and self-employed) would inevitably cause a further widening of minimum-maximum range and leading to results not useful for the analysis.

Results

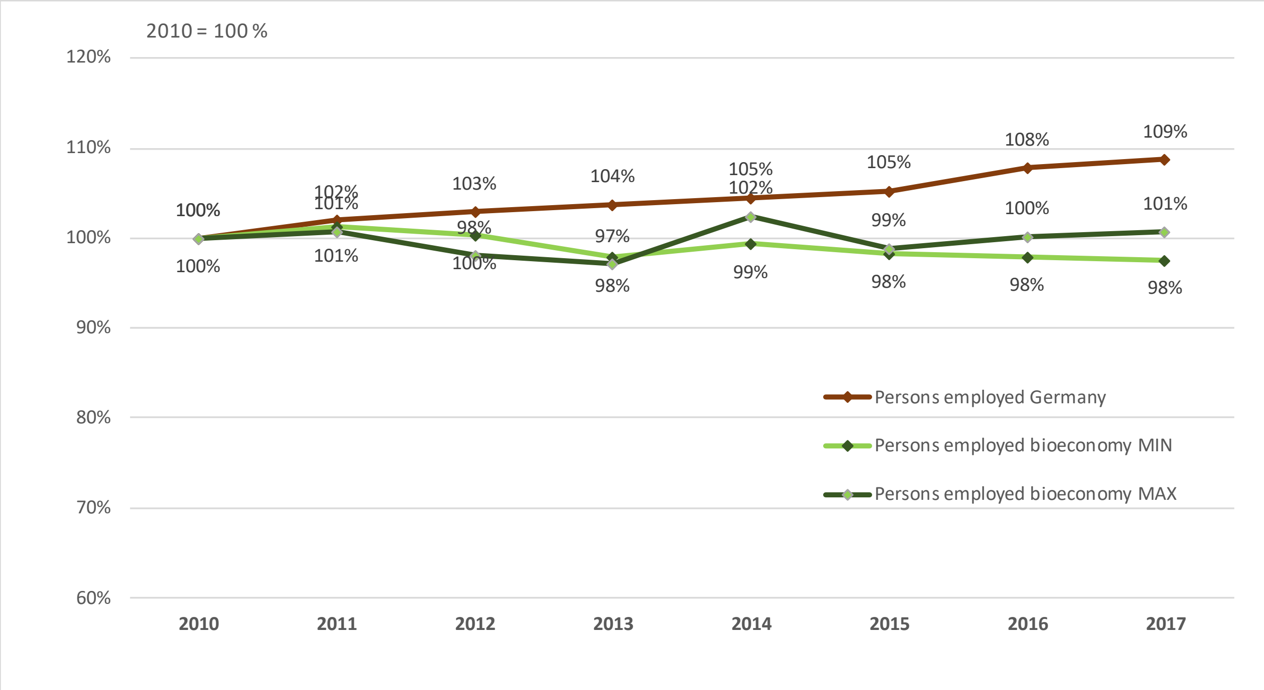
Figure 3.8: Persons employed in bioeconomy in the age group 20 – 64 years



Source: Own calculations based on EUROSTAT (2019 b-d)

3.0 – 3.6 million persons are employed in bioeconomy. This accounts for approximately 8 – 9 % of the total workforce in Germany (see Figure 3.8). Around three quarters of the persons are employed in the manufacturing sector (39 – 45 %) and in the food and beverage services (27 – 33 %). Agriculture, forestry and fisheries account for 13 – 16 % and construction to 8 – 10 %. Scientific research and the energy industry employ about 5 %. More than half of all employees in the manufacturing sector (51 – 67 %) work in food, feed and beverage manufacturing. The share of other economic activities is evenly distributed and does not exceed 10 %.

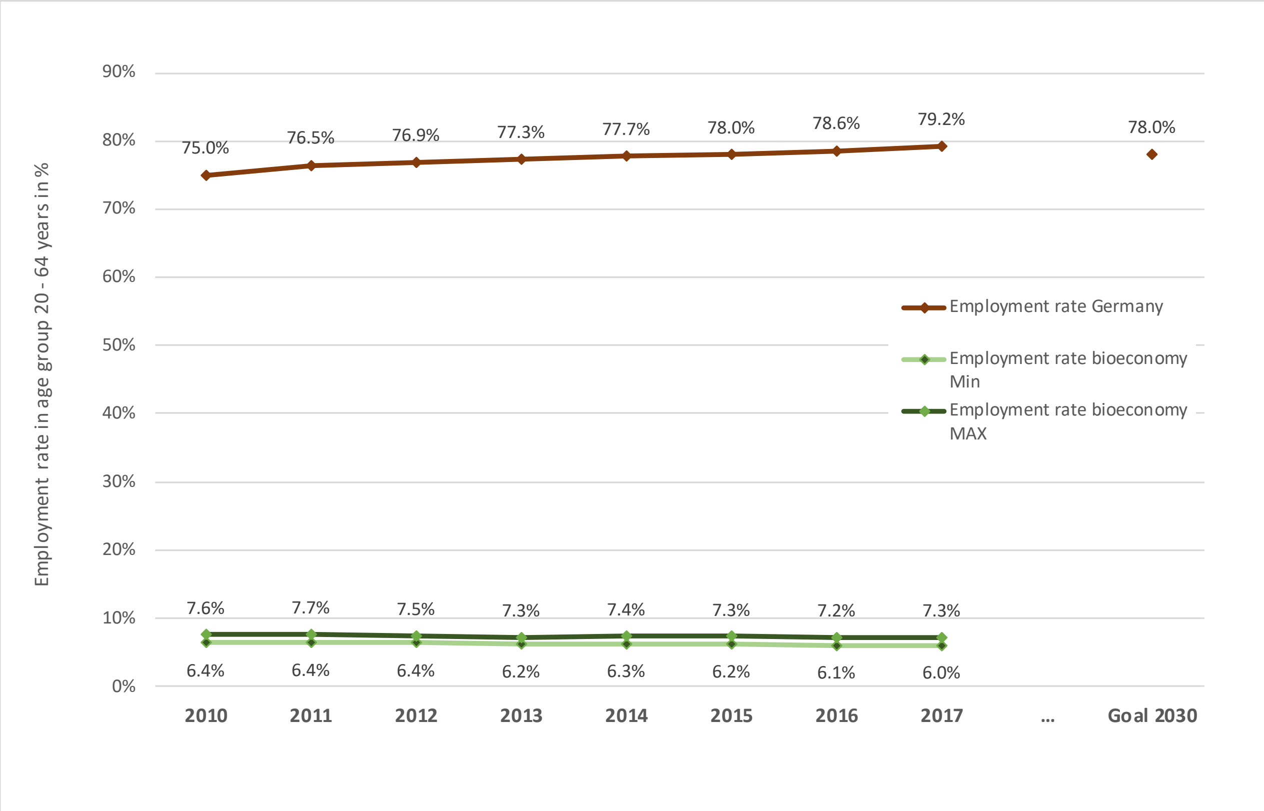
Figure 3.9: Development of persons employed in the age group 20 – 64 years in bioeconomy and in Germany



Source: Own calculation based on EUROSTAT (2019b-d)

While the number of employed persons in Germany increased by 9 % between 2010 and 2017, there has been a stable trend in bioeconomy (see Figure 3.9). The main reason for this was the drop in the number of people employed in agriculture (-15 % compared to 2010) as well as paper and printing industries, chemical industry and furniture production. This was partially offset by an increase in employment in food and beverage services (+6 % compared to 2010) as well as in food and feed manufacturing, construction and scientific research. The respective bio-based shares per economic activity remained almost unchanged.

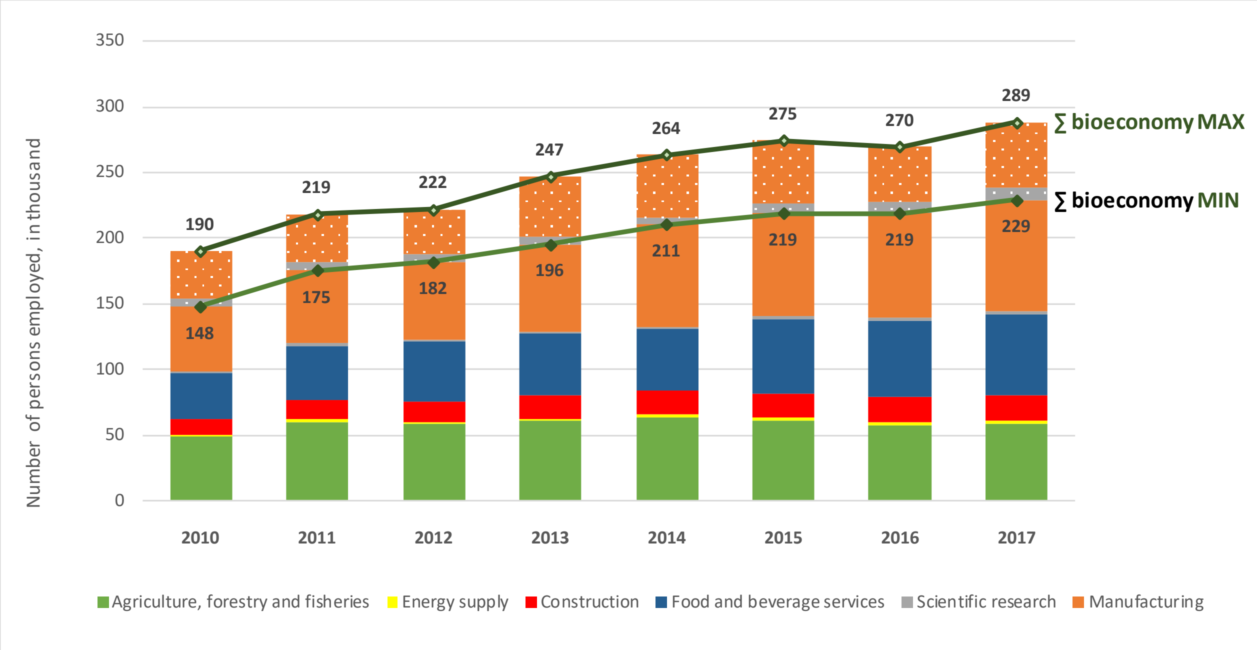
Figure 3.10: Employment rate in Germany and thereof in bioeconomy in the age group 20 – 64 years



Source: own calculations based on EUROSTAT (2019b-d)

The number of people employed in bioeconomy related to the total population of that age group gives the employment rate induced by bioeconomy. In 2010, 7.6 % of the German population in the age group 20 – 64 years was employed in bioeconomy (cf. Figure 3.10). This rate slightly decreased over time and reached 7.3 % in 2017 which contrasts with the increase in the employment rate for Germany from 75 to 79 %.

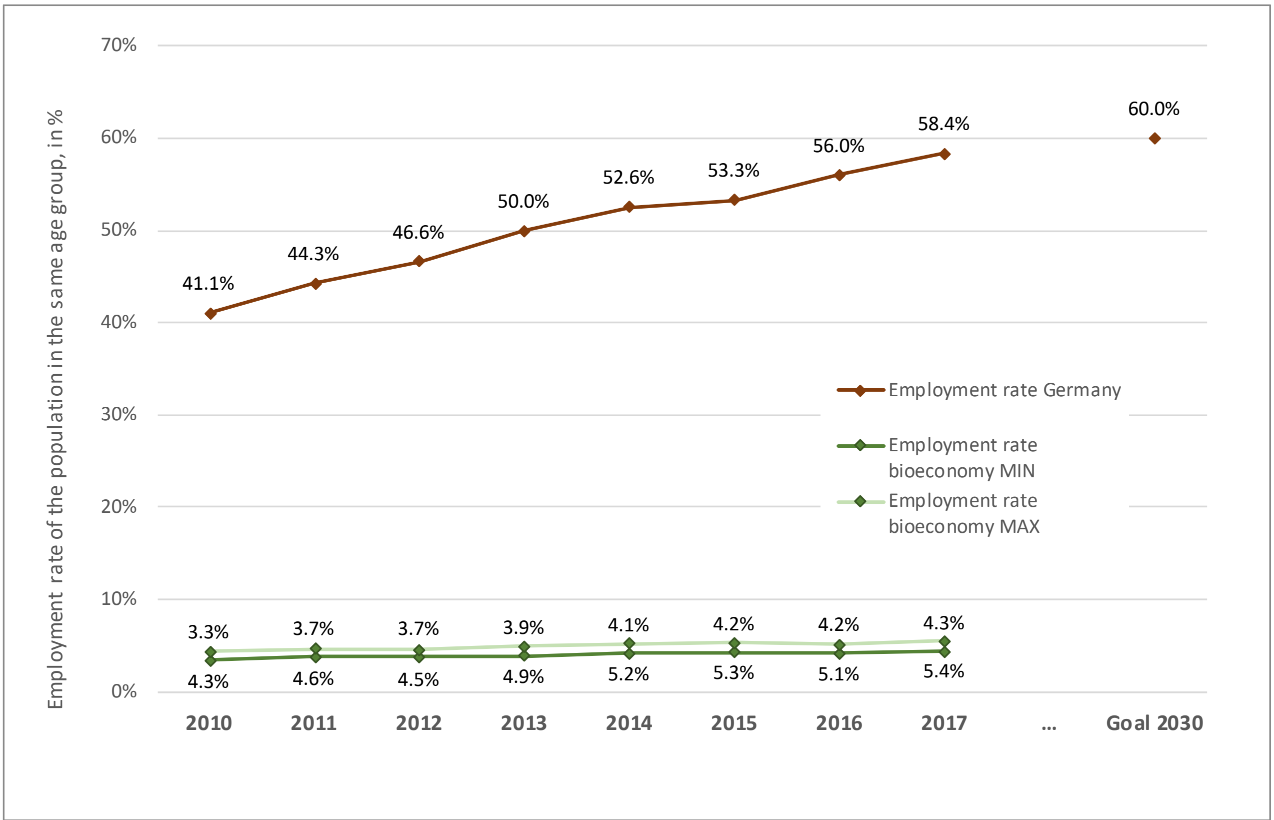
Figure 3.11: Persons employed in bioeconomy in the age group 60 – 64 years



Source: Own calculation based on EUROSTAT (2019b-d)

In line with the overall trend in Germany, the number of employed older people increased significantly also in bioeconomy (see Figure 3.12) Agriculture, forestry and fisheries have the highest proportion of older people employed within the sector, accounting for 12 % (in 2017). This is above the average rate in Germany of 8 %. This is reflected in the increased share of this economic sector in the total number of persons employed in the age group 60 – 64 as compared to the age group 20 – 64. Food services, construction and scientific research have the lowest proportion of older people employed, accounting for 6 % only. Since the overall number of persons employed in bioeconomy has not increased in the concerned period, a structural shift towards older persons has taken place during the considered time period.

Figure 3.12: Employment rate in Germany and thereof bioeconomy in the age group 60 – 64 years



Source: Own calculation based on EUROSTAT (2019b-d)

A higher number of persons employed in the age group 60 – 64 results in the accordingly higher employment rate of this age group in bioeconomy in 2017 as compared to 2010. This is in line with the overall trend for this age group in Germany, even though at a slower rate.

3.4.2.4 Primary Energy Consumption (SDG 7, indicator 7b)

The indicator “primary energy consumption” measures the energy demand of a country. It includes consumed energy in the energy sectors itself, energy losses from conversion and distribution, the final consumption by production activities, transport and households. Since energy saving and increasing energy efficiency reduce environmental impacts and as well lead to higher independency of energy supply, reduction of primary energy consumption is an explicate goal of the Federal Government in Germany. The indicator is calculated for Germany based on the data of energy balances of the Energy Balances Group (AGEB).

Data Sources

- Annual survey on energy use in manufacturing, mining and quarrying (pers. comm. DESTATIS 2018a)
- Annual survey of electricity generation plants of enterprises in manufacturing, mining and quarrying (DESTATIS 2019d)
- Environmental accounts, table of environmental accounts, part 3: Energy (DESTATIS 2019f)
- Energy balances (AGEB 2020a)
- Satellite balances (AGEB 2020b)
- Survey for energy use of the industry, trade and service sector (Schlomann et al. 2015)
- Time series on the development of renewable energies in Germany (AGEE-Stat 2020)

Methodology

Primary energy estimations of environmental accounts are the primary data source. However, two methods exist to allocate primary energy use to different sectors in environmental accounts. In the first approach, transformation losses and own energy use of the conversion sector are allocated where they origin. In the second approach, they are allocated to the sectors consuming energy. As a result, very little primary energy use is allocated to the energy sector itself. In principle, both methods are applicable to quantify bio-based shares of primary energy consumption. In any case of comparisons with other clusters, it is important that for all sectors the same approach is applied. Here, it is the first approach.

The primary energy consumption in environmental accounts is split per so-called homogenous branches (see chapter 3.2.2). However, a split per NACE economic activity is required to quantify bio-based shares. Fortunately, environmental accounts are based on energy balances and the annual survey on energy use in manufacturing, mining and quarrying as the main underlying statistical data sources. These data sources, however, are available per NACE economic activity. Only the electricity generation is coherently reflected as the homogenous branch “Energy conversion”, independently from the economic activities where the conversion occurs. There are no other differences between homogenous branches and economic activities, neither in energy balances nor in environmental accounts. Hence, primary energy consumption per economic activity is calculated based on the underlying statistical sources of environmental accounts. Any energy losses from electricity generation in manufacturing industry[15] are regrouped from the homogenous branch “Energy conversion” to the respective economic activities. This is done based on the annual survey of electricity generation plants of enterprises in manufacturing.

[15] In future, also the share of biomass used for power generation in agriculture should be regrouped. Cf. further explanations for energy sector.

Eq. 3.4.3 and Equation 3.4.4 are applied. The annual survey on energy use in manufacturing as an underlying statistical source of national accounts was used to calculate bio-based values at the 4-digit level. Since this statistic contains double-counting of energy transformation for electricity generation, the values of the concerned economic activities were adjusted by data from the annual survey of electricity generation plants of enterprises in manufacturing.

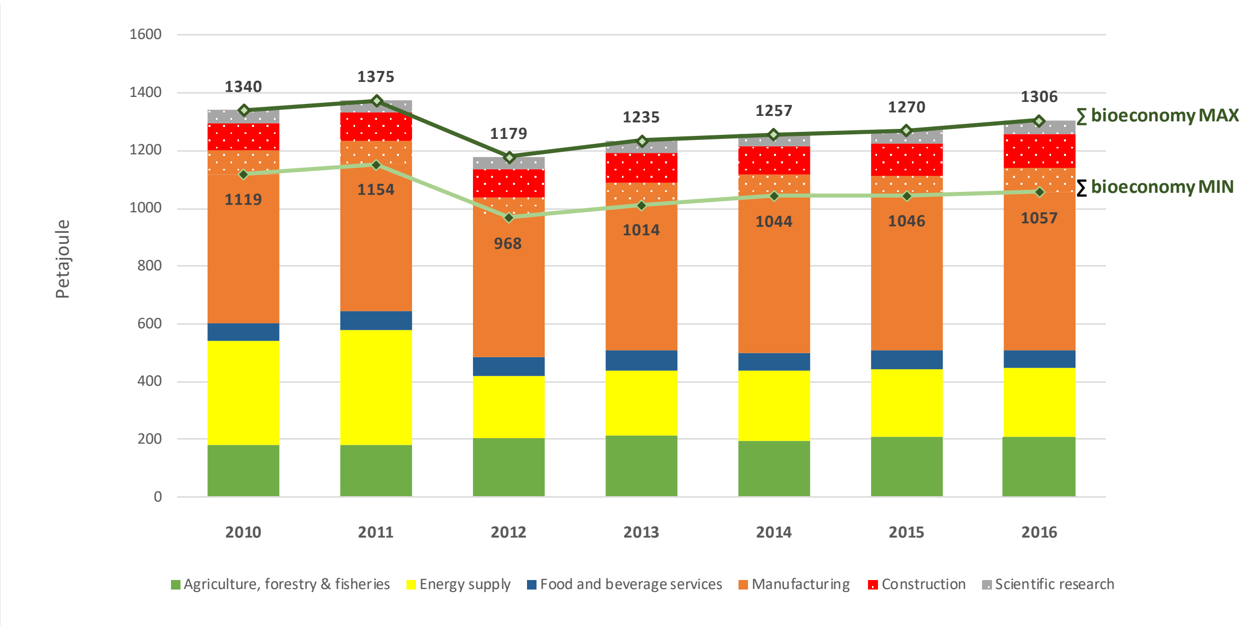
The primary energy consumption of energy supply sector includes transformation losses from biomass-based energy generation. It was quantified based on data of the energy balances and of the AGEE-Stat. However, biomass-based energy generation also takes place outside the energy sector, e.g. in agriculture. To our very best knowledge, data about transformation losses from bio-based energy generation in agriculture do not exist. That is why it is not considered in the calculations. In future, an approach should be developed to cover the losses (see explanations on this issue in chapter 2.5.2.2).

The economic sector I "accommodation and food services" is split into "food and beverage services" and "accommodation" based on the survey for energy use of the industry, trade and service sector (Schlomann et al. 2015). Equation 3.4.1 and

Equation 3.4.2 were applied. Energy use by households was not included as part of bioeconomy since it is not (yet) considered in the sectoral approach (see explanations in chapter 3.4.1 "Methodological Approach")

Results

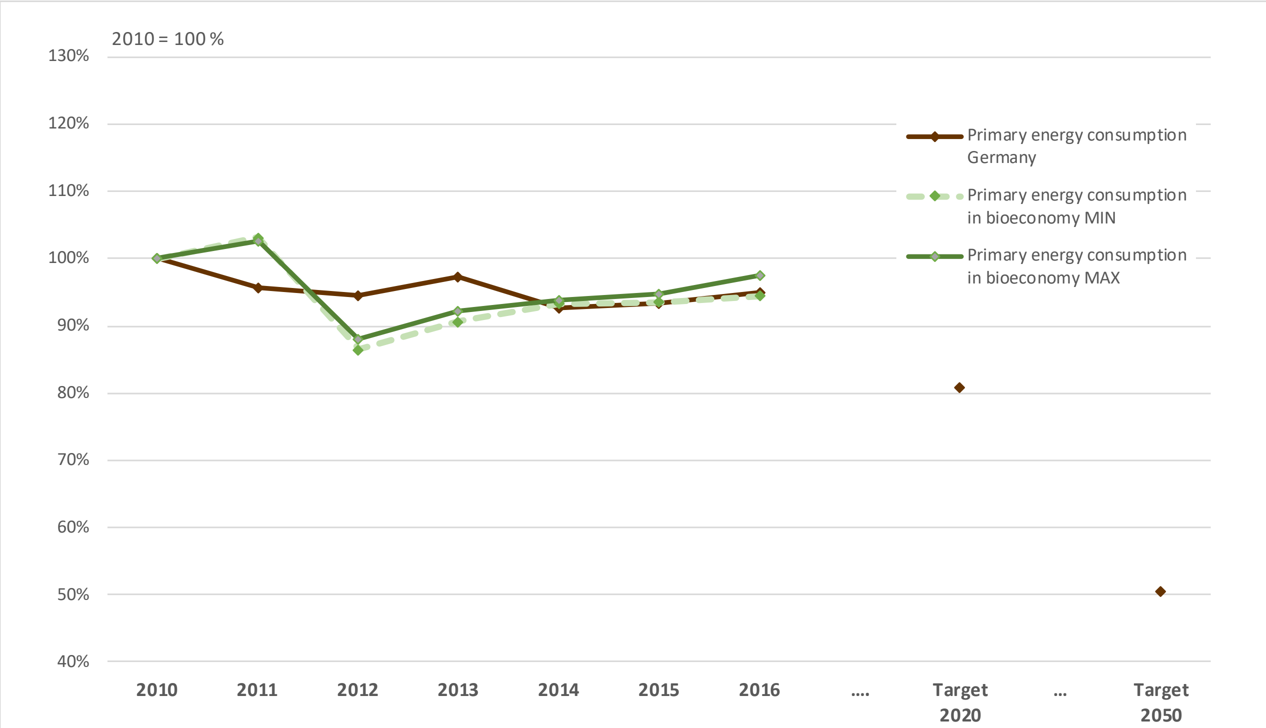
Figure 3.13: Structure of primary energy consumption in German bioeconomy



Source: Own calculation based on AGEB (2020a, 2020b), AGEE-STAT (2020), DESTATIS (2018a, 2019d, 2019f), Schlomann et al. (2015)

The share of bioeconomy in total primary energy consumption in Germany ranges between 8 % and 10 %, well above the range of value added (5 – 6 %). While manufacturing industry again accounts for about half of the total value, the share of energy supply is significantly higher amounting to 18 – 23 %. Overall, manufacturing, agriculture, forestry & fisheries and energy supply account in total for 82 – 94 % of the total primary energy consumption of bioeconomy. Construction, scientific research and food & beverage services account for only 6 – 18 %.

Figure 3.14: Development of primary energy consumption in German bioeconomy



Source: Own calculation based on AGEB (2020a, 2020b), AGEE-STAT (2020), DESTATIS (2018a, 2019d, 2019f), Schlomann et al. (2015)

As being presented in Figure 3.14, time series of primary energy consumption in bioeconomy reveal a relatively sharp drop in the year 2012, notably in energy supply sector. This is caused by the methodological changes in the accounting of electricity generation of biomass cogeneration plants, leading to a significant decrease of biomass-related primary energy consumption (AGEB 2014). Since 2012, primary energy consumption in bioeconomy increased in total by 9–11 %, while it remained almost at the same level in Germany, overall. Increased consumption in bioeconomy mainly results from an increased use of biomass for power generation and a significant growth of primary energy consumption in wood manufacturing. Also increasing bio-based shares of the energy intensive economic activity “paper production” in 2016 as compared to 2012 have contributed to the trend.

3.4.2.5 Share of Biomass in Gross Final Energy Consumption (SDG 7, DNS-indicator 7.2a)

The indicator measures the switch from fossil to renewable energy sources and at the same time security of energy supply. It shows the energy generated from biomass expressed relatively to all energy sources consumed in Germany. The indicator takes into account energy consumption in all areas of application including its use as mechanical energy, electric power, heat or fuel in the transport sector[16] (DESTATIS 2018g).
The use of biomass for energy supply is controversially accused to cause a range of negative environmental and social effects such as indirect land use change. Hence, a carefully differentiated analysis for each biomass type should be carried out. In response to this, biomass is divided into biomass types when presenting results for this indicator.

Data Sources

- Gross final energy consumption of renewable energy sources (energy concept of the Federal Government) (pers. comm. AGEE-Stat 2019).

Methodology

The share of biomass is calculated based on the data of AGEE-Stat. In line with the energy balances of AGEB biomass induces:

- biogenic solid fuels (incl. sewage sludge),
- biogenic liquid fuels (incl. biodiesel for agriculture, forestry, construction and military),
- biogenic transport fuels (excl. biodiesel for agriculture, forestry, construction and military),
- biogas,
- biomethane,
- sewage gas,
- biogenic fraction of waste[17],
- landfill gas.

[16] The gross final energy consumption for renewable energy sources is calculated without consideration of the calculation rules pursuant to the EU Renewable Energy Directive (Directive 2009/28/EC). The Renewable Energy Directive applies an average value across several years for hydropower and wind power due to their annually varying supply. Instead, the actually generated electricity quantities (of wind power and hydropower) are taken into account for this report (energy concept of the Federal Government) (DESTATIS 2018g).

[17] The biogenic share of waste in waste incineration plants is set at 50 % (AGEE-Stat 2019).

Results

Between 2010 and 2017, the share of biomass increased only slightly from 8.3 % to 8.8 % (Table 3.8). Nevertheless, more than half of all renewable energy consumption in 2017 is based on biomass. To achieve the renewable energy targets set by the German government, biomass is crucial.

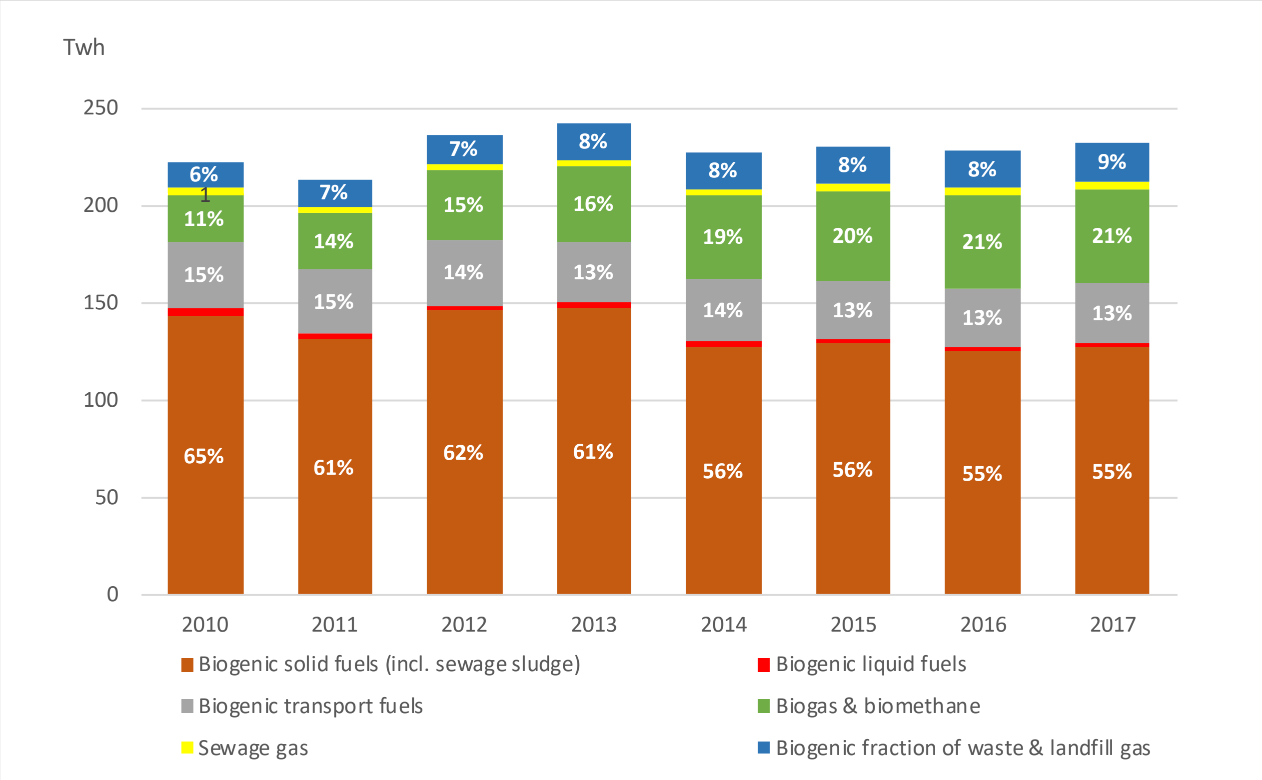
Table 3.8: Share of biomass in the gross final energy consumption in Germany

	2010	2011	2012	2013	2014	2015	2016	2017
Total gross final energy consumption, Twh	2,672	2,540	2,592	2,653	2,519	2,566	2,610	2,636
Gross final energy consumption of renewable energy, Twh	306	315	352	366	360	388	388	420
Gross final energy consumption of biomass, Twh	222	214	237	243	228	231	229	233
Share of renewable energies, in %	11.4%	12.4%	13.6%	13.8%	14.3%	15.1%	14.8%	15.9%
Share of biomass, in %	8.3%	8.4%	9.2%	9.1%	9.0%	9.0%	8.8%	8.8%

Source: Own calculation based on AGEE-Stat (2019)

As presented in Figure 3.15, biogenic solid fuels (such as wood) account for more than half of all biomass-based gross final energy consumption. However, the share dropped in the observed period. Also, the use of biogenic transport fuels has declined since 2010 and accounted for 13 % of all biomass consumption in 2017. This was compensated by an increasing consumption of biogas & biomethane as well as of biogenic fraction of waste which accounted for respectively 21 % and 9 % of biomass-based gross final energy consumption in 2017.

Figure 3.15: Biomass-based gross final energy consumption classified by biomass type in Germany



Source: Own calculation based on AGEE-Stat (2019)

3.4.2.6 Share of Electricity from Biomass in Gross Electricity Consumption (SDG 7, DNS-indicator 7.2b)

Like indicator 7.2a, this indicator also measures the progress made in shifting to a renewable energy system strengthening energy security. Gross electricity consumption is the sum of all generated and imported electricity minus the amount of exported electricity. Therefore, it comprises the domestic electricity generation, the balance of exchanges across national borders, the self-consumption of power plants as well as transmission losses (DESTATIS 2018g). Similar to the previous indicator, we provided a breakdown of biomass types.

Data Sources

- Time series for the development of the renewable energy sources in Germany (AGEE-Stat 2020)

Methodology

The share of biomass is calculated based on the data of AGEE-Stat. Similar with the indicator "share of biomass in final energy consumption", biomass types covered by this indicator are based on the biomass definition in the energy balances of AGEB. They are listed in chapter 3.4.2.5.

Results

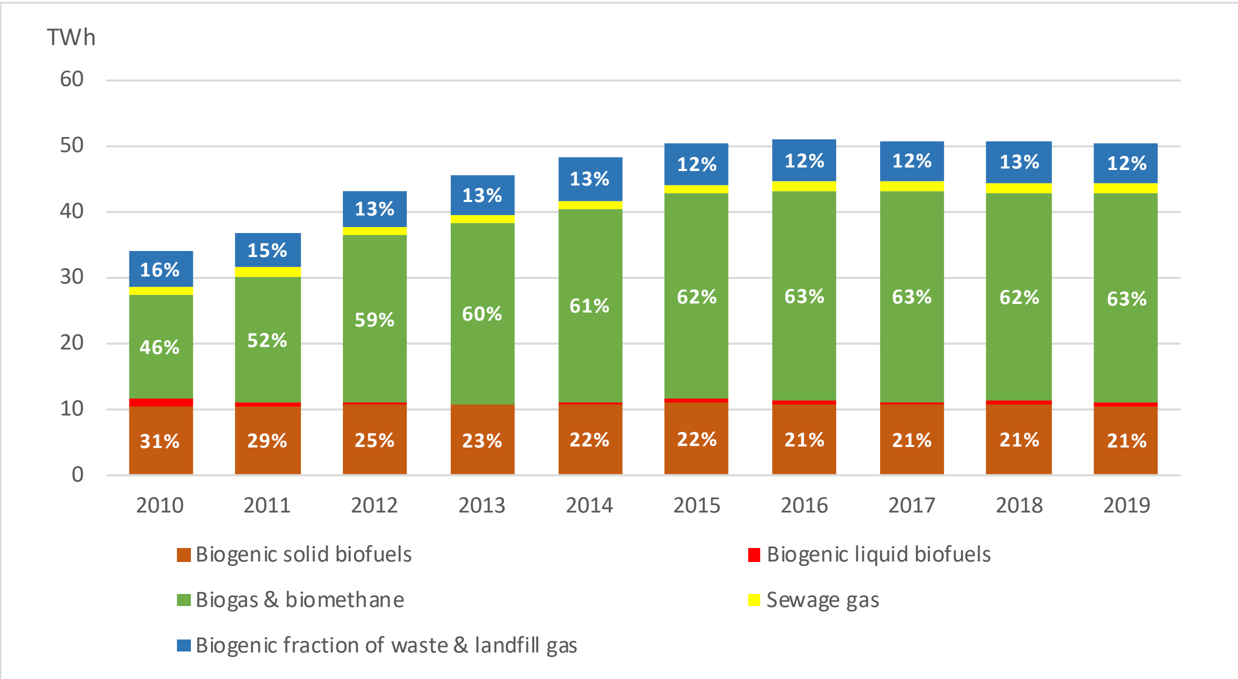
Table 3.9: Share of biomass and renewable energy sources in gross electricity consumption in Germany

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Biomass, in %	5.6	6.1	7.1	7.6	8.1	8.4	8.5	8.6	8.6	8.7
Renewable energy, in %	17.0	20.4	23.5	25.1	27.4	31.5	31.6	36.0	37.8	42.1

Source: AGEE-Stat (2020)

Table 3.9 shows the proportion of biomass and of renewable energy sources in total electricity consumption. The share of electricity produced from biomass increased from 5.6 % in 2010 to 8.7 % in 2017. However, the annual increase significantly slowed down since 2015. Compared to electricity consumption from all renewable energies, the absolute share of biomass-based electricity in total electricity consumption decreased between 2010 and 2019.

Figure 3.16: Gross electricity consumption generated from biomass divided by biomass type in Germany



Source: AGEE-Stat (2020)

Biogas and biomethane are the main sources of biomass used for electricity generation. Their proportion increased from 46 % to 63 % since 2010. Share of biogenic solid biofuels and of waste and landfill gas has decreased from 31 % and 16 % to 21 % and 12 %, respectively. Other biomass types are insignificant for electricity generation.

3.4.2.7 Greenhouse Gas Emissions (SDG 13, DNS-indicator 13.1a)

Climate change caused by anthropogenic greenhouse gas emissions is one of the most urgent environmental problems, requiring fast actions. The indicator greenhouse gas emissions measures progress in emissions reduction, thus reflecting SDG 13 “Climate action”. The indicator covers emissions of the following greenhouse gases in CO_2 equivalents: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen triflouride (NF_3), hydroflourocarbons (HFC), perflourocarbons (PFC) as well as sulphur hexaflouride (SF_6). Bioeconomy’s share of greenhouse gas emissions is estimated in line with the methodological definition of this indicator in the DNS. It is based on data reported under the UN Framework Convention on Climate Change and the Kyoto Protocol in accordance with the territorial (domestic) concept. Consequently, only emissions occurring on German territory are accounted for. The indicator does not include carbon dioxide emissions from land use, land use change and forestry (LULUCF). Furthermore, emissions due to biomass combustion are regarded as climate neutral and also not accounted for.

Data Sources

- Environmental accounts, table of environmental accounts, part 3: Anthropogenic air emissions (DESTATIS 2019g)
- Air emission accounts by NACE Rev. 2 activity (EUROSTAT 2019a)
- National Inventory Report 2019. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol (UBA 2019a))
- National Inventory Report 2019. Common Reporting Format Tables for years 2010 – 2016 (EEA 2019)
- Annual survey on energy use in manufacturing, mining and quarrying (pers. comm. DESTATIS 2018a)
- Annual survey of electricity generation plants of enterprises in manufacturing, mining and quarrying (DESTATIS 2019d)

Methodology

As described in chapter 3.2.2, environmental accounts report emissions into air for homogenous branches. In order to calculate bio-based shares of greenhouse gas emissions, this high level of aggregation does not reflect the requirements of our monitoring approach. This is why our calculation of bio-based shares of greenhouse gas emissions is based on “Air emission accounts by NACE” of EUROSTAT. We additionally used the breakdown by homogenous branches of environmental accounts in cases where economic activities published by Eurostat had a higher aggregation level than the respective homogenous branches[18]. In these cases, we assumed that the proportion

[18] These are the economic activities C 23 “Manufacture of other non-metallic mineral products” and F “Construction”.

of the underlying economic activities at the overarching economic sector is the same as of the related homogenous branches.

Since the tables for economic activities published by EUROSTAT only contain a total for emissions from energy use, from manufacturing and from road transport, we used the percentage relation available in environmental accounts for homogenous branches to calculate the emission types separately for each economic activity. For carbon dioxide, a separate record of emissions from biomass is available for both, homogenous branches and economic activities.

CO2-emissions from energy consumption are calculated on the detailed NACE 4-digit level, based on the annual survey on energy use in manufacturing and the annual survey of electricity generation plants in manufacturing. Both surveys contain a breakdown of energy input per energy source which, when multiplied by the respective fuel emission factor, result in the output of CO2-emissions per economic activity[19]. Hence, in principle, energy-related CO2-emissions could be calculated according to Eq. 3.4.3 and Eq. 3.4.4. However, due to time restrictions, our first calculation is based on aggregated data of environmental accounts and Eq. 3.4.1 and Eq. 3.4.2 for bio-based greenhouse gas emissions for all economic sectors except energy generation.

Bio-based greenhouse gas emissions in energy supply include emissions resulting from biomass-based energy generation. For carbon dioxide, a separate record for biomass is provided in environmental accounts[20]. For all other gases (as for example methane), data of the National Inventory Report of UBA was used. The National Inventory Report was also used to narrow the range of results for process-based greenhouse gas emissions. The very detailed documentation and description of all sources of these emissions in the National Inventory Report allows to classify some of them as not belonging to bioeconomy. In particular, this was the case in the economic sectors "manufacture of chemicals and chemical products" and "manufacture of glass and glass products". We assume that access to the central emissions database would allow a more specific allocation of process-related emissions to different economic activities, thus reducing the minimum – maximum range of results. However, due to data protection issues, access was not permitted.

Emissions from households are not considered, since they represent the product use phase, which is not (yet) included in the scope of the sectoral approach (see explanations in chapter 3.4.1 "Methodological Approach").

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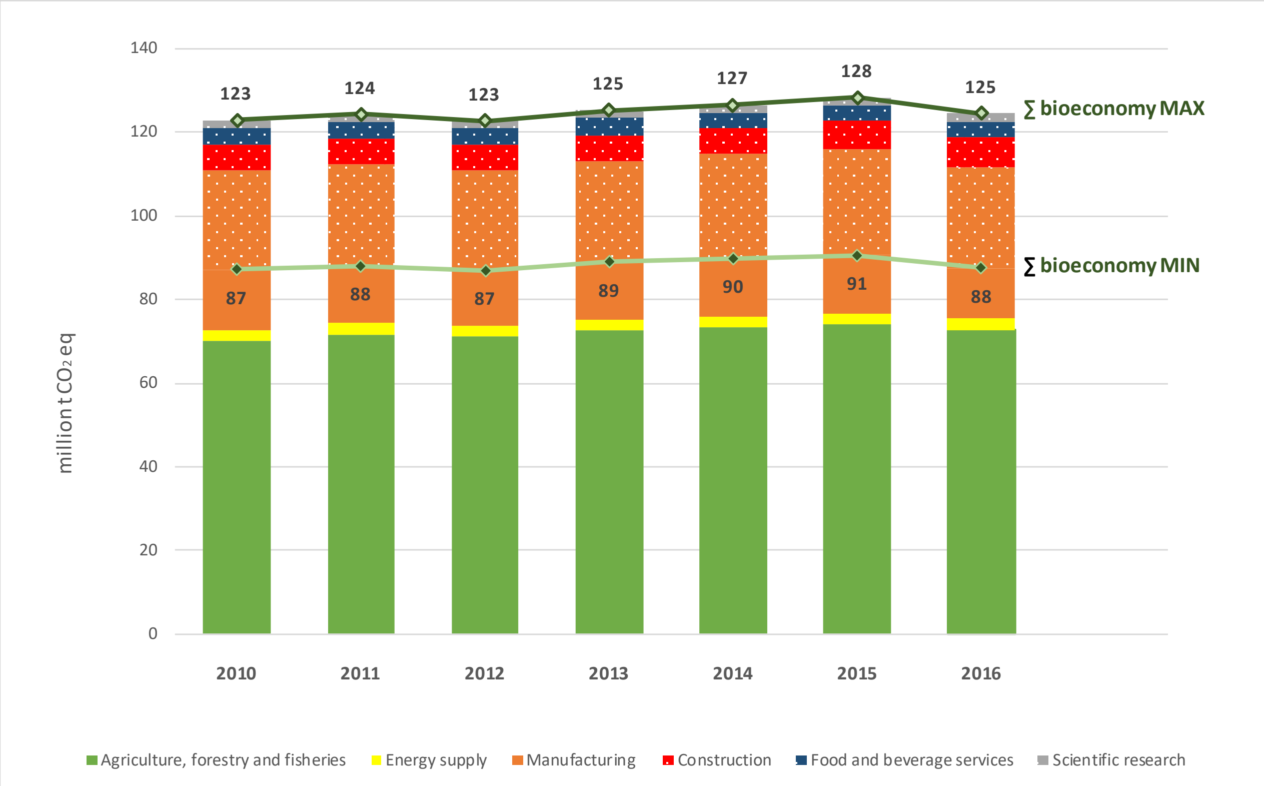
[19] This approach, however, is not applicable to any other greenhouse gases since their emission factors vary significantly depending on the respective technology.

[20] CO_2- emissions from biomass are not included in the scope of the DNS indicator as they are considered to be climate neutral. Therefore, they are also not included in the calculated greenhouse gas emissions of bioeconomy. Nevertheless, for information purposes, we made additional estimations on the amount of greenhouse gases including the CO_2- emissions from biomass, which are commented in the subchapter results.

Results

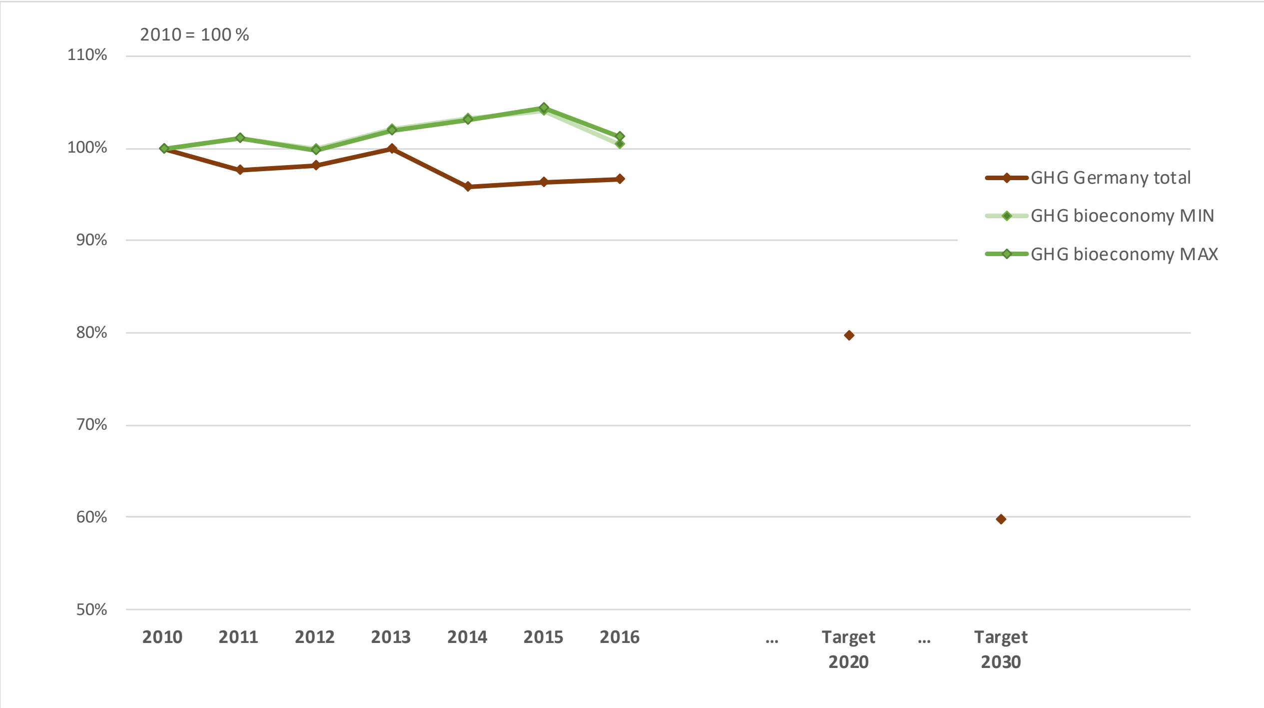
Figure 3.17. Structure of greenhouse gas emissions of German bioeconomy



Source: Own calculation based on DESTATIS (2018a, 2019d+g), EEA (2019), EUROSTAT (2019a), UBA (2019a)

The contribution of bioeconomy to total greenhouse gas emissions in Germany in 2016 was 9 – 14 %. Figure 3.17 shows the structure of bioeconomy's greenhouse gas emissions. Agriculture, forestry and fisheries have the largest share of greenhouse gases in bioeconomy, accounting for roughly three quarters of all emissions. 14 – 31 % of emissions result from manufacturing, in which food and beverage manufacturing, paper production and chemical industry have the largest share and cause together about 13 to 22 % of the total greenhouse gas emissions in bioeconomy. Energy supply, construction, food & beverage services as well as scientific research contribute in total up to a maximum of 12 %. This structure has remained almost unchanged since 2010. About one third of each, carbon dioxide, methane, and nitrous oxide contribute to the total emissions. While carbon dioxide is mainly emitted by fuel combustion, methane and nitrous oxide is emitted almost entirely in agricultural production. In 2016, livestock farming and manure management accounted for 28 – 40 % of the total greenhouse gas emissions in bioeconomy. Additional 22 – 31 % resulted from the agricultural use of land.

Figure 3.18: Development of greenhouse gas emissions of German bioeconomy



Source: Own calculation based on DESTATIS (2018a, 2019d, 2019g), EEA (2019), EUROSTAT (2019a), UBA (2019a)

While the total GHG emissions in Germany slightly decreased since 2010, the level of greenhouse gases of bioeconomy are rather unchanged. Since bioeconomy's share in greenhouse gas emissions is twice as high as its share in the total value added, a need to reduce greenhouse gas emissions is evident.

As explained at the beginning, the results presented above do not include the so-called LULUCF emissions. CO_2-emissions from the combustion of biomass are also not accounted for. However, if the LULUCF greenhouse gas emissions are added, bioeconomy's share of greenhouse gas emissions is reduced by about 2 %. This is due to significant sequestration of carbon dioxide in German forests. If, on the other hand, LULUCF and the carbon dioxide emissions from the biomass are considered, bioeconomy's share is 13 – 17 %.

3.4.2.8 Nitrate in Groundwater (SDG 6, DNS-indicator 6.1a)

Groundwater is not only the most important source of drinking water, but also a vital resource. It is a part of the water cycle and has important ecological functions. The quality of groundwater in Germany, however, is threatened by nitrate inputs. The indicator measures the proportion of the groundwater monitoring points that exceed and do not exceed the threshold value of 50 mg/l on an annual average[21]. The goal of the German government is to have no monitoring points exceeding this threshold value on an annual average. The state of the groundwater is measured by the European Environment Agency's (EEA) monitoring network. The EEA-network has about 1,200 monitoring points and a monitoring network density of about 3.5 monitoring points/1000 km^2 (BMEL, BMU 2017). Thus, it provides a representative overview of the nitrate pollution of groundwater in Germany across all land uses. The available data do not allow for an accurate quantification of the extent of exceedances caused by the bioeconomy. However, it is feasible to measure the minimum percentage of monitoring points attributed to agricultural land and thus, represents the minimum value of nitrate in groundwater associated with bioeconomy.

Thus, for the purposes of bioeconomy monitoring, we suggest to use the indicator "Share of monitoring points in areas dominated by agricultural use exceeding 50 mg/l in the total number of monitoring points".

Data Sources

- Data on nitrate concentration in groundwater in monitoring points of EEA monitoring network (pers. comm. UBA 2019b)

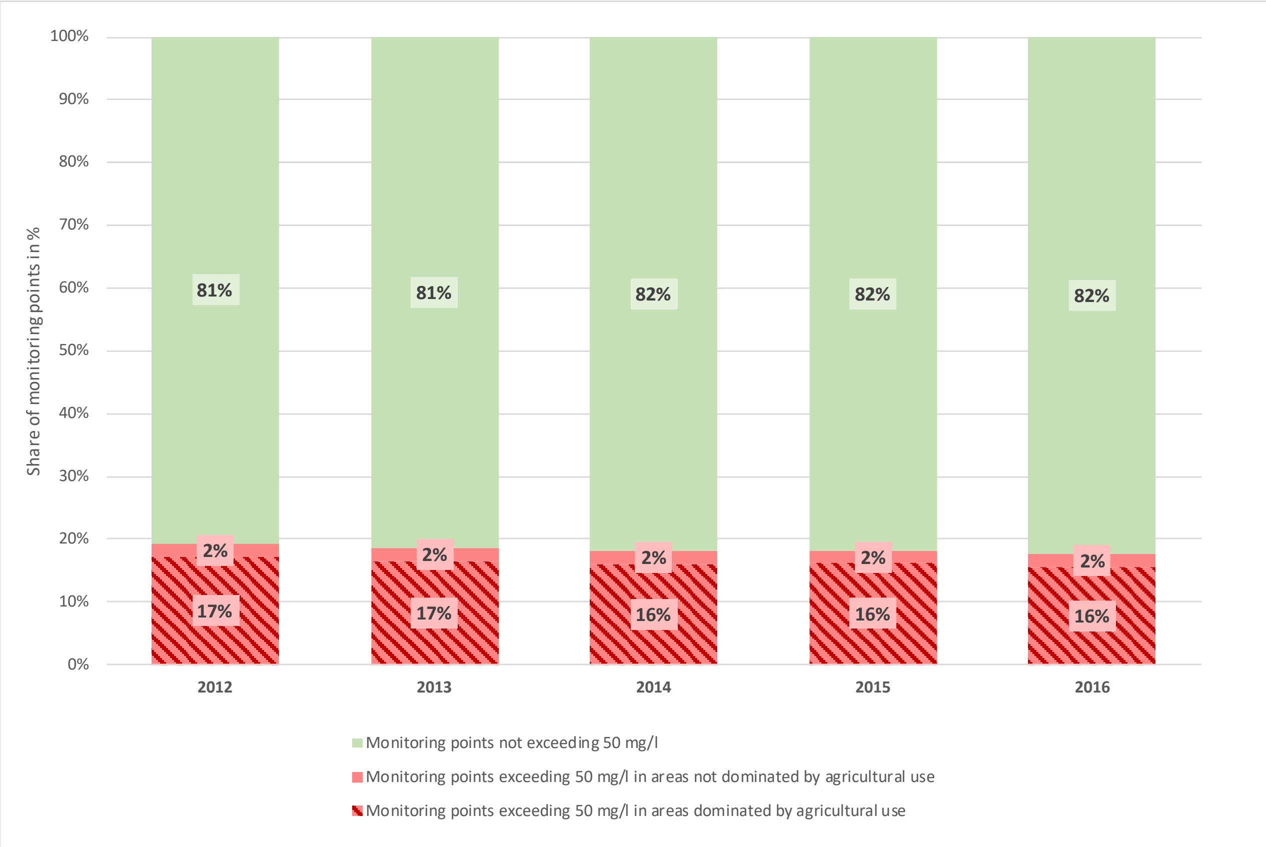
Methodology

The indicator is quantified by all EEA-networks nitrate monitoring points located in areas dominated by the agricultural use. Furthermore, data are available for individual federal states. Due to the data delivery issues, the indicator is only quantified for the years 2012 – 2016.

[21] The natural level of pollution for nitrate is between zero and a maximum of 10 mg/l. Concentrations between 10 and 25 mg/l are signs of minor to medium pollution. Concentrations between 25 and 50 mg/l indicate a high level of groundwater pollution. If the threshold value of the Ground Water Ordinance of 50 mg/l is exceeded, the groundwater is in a poor chemical state and without treatment not ready to be utilised as drinking water (DESTATIS 2018c).

Results

Figure 3.19: Share of monitoring points exceeding 50 mg/l nitrate in groundwater in Germany



Source: Own calculation based on UBA (2019b)

In 2016, the share of all monitoring points exceeding the threshold of 50 mg/l in areas dominated by agriculture accounts for 16 %. It has only slightly decreased since 2012 (Figure 3.19). Only 2 % are in areas not dominated by agricultural use. Thus, 88 % of all monitoring points exceeding the limit value are in areas with agricultural use and, hence, associated with bioeconomy. It is quite obvious that groundwater pollution by nitrate is one of the biggest environmental challenges for a more sustainable development of bioeconomy. It is important to notice in this context that measures taken to reduce the nitrate pollution need several years to show an effect (DESTATIS 2018g).

3.4.2.9 Greenhouse Gas Emissions per Value Added (SDG 9)

This indicator reflects the need to shift economic activities towards cleaner and environmentally sound technologies and industrial processes. Although not included as a specific indicator in the DNS, it represents a pendant of the indicator "CO_2-emissions per GDP" which is part of the global indicator framework for the SDGs and targets of the 2030 Agenda for Sustainable Development. The indicator measures the amount of greenhouse gas emissions by economic activities per unit of value added. It is a measure of the combined effects of (1) the average carbon intensity of the energy mix (linked to the shares of the various fossil fuels in total); (2) the structure of an economy or economic sectors in scope (linked to the relative weight of more or less greenhouse gas-intensive sectors) and (3) of the average efficiency in the use of energy and handling of process related emissions (UNSTATS 2018).

Data Sources

- Results of own calculations for greenhouse gas emissions and price adjusted value added in bioeconomy (cf. chapters 3.4.2.1 and 3.4.2.7).

Methodology

The indicator is calculated as a ratio of greenhouse gas emissions in bioeconomy to the price adjusted value added generated in bioeconomy. We applied a simplified method to quantify the minimum and maximum range of the ratio. In particular the following equations were applied:

$$GHG\ emissions\ per\ value\ added\ min = \frac{minimum\ greenhouse\ gas\ emissions\ in\ bioeconomy}{maximum\ price\ adjusted\ value\ added\ in\ bioeconomy}$$

$$GHG\ emissions\ per\ value\ added\ max = \frac{maximum\ greenhouse\ gas\ emissions\ in\ bioeconomy}{minimum\ price\ adjusted\ value\ added\ in\ bioeconomy}$$

This simplified method leads to a wide range of results. Nevertheless, the results allow conclusions if compared to the ratio for Germany as a whole. In future, a detailed method described in chapter 3.4.1 “Methodological Approach” should be applied, which will narrow the minimum – maximum range for bioeconomy.

Results

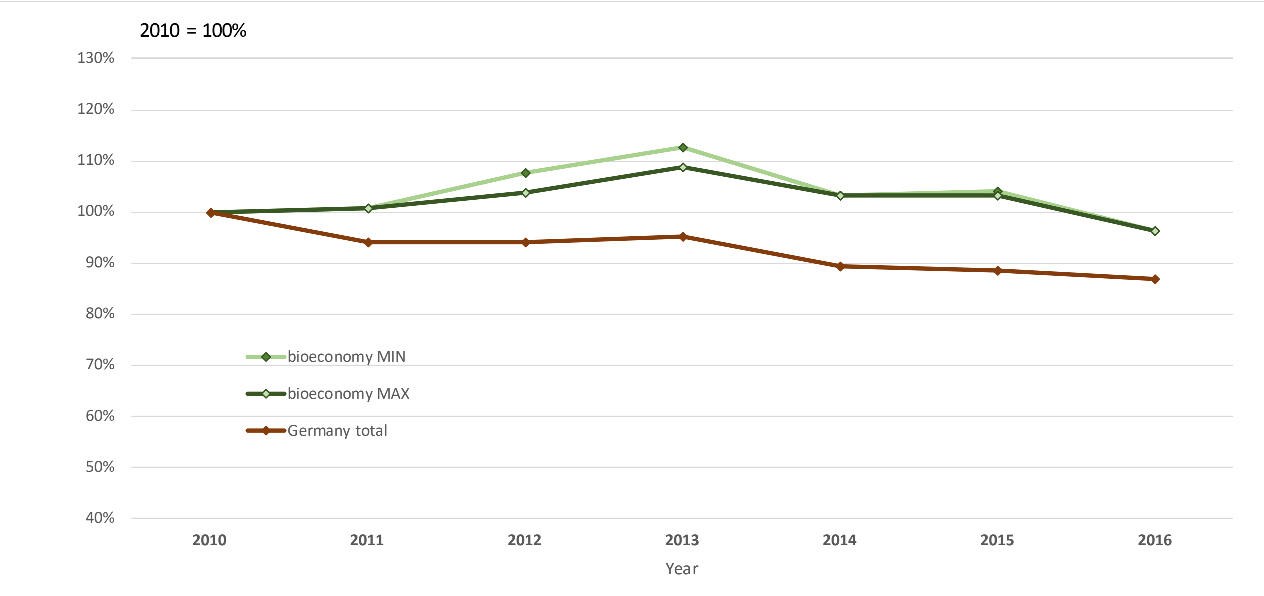
Table 3.10: Greenhouse gas emissions per value added in bioeconomy and in Germany

	Greenhouse gas emissions per value added in bioeconomy (g/€)						
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Bioeconomy MIN	0.55	0.56	0.57	0.60	0.56	0.56	0.53
Bioeconomy MAX	0.90	0.91	0.93	0.96	0.92	0.92	0.86
Germany total	0.38	0.35	0.35	0.36	0.34	0.33	0.33

Source: Own calculation based on DESTATIS (2017e, 2018a, 2018k, 2019d, 2019g, 2020a), EEA (2019), EUROSTAT (2019a, 2019d), UBA (2019a)

According to the indicator values displayed in Table 3.10, bioeconomy is characterised by a higher share of greenhouse gas emissions per price-adjusted gross value added unit than the German economy as a whole. This reflects a very high amount of greenhouse gas emissions in agriculture. With regard to the development of the ratio, it is evident that emissions per unit of value added decreased only by 4 % since 2010. This was also significantly below the trend for Germany as a whole (Figure 3.20). Options to reduce emissions and increase value added are among others reduced meat consumption, less intensive agriculture, avoiding food waste and high value bio-based products. Furthermore, the forestry and wood processing sector still has potential to increase carbon sequestration in forests and forest products.

Figure 3.20: Development of greenhouse gas emissions per value added in German bioeconomy



Source: Own calculations based on DESTATIS (2017e, 2018a, 2018k, 2019d, 2019g, 2020a), EEA (2019), EUROSTAT (2019a, 2019d), UBA (2019a)

3.4.2.10 Employees per Value Added (SDG 8)

This indicator measures one aspect of labour productivity. When monitored over time, it describes the development of labour productivity and efficiency as well as quality of human capital in production processes. Economic growth in a country is achieved either by an increased labour input or by employed persons being more effective. The indicator allows to analyse and monitor these effects.

Data Sources

- Results of own calculations for a number of persons employed in the age group 20 – 64 years and price-adjusted value in bioeconomy (see chapters 3.4.2.1 and 3.4.2.3)

Methodology

The indicator is calculated as a ratio of the price-adjusted value added in bioeconomy per person employed in bioeconomy. In contrast to the labour productivity calculated within national accounts, here the number of persons employed is based on the Labour Force Survey of EUROSTAT. Detailed explanations about calculation of the number of persons employed in bioeconomy and the value added in bioeconomy are explained in the chapters 3.4.2.1 and 3.4.2.3.

Similar to the previous indicator, we used a simplified method to quantify the minimum and maximum range of the ratio. In particular, the following equations were applied:

$$Value\ added\ per\ person\ employed\ \mathrm{min} = \frac{minimum\ value\ added\ in\ bioeconomy}{maximum\ number\ of\ persons\ employed\ in\ bioeconomy}$$

$$Value\ added\ per\ person\ employed\ \mathrm{max} = \frac{maximum\ value\ added\ in\ bioeconomy}{minimum\ number\ of\ persons\ employed\ in\ bioeconomy}$$

This simplified method causes a wide minimum – maximum range of results. Nevertheless, the results allow to compare bioeconomy with German economy as a whole. In future, the more accurate approach described in chapter 3.4.1 "Methodological Approach" should be applied.

Results

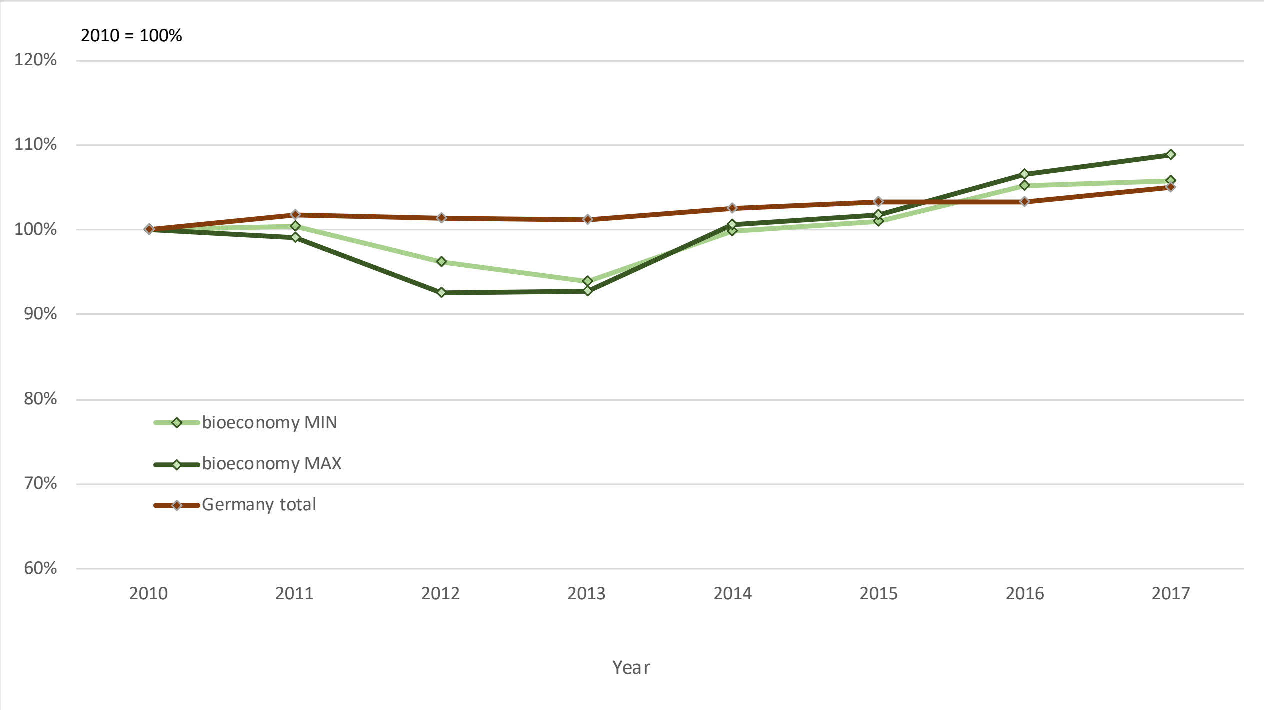
Table 3.11: Price-adjusted value added per person employed in bioeconomy and in total in Germany

	Value added per person employed in bioeconomy (thousand €/person)							
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Bioeconomy MIN	37	37	36	37	38	39	40	40
Bioeconomy MAX	51	50	49	49	52	54	55	56
Germany total	69	70	70	70	71	71	71	73

Source: Own calculation based on DESTATIS (2017e, 2018k, 2020a), EUROSTAT (2019 b-d)

Table 3.11 summarises the results for bioeconomy and for Germany in total. In comparison to the German economy, bioeconomy is characterised by a relatively low labour productivity. This is due to the fact that agriculture, forestry & fisheries, food & beverage services, construction but also scientific research do represent labour-intensive sectors. On the other hand, economic branches with the highest labour productivity, notably information and communication, financial services and real estate significantly influence the overall labour productivity level in Germany. However, in the period under consideration, labour productivity in bioeconomy is pretty much in line with the German-wide development. In 2017, it even exceeded German-wide productivity by 3 – 5 % (see Figure 3.21).

Figure 3.21: Development of price-adjusted value added per person employed in German bioeconomy



Source: own calculations based on DESTATIS (2017e, 2018k, 2020a), EUROSTAT (2019b-d)

3.5 Discussion and Conclusions

The first selected results of the sectoral approach presented in this working paper reaffirm the importance of sustainability analysis when pursuing bioeconomy growth strategies. Thus, the environmental indicators quantified within the project show a disproportionately high share of bioeconomy in environmental effects as compared to its economic importance. While bioeconomy accounts only for 5 – 6 % of value added and 8 – 9 % of total persons employed, it is responsible for 9 – 14 % of all greenhouse gas emissions and at least 88 % of all nitrate limit exceedances in the groundwater. To a large extent, this is attributed to agriculture which has the largest share of the raw material supply in bioeconomy. The time series of environmental indicators “greenhouse gas emissions”, “nitrate and groundwater”, “nitrogen surplus in agriculture” and “biodiversity” show only a slight or no improvement in the period under review. Also, primary energy productivity has remained unchanged. Overall energy use efficiency in bioeconomy-relevant sectors did not improve. Clearly, there is room for improvement.

The increase of price-adjusted value added generated in bioeconomy of 105 – 106 % in the analysed time period significantly lags behind the overall increase in Germany of 114 %. Also the number of persons employed in bioeconomy has been decreasing which is in contrast to the significantly raising total employment numbers in Germany. This development contradicts the desired shift to a bio-based economy. However, in the absence of particular political targets, it is difficult to make judgments regarding bioeconomy development.

4 Conclusions and Recommendations

4.1 Material Flows

The visualized aggregated and detailed material flows provide the basis for a better understanding of biomass production, processing and uses, i.e. bio-based value chains. However, in compiling the data it became more than obvious that the identification, mapping and quantification of biomass material flows and connected bio-based value chains remain a major challenge. First of all, official statistics do not provide sufficient information to trace biomass through the economic system. Based on official statistical data, expert interviews, published empirical studies and information provided by trade associations or marketing boards, own estimations of processed or used biomass quantities and biomass contents were made. The derived calculation methods and material flow models are static and require periodic validation and updating.

The shown material flows also contain by-products and waste streams at different levels. These streams occur at the stage of domestic production as well as during processing. The results of our partner project AGBioRestMon (results database at http://webapp.dbfz.de/resources) showed that also side and residue streams can be identified, mapped and estimated in their respective quantities. In our aggregated material flow, we only started to integrate main and residue material flows. For example, quantities of the residue material flows of recycled paper and recycled wood are well known and these residue materials have by now become important resources in value chains. AGBioRestMon identified 77 different residue streams in total. The majority of 42 occur in production and processing of biomass for food and feed which reflects the huge potential of such residue streams for cascade or sideline uses. One example is the use of marketable agricultural raw materials for biofuel production while non-marketable agricultural raw materials are mainly used for electricity/ heat production. Establishing such uses for other residues as well improves the overall efficiency of biomass use which is one of the dedicated objectives of the German Bioeconomy Strategy.

Full mapping and estimation of bio-based material flows is hampered by the diversity of end products. Often, these are not covered by official statistics in full detail, their biomass contents vary and are partly unknown. Even including available additional information from market reports and empirical studies cannot sufficiently fill this gap and provide the information needed. Thus, the presented material flows are subject to a certain, sometimes unknown level of uncertainty.

4.2 Bio-based Shares of Sectors

We presented a consistent and replicable method to estimate bio-based shares of economic sectors which has been peer-reviewed and published (Iost et al. 2019). Concerning a sectoral approach for quantifying bioeconomy, a lot of research and work is being done in different countries and at EU level. Sectoral approaches have in common that they mainly rely on official statistics. At the level of economic indicators, official economic statistics usually rather provide data on monetary values than on resource use in quantitative terms. One reason for the prevalence of monetary values is that data is published in harmonized form across all EU Member States. It is a feasible approach that allows for national and EU level comparisons. Therefore, sectoral bio-based shares until now do not provide information on the actual amount of used biomass and monetary data can only serve as a proxy. Consequently, estimations of resource efficiency based on such data are not reliable, even if raw material prices could be included in the estimates.

Another challenge of this approach is the understanding and operationalisation of the term bioeconomy. Even though the European Bioeconomy Strategy provides a common ground, many countries define bioeconomy differently, also depending on their respective economic structures. Especially the question which bio-based services should be included in bioeconomy monitoring and how this could be done in terms of data and method are currently widely discussed.

Consequently, policy implications, stakeholder interests, data availability and market development influence our ability to define and quantify bioeconomy at both, economy-wide and at sectoral level.

4.3 Assessment of Sustainability Effects

Complementary approaches for the assessment of sustainability effects allow measuring the performance of bioeconomy from the macroeconomic perspective as well as the detailed level of its most important material flows. They set ground for further analyses and decision-making by stakeholders and politics. Both methods have been successfully tested using examples of softwood lumber and its core product EPAL 1 pallet for the material flow-based approach and a number of indicators from the German Sustainable Development Strategy for the sectoral approach.

The sectoral approach allows to put sustainability effects of the bioeconomy into perspective with respective effects of German national economy in total. Furthermore, the sectoral approach allows to quantify the contribution of bioeconomy to some German SDG targets. Since mainly frequently updated official data sources are utilized, time-series and thus, time trend analyses are possible.

While the sectoral approach gives a general overview of the status quo and historical development, analysis of key material flows and its products enables a closer look into the structure of bioeconomy. As presented in this report and the paper by Schweinle et al. (2020), it is possible to assess selected environmental, economic and social sustainability effects associated with a bio-based material flow and its core products based on currently available information. The proposed approach allows also to compare sustainability effects of bio-based material flows and core products with references such as non-renewable or alternative bio-based material flows and core products over time. The efforts to be made for more complex material flows and core products might be significantly higher and currently data gaps are most likely. As mentioned by Schweinle et al. (2020), the approach also allows quantifying effects from cascading, increased efficiency of material use or potential substitution. However, the implementation is not straight forward and requires substantial efforts regarding the selection of indicators matching the assessment goals, stakeholder needs and notably data provision.

The approach itself requires further development. Currently, it does not consider effects resulting from consumption of imported bio-based goods at both, the sectoral and material flow-based level. This needs to be addressed. The assessment of sustainability effects of the use and post-use phase also needs to be elaborated in more detail.

The presented monitoring concept is designed to provide information on sustainability effects in a way that stakeholders and decision makers are able to aggregate results, apply references and targets or use evaluation tools (e.g., multicriteria-analysis) to meet their specific needs. If required, evaluation tools will be provided as a next step of the methodology development.

4.4 Emerging Sectors

The basic line of thinking in elaborating a concept for monitoring the bioeconomy resource base and sustainability assessment was oriented along actual biomass flows, i.e. production, processing and use of all kinds of biomass. We identified official economic activities which in one or the other way produced, processed or used biomass. We also identified biomass flows from the processing angle without allocation processing steps to defined economic activities.

One dedicated objective of bioeconomy is the substitution of fossil with renewable resources. In a developing bioeconomy, the share of bio-based processes (activities) and products is expected to rise through bio-based innovations. Our biomass-focused approach allows for the integration of such emerging sectors, including economic activities and products. The first step of each new monitoring cycle includes an update of economic activities and products and the underlying material flows compared with the current situation. However, this approach requires a regular update of official classifications and additional empirical data.

4.5 Data Gaps

Material Flow Analysis and bio-based Shares of Sectors

Basic premise of developing a bioeconomy monitoring concept was to build it on official statistics. Official statistics are characterized by harmonized methods and classifications, providing the basis for temporal and spatial comparisons. We implemented official statistics in our methods and identified missing data. One major data gap is caused by legal restrictions, i.e. cut-off thresholds and non-disclosure policy of DESTATIS and other Federal bodies in Germany. Basically, indicators describing any economic activity of companies with less than 20 employees are often not directly surveyed but estimated in order to reduce bureaucratic efforts. These estimations are often based on the assumption that small companies have similar structural characteristics as medium-sized and large companies. Furthermore, data is not officially published if it allows conclusions to be drawn about an individual company. This means that DESTATIS either does not collect or does not publish data. For a long-term monitoring, such data should be made available for bioeconomy estimations. The Federal Research Data Centre operated by DESTATIS provides, upon request, data if no conclusion on single companies can be made from the results of the study, i.e. for bioeconomy estimates at higher levels of aggregation.

Official classification systems are set-up to reflect the structure of the economy and are updated on a regular basis to include new economic activities. The level of detail in these classifications determines the ability to detect biomass in economic activities, products or goods. Products with small market shares and little relevance are often aggregated within miscellaneous categories (labels include “not elsewhere mentioned”, “other” or similar). Substitutions of fossil with renewable inputs in processed products will occur either as drop-in or as a new product. In official statistics, the latter supposedly will first occur within those miscellaneous categories. Only if a product gains a certain market share, it will be visible in more homogeneous categories. While PRODCOM and CN are updated annually, the update of classification schemes at national level might take several years. Consequently, emerging bio-based products and resulting resource substitution in official data will become visible, but only with a long delay. Recently, revisions of official classifications like GP19 (and currently NACE) involve stakeholders. In such processes, results of bioeconomy monitoring may provide reliable information on new bio-based products and processes and help in structuring official classification to better reflect bioeconomy monitoring data needs.

To fill identified data gaps in official statistics, monitoring of bioeconomy must include constant market observation and periodical empirical studies on use of biomass in economic activities and on biomass or carbon contents in bio-based products. The focus of the updated bioeconomy strategy on circularity underlines the necessity for more official data on biomass inputs into economic activities. The MGrE has proven an important tool for determining inputs. In order to determine resource efficiency, data on inputs should be reflected on output data more strongly.

Our approach to bioeconomy monitoring focuses on main material flows and bio-based shares of economic sectors. In order to provide a complete picture of biomass production, processing and use, this monitoring must be connected to residue materials flows and other existing monitoring approaches like the food waste monitoring.

Assessment of Sustainability Effects

Although our approach does not impose any restrictions on the indicators to be used, data availability may significantly limit their selection. Providing sufficient data for the assessment of sustainability effects within the bioeconomy monitoring is one of the biggest challenges. Indeed, the assessment of sustainability aspects within the monitoring requires not only reliable data about the respective resource base (material flows, bio-based shares in economic sectors), but also a range of suitable data sources allowing assessment of various economic, social and ecological effects.

Therefore, the verification and consideration of data availability have been an integral part of our work when developing and testing the approaches presented in this report.

Our case studies have shown the basic availability of a range of data allowing an initial assessment of selected sustainability effects at sectoral and material flow level. Thus, out of the 27 indicators of the German Sustainable Development Strategy identified as bioeconomy-relevant, 23 indicators are in principle ready to be quantified. Nevertheless, there are many data gaps that considerably reduce both, the number of indicators ready to be measured and the precision of the results achieved. A major data restriction in sectoral and material flow-based approaches is the insufficient breakdown of economic activities of the respective data sources. This particularly affects social aspects where a high level of detail is essential to calculate meaningful results. Since such statistical sources are scarce, the potential number of quantifiable social effects is very limited. It is improbable that the breakdown of the social statistical sources will be enlarged, certainly not in the short term. Thus, the problem currently needs to be addressed by a "blending" of different statistical sources with deviating collection methods and scopes. Therefore, we conclude that the assessment of social aspects is the main challenge for the sustainability assessment of bioeconomy.

Basically, a number of regularly collected statistical and non-statistical data sources is available for measuring environmental effects on a sectoral level. However, not all data is available at the same level of detail, which results in high minimum – maximum ranges of indicator values. In many cases, however, the range could be reduced. Mainly because of data protection restrictions could be overcome and DESTATIS and the Federal Environment Agency provided data on request. For some indicators, however, data collection needs to be extended.

None of the publicly available statistical and non-statistical data sources is suitable for the material flow-based assessment of environmental effects. Hence, our approach, at least in the medium term, requires information provided by life cycle assessments. These life cycle assessments need to meet the requirements of bioeconomy monitoring with regard to system boundaries, functional units and cut-off criteria. As outlined in this report, bioeconomy is based on a variety of biomass types. The use of different biomass types in manufacturing and other economic activities results in a broad variety of bio-based products. Life cycle assessments are not available for each single bio-based product and even the material flow-based assessment of sustainability effects for core products, representing the different biomass types, requires huge effort. On the long term, official statistics should enlarge the portfolio of data provided in the area of environmental effects.

Availability of economy related data is fairly good. Current statistical sources contain a number of economic indicators with a sufficient level of detail per economic activity. Nevertheless, there are still some data gaps. However, to adjust data protection and to engage DESTATIS restrictions are essential to overcome them.

Closing further data gaps, however, requires an expansion of the scope of statistical surveys or an additional data collection. Thus, the next step required for a continued monitoring of sustainability effects is a stakeholder driven selection of sustainability indicators. Based on the selected set of indicators, a permanent solution for data provision needs to be developed to close data gaps.

Indicator Selection

Schweinle et al. (2020) have described the problems to select indicators according to LOFASA (Meier, 2015). Nevertheless, a stakeholder-based indicator selection process is highly recommended. Stakeholders need to accept criteria and indicators. This is a prerequisite for a successful implementation of any criteria and indicators system. A combination of participatory bottom-up approaches and science based top-down approaches might be the most promising way to implement an assessment framework. This is exactly how the LOFASA works. Hence, prior to a bioeconomy monitoring on a regular basis, a participatory process should be started that leads to the identification of sustainability themes and selection of indicators.

Limitations

The approach described in this report might have several limitations. A major limitation, however, is that it cannot monitor activities within bioeconomy that are not related to the use of bio-based materials. In our defence, this was not our task. However, as a consequence, with our approach the monitoring of enhancement and application of biological knowledge (third goal of the German National Bioeconomy Strategy) is limited to activities that involve bio-based materials. Production or IT processes that mimic biological processes and thus, apply biological knowledge, but do not involve bio-based materials for example are not covered. Monitoring of these processes might be even challenging and would require a completely different approach, but in another challenging project.

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Annex

Annex 1

Overview of the bioeconomy-relevant indicators of the German Sustainable Development Strategy (DNS) and the related data sources for their quantification

SDG Nr.	Indicator of the DNS	Suggested indicator for bioeconomy	Data sources	Comment
SDG 2	2.1.a: Nitrogen surplus on utilised agricultural areas	Nitrogen surplus on utilised agricultural areas	1. Data of Institute for Crop and Soil Science, Julius Kühn Institute 2. Data of Institute of Landscape Ecology and Resources Management, University of Giessen	The indicator does not require any additional calculations
	2.1.b: Share of organic farming	Share of organic farming	1. Agricultural structural survey on ecological farming - Fachserie 3, Reihe 2.2.1 (Destatis) 2. Betriebe und Flächen des ökologischen Landbaus in Deutschland (BMEL)	The indicator does not require any additional calculations
	2.2: Share of disbursed funds in total expenditure on food security that is used for the implementation of relevant international norms and recommendations for the realisation of the right to food	Share of disbursed funds in total expenditure on food security that is used for the implementation of relevant international norms and recommendations for the realisation of the right to food	1. Data of the Federal Ministry of Food and Agriculture (BMEL) 2. Data of the Federal Ministry for Economic Cooperation and Development (BMZ)	The indicator does not require any additional calculations
SDG 3	3.2.a: Emissions of air pollutants	Emissions of air pollutants in bioeconomy	3. Tables of Environmental accounts – Part 3: Anthropogenic air emissions (Destatis) 4. Central Emissions System Database (UBA)	
SDG 5	5.1.a: Gender pay gap	Gender pay gap in bioeconomy	None. Due to the insufficient breakdown of economic activities, data sources used for Germany in total are not suitable for bioeconomy	Quantification is not possible
SDG 6	6.1.a: Phosphorous in flowing waters	Share of phosphorous in flowing waters caused by agriculture	1. Analysis of the LAWA monitoring points (UBA) 2. UBA – Calculations of entry paths based on MoRE (Modelling of Regionalized Emissions) (UBA 2017)	Only a rough estimation of effects from agriculture (min bioeconomy value) based on entry paths is possible
	6.1.b: Nitrate in groundwater (share of monitoring points at which the threshold value of 50 mg/l of nitrate in the groundwater is not exceeded on an annual average)	Share of monitoring points in areas dominated by agricultural use exceeding 50 mg/l in the total number of monitoring points	1. Data on nitrate concentration in the groundwater in monitoring points of EEA monitoring network (UBA)	Only a minimum value for bioeconomy can be calculated

SDG 7	7.1.a: Final energy productivity	Final energy productivity in bioeconomy	1. Environmental accounts, table of environmental accounts, part 2: Energy (Destatis) 2. Additional data of Destatis (UGR) on energy consumption in energy transforming sectors and non-energy consumption (can be made available upon request) 3. National Accounts, production accounts, (Destatis)	
	7.1.b: Primary energy consumption	Primary energy consumption in bioeconomy	1. Environmental accounts, table of environmental accounts, part 2: Energy (Destatis) 2. Energy statistics (Destatis) 3. Energy and satellite balances for renewable energy (AGEB) 4. Data of AGEE Stat For more details on data sources please refer to the chapter 3.4.2.4 "Primary energy consumption"	
	7.2.a: Share of renewable energies in gross final energy consumption	Share of biomass in gross final energy consumption	1. Data of AGEE Stat (UBA)	Data on biomass is not published but can be made available upon request
	7.2.b: Share of electricity from renewable energy sources in electricity consumption	Share of electricity from biomass in electricity consumption	1. AGEE Stat, Time series on the development of renewable energies in Germany (UBA)	
SDG 8	8.1: Raw material input productivity	Two indicators can in principle be considered: (a) Raw material input productivity in bioeconomy (b) Biomass productivity	None. Due to the insufficient breakdown of homogeneous branches/economic activities, the data sources used for German economy in total (environmental accounts, Destatis) are not suitable for bioeconomy	Quantification is not possible
	8.3: Gross fixed capital formation in relation to GDP	Gross fixed capital formation in relation to value added in bioeconomy	1. National Accounts, production accounts (Destatis) 2. Structural Business Statistics (Eurostat) 3. Turnover tax statistics (Destatis) 4. Business Register (Destatis)	
	8.5.a: Total employment rate (20 – 64 years-olds)	Total employment rate (20 – 64 years-olds) in bioeconomy	1. Labour Force Study (Eurostat) 2. Structural Business Statistics (SBS) (Eurostat)	
	8.5.b: Total employment rate (60 – 64 years-olds)	Total employment rate (60 – 64 years-olds) in bioeconomy	1. Labour Force Study (Eurostat) 2. Structural Business Statistics (SBS) (Eurostat)	

	8.6: Number of members of the Textiles Partnership	About 30 % of all worldwide produced textiles are made from bio-based fibres[22]. Due to this high share the unchanged indicator can be applied also for bioeconomy.	1. Data of Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	The indicator does not require any additional calculations
SDG 9	9.1: Private and public expenditure on research and development in relation to GDP	Private and public expenditure on bioeconomy-related research and development in relation to value added	Due to an insufficient data breakdown of private expenditures for R&D into research topics, the indicator cannot be calculated	Quantification is not possible
SDG 12	12.1.b: Energy consumption and CO2 emissions from consumption	Energy consumption and CO2 emissions from consumption of bio-based goods	1. Environmental accounts, table of environmental accounts, part 2: Energy (Destatis) 2. Environmental accounts, table of environmental accounts, part 3: Anthropogenic air emissions (Destatis)	For most imported goods, domestic assumption is applied, meaning that imported goods were produced using the same materials and technology as in Germany
	12.3.b: Recycled paper bearing the Blue Angel label as a proportion of the total paper consumption of the direct federal administration	Recycled paper bearing the Blue Angel label as a proportion of the total paper consumption of the direct federal administration	1. Data of Competence Center for Sustainable Procurement	The indicator does not require any additional calculations
SDG 13	13.1.a: Greenhouse gas emissions	Greenhouse gas emissions in bioeconomy	1. Table of environmental accounts, part 3: Anthropogenic air emissions (Destatis) 2. Air emissions accounts by NACE (Destatis) 3. National Inventory Report (UBA) 4. Energy statistics (Destatis) For more details on data sources please refer to the chapter 3.4.2.7 "Greenhouse gas emissions"	
SDG 14	14.1.aa: Nitrogen input to the North Sea through German inflows	Nitrogen input to the North Sea through German inflows caused by agriculture	1. Data on nitrogen input of the respective inflows (UBA) 2. UBA – Calculations of entry paths based on MoRE (Modelling of Regionalized Emissions)	Only a rough estimation of effects from agriculture (min bioeconomy value) based on entry paths is possible
	14.1.ab: Nitrogen input to the Baltic Sea through German inflows	Nitrogen input to the Baltic Sea through German inflows caused by agriculture	1. Data on nitrogen input the respective inflows (UBA)	Only a rough estimation of effects from agri-

[22] Cirfs (quoted from Gesamtverband der deutschen Textil- und Modeindustrie e. V. 2017)

			2. UBA – Calculations of entry paths based on MoRE (Modelling of Regionalized Emissions)	culture (min bioeconomy value) based on entry paths is possible
	14.1.b: Proportion of sustainably fished stocks of fish in the North and the Baltic Sea	Proportion of sustainably fished stocks of fish in the North and the Baltic Sea	1. Data of International Council for the Exploration of the Sea (ICES)	The indicator does not require any additional calculations
SDG 15	15.1: Biodiversity and landscape quality. Index for population development for 51 selected bird species. It is divided into sub-indexes forest, farmland, coasts/seas, inland waters and settlements	Subindexes for the development of bird species in farmland and forest	1. Data of the Federal Agency for Nature Conservation	The indicator does not require any additional calculations
	15.2: Share of sensitive ecosystem area where the critical ecological loads have been exceeded due to atmospheric nitrogen inputs, as a proportion of the total assessed sensitive ecosystem area	Share of sensitive ecosystem area where the critical ecological loads have been exceeded due to atmospheric nitrogen inputs from bioeconomy, as a proportion of the total assessed sensitive ecosystem area	Quantification of the indicator requires complex modelling of spatial distribution of atmospheric inputs using several data sources. It is currently not possible to estimate the share of bioeconomy or agriculture causing exceedance of crucial loads in the sensitive areas	Quantification is not possible
	15.3: Payments by Germany to developing and emerging countries for the verified preservation or restoration of forests under the REDD+ rulebook	Payments by Germany to developing and emerging countries for the verified preservation or restoration of forests under the REDD+ rulebook	1. Data of the Federal Ministry for Economic Cooperation and Development	The indicator does not require any additional calculations
SDG 17	17.3: Imports from the least developed countries (LDCs) as a proportion of all imports to Germany	Imports of bio-based goods from the least developed countries (LDCs) as a proportion of all imports to Germany	1. Foreign trade statistics (Destatis) 2. List of recipients of official development assistance kept by the Development Assistance Committee (OECD)	For some goods quantification is only possible based on “domestic assumption”, assuming the imported goods have the same share of bio-based inputs as the ones produced in Germany

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