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1 Executive Summary

The project "*Harmonization and monitoring platform for certification schemes and labels to advance the sustainability of bio-based systems"* (HARMONITOR) targets different certification schemes and labels (CSLs) in various sectors of the bioeconomy within the European Union, aiming at improving the effectiveness of these CSLs, and additionally the use of CSLs as co-regulation instrument. The goal of this report is to investigate the environmental impacts of the EU's bioeconomy not just within its borders, but also outside Europe as driven by supply chain linkages, and estimate the monetary value of the impacts. This study uses environmentally extended multi-regional input output[1] (EE-MRIO) analysis and global MRIO tables from Exiobase[2] for three years (2011, 2015 and 2022). The environmental impacts considered are GHG emissions, land use and water use.

Overall, this study found that the production of bio-based feedstocks, materials and products in the EU in 2022 accounted for 585 MtCO_2eq of GHG emissions, 193 million ha of land use, and 941 billion m³ of water use from production. This is equivalent to 6%, 7% and 4% of the total GHG emissions, land use and water use attributed to the global bioeconomy, respectively. However, consumption-based impacts were significantly higher at 762 MtCO_2eq, 196 million ha land, and 1338 billion m³ water, indicating the EU's reliance on imports to meet its demand for bio-based feedstocks, materials and products. 70-85% of GHG emissions driven by the top consumers occur within the EU-27 region itself, while this is 60-80% for land use, and 55-75% for water use. In both the accounting perspectives, the impacts attributed to Germany, France, Spain, Italy and Poland are most prominent where particularly Germany has a relatively high footprint in other world regions, mainly the Rest of Europe, African region and the Asia Pacific region. Spain and France have significant land and water use footprints in the African region. The Netherlands and Belgium are also important for GHG emissions (both as producers and consumers) and consumption-based water use, especially considering that more than half of their footprints for all three impacts occur in other world regions.

At the EU-27 sector level, primary agricultural products, particularly *Raw milk* and *Cattle*, are critical direct emitters of GHG. From a demand perspective, it is observed that the consumption of processed foods and meat products drive the largest share of emissions as these are based on the biggest directly emitting sectors *Raw milk* and *Cattle*.

From the cost estimation of GHG emissions, it is found that the countries associated with the highest footprint identified above are also those that have the highest production- and consumption-based costs in absolute terms. However, the shares of the total external costs relative to GDP are higher especially for eastern European states. Taking the Netherlands and its GHG emissions of the bioeconomy as a test case, it is found that the profits of its "Agriculture, forestry and fishing" sector would be reduced by 13% and the "Manufacture of food, beverages and tobacco" sector by 40% if they had to bear the costs of emissions.

The European Commission has emphasized the importance of a *sustainable* EU bioeconomy, but, to achieve that, more efforts to address impacts outside of Europe are needed. Therefore, it is recommended to address consumption-based impacts of the EU bioeconomy in future policy making. This is possible by incentivizing imports of sustainable bio-based feedstocks, materials and products in combination with expanding the use and strengthening of certification schemes and labels. Improved monitoring of bioeconomy flows (including international trade), impacts, and levels and

impacts of certification schemes and labels are important underlying aspects that can facilitate these efforts. Together, these tools can help enforce sustainable practices across the supply chain, extending their influence beyond EU borders and supporting the alignment of global supply chains with EU sustainability goals.

2 Introduction

In the European Union (EU), there has been a strong policy push in recent years towards a more bio-based economy because of its potential to contribute towards climate goals, food, natural resource and energy security, and preserving biodiversity, in addition to employment generation and growth.[3–5] The bioeconomy pertains to the production of biologically renewable resources termed "biomass" (e.g. agriculture and forestry), the use of biomass to produce bio-based products, materials and chemicals (e.g. food, furniture, textiles and chemicals), and their subsequent reuse or end-of-life treatment (e.g. compositing of waste, energy from waste).[6] The bioeconomy is integral to various European political initiatives such as the European Green Deal and its Circular Economy Action Plan.[7]

The EU bioeconomy strategy[4] laid out the environmental advantages of a larger bioeconomy. Namely, producing more from less including from waste, while limiting negative impacts on the environment and reducing the heavy dependency on fossil resources. This in turn allows also mitigating climate change and moving Europe towards a more sustainable society. It also highlighted that the bioeconomy is no longer a niche area but is an important vehicle for growth and employment. According to recent studies, in the year 2017 the bioeconomy of the EU-27 region employed about 18 million people (i.e., 8.9% of the EU-27 labour force), and generated €2.2 trillion of turnover or €614 billion in terms of value added (i.e.,4.7% of the EU-27 gross domestic product, GDP). In terms of sectors, agriculture and food-related sectors were found to be the most prominent. They employ more than three quarters of the bioeconomy's labour force (53% in agriculture, and 25% in the food, beverages, and tobacco industry), and generate two thirds of the bioeconomy value added (35% from the food, beverages, and tobacco industry, and 31% from agriculture).[8] The manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels) was found to employ no more than 3% of the workers in the bioeconomy but contributed to more than 9% of its value added.[9] Several other studies have investigated the contribution of the European bioeconomy to jobs and economic growth[10–13], some focussing on individual EU member states[14–16].

The updated bioeconomy strategy of the EU re-emphasises that deep de-fossilisation and global 2°C climate goals rely significantly on sustainable bioeconomy activities. The bioeconomy is expected to contribute to the de-fossilisation of major industries, such as energy, transport, chemicals, plastics and construction. However, it clearly recognizes that the production of bio-based products also comes with greenhouse gas emissions and other environmental risks.[17] Some studies have also considered the environmental sustainability dimension of the bioeconomy. Bruckner et al.[18] studied the global cropland footprint of the EU's non-food bioeconomy between 1995–2010. They found that two-thirds of the cropland required to meet the non-food biomass demand in EU are outside the EU, particularly in China, the US and Indonesia. Bringezu et al.[19] studied global environmental footprints of the German bioeconomy during 2000–2015 (with projections up to 2030). They conclude that the German bioeconomy contributes significantly to impacts such as greenhouse gas (GHG) emissions, land transformation and water scarcity in other world regions. Lazorcakova et al.[20] studied the GHG emissions of the Visegrad regions' bioeconomy along with economic indicators for the year 2015. Brizga et al.[21] focused on the Baltic Sea region and compared its production- and consumption-based bio-resource, land and water footprints during 2011-2015. All these studies have used an environmentally extended multi-regional input-output (EE-MRIO) model, as in the present study. This method allows for footprint analysis from a demand perspective considering all impacts upstream of global or regional supply chains. However, these studies are limited in scope, either geographically (focusing either on specific EU member states or groups of member states), temporally or in terms of the environmental indicators considered. Further, the use of bio-based resources and their processing results in environmental damage, which is not reflected in decision making about the bioeconomy, i.e. environmental externalities. The costs associated with this damage are also not generally reflected in financial accounts. The lack of sufficient information on environmental externalities makes it difficult to keep track of the dependence of economies on ecosystem services such as a stable climate, and availability of land and freshwater. An earlier report[22] estimated that environmental costs from anthropogenic activities amounted to US$ 6.6 trillion in 2008 (11% of global GDP), of which 69% was due to GHG emissions and resultant climate change. Smeets et al.[23] estimated the total environmental damage costs of the Dutch economy in the year 2015 at 50 billion euros (7.3% of Dutch GDP that year). Environmental externalities are becoming increasingly financially material as they can reduce returns to investors. For large investors, environmental costs can materialize as insurance premiums, taxes, inflated input prices, and physical costs associated with natural disasters. To the best of our knowledge, a comprehensive EU-wide study of the environmental externalities of the bioeconomy and their monetarization is missing.

The present study **aims to i) investigate the environmental impacts of EU's bioeconomy not just within its borders, but also outside through supply chain linkages, and ii) estimate the monetary value of the impacts.** This study comprehensively covers all relevant sectors of the bioeconomy, studies different environmental impacts, and looks at effects over time. It conducts an environmentally extended multi-regional input output[1] (EE-MRIO) analysis using global MRIO tables from Exiobase[2] for three years (2011, 2015 and 2022). The environmental impacts considered are GHG emissions, land use and water use. For the monetarization of environmental impacts, GHG emissions attributed to the EU-27's production and consumption of bio-based commodities are monetized using a monetisation factor for the contribution of GHGs to climate change. Moreover, taking the case of the Netherlands, the effects on profits of economic sectors are analysed considering they were to internalise their externalities.

The report is structured as follows: Section 3 describes the methods and data used for the study, Section 4 presents the results, and Section 5 discusses the key research findings, limitations, conclusions and policy implications.

3 Methods and Data

3.1 Environmentally extended multi-regional input-output (EE-MRIO) analysis

Two accounting perspectives are adopted to attribute impacts to a country or sector, namely, *production-based* and *consumption-based accounting*. In production-based accounting, impacts are allocated to the country or sector producing goods and services. Production-based impacts are directly calculated using the environmental extensions of Exiobase[2]. For instance, total production-based GHG emissions of a region is the sum of the products of sector outputs (in million euros) and respective sector emission intensities (in $MtCO_2eq$ per million euros) of that region.

In consumption-based accounting, also called demand perspective, impacts are allocated to the country consuming goods and services, or the sector where the final demand is. Sometimes, the final demand for a commodity causes environmental impacts directly in its production. This is termed *direct demand-driven impact*. For example, there could be a high demand from the *Vegetables, fruits, nuts* sector in a region. The demand is for vegetables, fruits and nuts, and the impacts directly occur from their cultivation. In other cases, the demand could be for a commodity that does not involve high impacts in its direct production but does cause large impacts in its supply chain. This is termed *indirect demand-driven impact*. For example, the *Food products nec* sector ("nec" stands for "not elsewhere classified") refers to processed food products. Impacts occur across the entire, underlying supply chains, from cultivation of crops or rearing of cattle for instance, and finally to processing. The impacts associated with the supply chain such as cultivation of crops or rearing cattle are indirect demand-drive impacts as they result from the demand for product inputs that are needed to produce the sector's products (here food products). Further, if the final demand for a commodity is high in a country, and that commodity is largely imported, or if the supply chain involves a significant amount of high-impact foreign commodities, the consuming country can have a large footprint in the supplying countries. Therefore, whereas the production-based impacts refer to territorial impacts, consumption-based impacts refer to impacts occurring anywhere in the world due to the final demand for a commodity in a region. In this study, we assess the direct and indirect environmental impacts of the EU's consumption of bio-based commodities produced within the EU and imported from other countries.

The method used in this study to assess the consumption-based impacts of the EU-27 member states is environmentally extended multi-regional input-output (EE-MRIO) analysis. Input-output analysis is an economic modelling technique developed by Wassily Leontief[24] in the 1930s, which maps the interactions between economic sectors, producers, and consumers. Underlying an EE-MRIO analysis is a multi-regional input-output (MRIO) table, which contains the flow of goods and services between economic sectors of multiple regions in monetary terms.[1] A satellite account containing environmental impact intensities (a row vector of direct GHG emission intensities of sectors for instance) is added as an extension to the MRIO table to set up the environmentally extended MRIO model. In this study, the global MRIO tables and the environmental extensions (i.e., intensities per sector per region) are taken from Exiobase database[2]. This EE-MRIO model is used to assess the global impacts of the EU's consumption of bio-based commodities; in other words, to calculate the consumption-based environmental impacts of the EU-27 member states.

The Leontief input−output model[1] is used for consumption-based accounting, which views the economy as demand-pull. That is, the final demand directly and indirectly drives upstream production and related environmental impacts.

First, a row vector q of environmental impact intensities (say GHG emission intensities) is calculated using equation 1:

$$q = h(\hat{x})^{-1} \quad (1)$$

The column vector x denotes the total output of nation-sectors. The row vector h is the satellite account row vector of total GHG emissions of nation sectors. The hat (∧) indicates diagonalizing the vector. GHG emissions driven globally by the final demand of each EU-27 member state (c) are calculated by equation 2:

$$c = q * L * y \tag{2}$$

The notation L denotes the Leontief inverse matrix and is computed as $(I - A)^{-1}$; A is the direct input coefficient matrix, and I is an identity matrix. An element a_{ij} of matrix A indicates the direct input from nation sector i required to produce unitary output of nation sector j. The element l_{ij} of matrix $(I - A)^{-1}$ indicates the direct and indirect inputs from nation sector i required to satisfy unitary final demand on nation sector j. The column vector y denotes the final demand of any EU-27 member state on all nation sectors. Therefore, an element c_{ij} of row vector c is the amount of GHG emissions occurring due to the final demand on nation sector j.
For this study, the Exiobase[2] MRIO database was selected. It covers 49 world regions, of which 27 are the EU-27 member states, and the rest are individual countries or aggregate world regions (Appendix Table A1). Each country is classified into 200 economic sectors (Appendix Table A2). Exiobase was chosen due to this high level of geographic detail suitable for the focus of this study (i.e., EU-27), and since it already differentiates between many sectors relevant for the bioeconomy, thus distinguishing between bio and non-bio sectors. For example, Biogasoline, Biodiesels, Other Liquid Biofuels are three sectors separated from fossil-based fuel sectors. However, based on an analysis of the other sectors in Exiobase, it was determined that seven sectors still needed to be disaggregated into their bio- and non-bio- components. The disaggregation was a preliminary step to the EE-MRIO analysis and is explained in more detail in Section 3.2.
The study is conducted for three years: 2011, 2015 and 2022. 2011 is the last year for which Exiobase MRIO tables are based on actual global economic trade data, beyond which the tables are based on forecasted data. 2022 is the last year for which these forecasted tables are available. 2015 was also considered as a somewhat middle point between 2011 and 2022, to give a better sense of the trends over time.
Exiobase categorises the final demand of countries into seven kinds, namely, Final consumption expenditure by households, Final consumption expenditure by non-profit organisations serving households (NPISH), Final consumption expenditure by government, Gross fixed capital formation, Changes in inventories, Changes in valuables, and Exports: Total (fob). In this study, all these categories are combined into one total final demand column per country. The final demands of the EU-27 member states are considered, and the impacts occurring globally due to the total final demands of each of the EU-27 member states are estimated.

3.2 Disaggregation of partially bio-based sectors

The list of regions and sectors in Exiobase are shown in Tables A1 and A2 of the Appendix. 39 out of 200 sectors in Exiobase were identified as fully bio-based, and seven sectors were identified as partially bio-based. The latter were disaggregated into their bio- and non-bio- parts for each of the 49 regions. This was done to improve the accuracy of the assessment of the impacts of bio-based commodities based on production-based and consumption-based accounting. The disaggregation was performed for each year of study (2011, 2015, and 2022).
The partially bio-based sectors are "*Textiles", "Wearing apparels; furs", "Plastics basic", "Chemicals nec", "Rubber and plastic products", "Furniture; other manufactured goods n.e.c.", and "Electricity by biomass and waste"*. Depending on data availability, disaggregation of a region-sector was based on either the market share of its bio- versus non-bio- parts; or its average bio-based trade share (imports

or exports) with all other regions collectively, due to absence of more detailed trade data. Three data sources were used to disaggregate the sectors: UN Comtrade[25], IEA's World Energy Statistics[26], and a technical report from the European Commission's Joint Research Centre (JRC)[27]. These data sources were, however, not specifically focused on the EU and so they do not necessarily have data for every EU member state. This is particularly the case for states with lower GDPs. For these states, an EU level average value of bio- and non-bio shares was used. Regions and partially bio-based sectors for which data were missing are discussed under the respective sectors below. Exiobase has five rest of world areas (RoW Africa, RoW Asia and Pacific, RoW Europe, RoW America, and RoW Middle East). Other databases or studies used for disaggregation do not necessarily have data for this geographic classification. Trade data for these five regions was obtained by taking the average of all countries in those regions, regional aggregation being based on the 'Standard country or area codes for statistical use (M49)' of the UN Statistics Division[28]. The collected bio-based shares for all years are shown in section A2 of the Appendix. In the following, the disaggregation of the seven partially bio-based sectors is briefly discussed by sector, with more details being available in the Appendix.

The *Textiles* sector is a combination of bio-based textiles such as cotton and fossil-based textiles such as polyester. There was no data available on the total bio-based share of the *Textiles and Wearing Apparels* sector. There is, however, global trade data available for cotton. Cotton is the primary component of bio-based fibers together with wool (however, wool is a separate sector in Exiobase). The share of cotton in the *Textiles and Wearing Apparels* sector was used as a proxy for its bio-based share. The data for trade between countries was obtained for the respective years from Comtrade[25]. The commodity codes used to obtain the bio-based share and other assumptions are presented in section A3.1 of the Appendix.

Furniture is made from materials such as metal, wood, and plastic. There was no data directly available on the bio-based share of the *Furniture* sector. This share was calculated based on international trade data for the respective years from Comtrade[25]. Within Comtrade, the *Furniture* sector is split up into product groups such as chairs or couches, but also the materials they are made of. It was assumed that wood-based products are bio-based, while other materials, such as plastics and metals, are non-bio-based. Even though plastics can be bio-based, the share of bio-based plastic used in furniture produced or consumed in each country or regions was not available. So, it was assumed that all plastics used are non-bio-based. The wood-based group codes in Comtrade are presented in section A3.2 of the Appendix.

Bio-based plastics are only recently emerging as their costs are still significantly higher compared to fossil-based plastics. This results also in limited trade data for bio-based plastics. A report by the Joint Research Centre (JRC)[27] was used to estimate bio-based shares of the *Plastics basic, and rubber and plastics* sector as it contains import and export data on bio-based plastics for 21 Exiobase regions. For the remaining 28 regions (mainly smaller countries), regional level average values from the report were used. While Exiobase has two separate sectors called *Plastics, basic* and *Rubber and Plastics*, there is no separate data available on the bio-based share of the rubber sector. The same bio-based shares as for the "Plastics, basic" sector were assumed for the *Rubber and Plastics* sector. The data from the JRC report is for the year 2019. Two other data sources were available that provide the bio-based share of plastics on a global scale for the years 2007[29] and 2018-2021[30]. A linear growth rate of the global

bio-based plastics shares between the years 2007 and 2018 (taken from aforementioned studies) was estimated. This was used to backtrack the regional bio-based plastics shares in 2011 and 2015, from the 2019 regional bio-based shares in the JRC report. For the 2022 value, a linear growth rate of the global bio-based plastics shares between the years 2018 and 2021 (taken from aforementioned studies) was estimated. This was then used to forecast the bio-based share in 2022 from the 2019 regional bio-based shares from the JRC report.
To estimate regional bio-based chemicals shares, 2019 bio-based import and export shares for the *Chemicals* sector from the above-mentioned JRC report[27] were used. An assumed linear growth rate of the bio-based chemicals share between 2010 and 2012 obtained from an earlier study[31] was used to estimate the regional bio-based chemicals shares for 2011, 2015 and 2022 starting from the 2019 values in the JRC report.
Bio-based shares for *Electricity from biomass and waste* were calculated using the IEA World Energy Statistics[26] database. It provides detailed data on electricity production from several sources. Three sources are relevant for this sector: municipal waste (renewable), municipal waste (non-renewable), and primary solid biofuels. The definition of these sectors (from IEA) is presented in section A3.3 of the Appendix. It was assumed that non-renewable municipal waste is non-bio-based, while the municipal waste (renewable) and primary solid biofuels are considered bio-based. The bio-based share of the *Electricity from biomass and waste* was calculated as the share of municipal waste (renewable) and primary solid biofuels in the total of the three sources (i.e., including municipal waste (non-renewable). The 2022 version of the dataset was used which had data up to the year 2021. For the year 2022, the electricity generation values of 2021 were assumed.

Disaggregating an input output table disturbs its balance (i.e., a square transactions matrix with row and column totals being equal). The RAS balancing method (also known as bi-proportional matrix balancing), developed in the 1960s, is commonly used to balance MRIO tables.[32] RAS is an iterative method, where the rows and columns of the initial matrix are alternatively scaled using prescribed row and column sums (marginal totals) to obtain a balanced matrix. However, this approach changes the production of other sectors in the economy, apart from the newly disaggregated sectors. As justified by Malik et al.[33], there is no reason for the production of other sectors to change. Therefore, only the newly disaggregated rows and columns are balanced following their "analytical approach". This is done as follows.
Let the new technical coefficients matrix with only the new rows and columns be A^1 and the new global final demand vector with only the new rows be y^1. The dimensions of A^1 and y^1 are 686x686 and 686x1, respectively. The new production vector with only the new rows can be calculated as shown in equation 3.

$$x^1 = (I - A^1)^{-1} * y^1 \tag{3}$$

x^1 is therefore a 686x1 vector. The balanced intermediate matrix z^1 with only the new rows and columns is obtained as shown in equation 4.

$$z^1 = A^1 * x^1 \quad (4)$$

The newly disaggregated rows and columns in the disaggregated 10143x10143 Z matrix are replaced with the balanced rows and columns from z^1.
Disaggregation and balancing were performed using MATLAB.

3.3 Environmental impact factors

Environmental impact data, i.e., GHG emissions, land use and water use per sector of every country or region, are provided by Exiobase. The GHG emissions intensity, land use intensity and water use intensity can be derived per region-sector as the ratio of its total respective impact and total production. For GHGs, emissions of carbon dioxide (CO_2), methane (CH_4) and N_2O (nitrous oxide) are considered. CH_4 and N_2O are converted into CO_2 equivalent based on IPCC 100-year global warming potential values. As per the Fifth Assessment Report, on a 100-year timescale, methane has 28 times greater global warming potential than carbon dioxide, and nitrous oxide has 265 time greater potential than carbon dioxide.[34] Agricultural emissions are included, however, emissions from land use change are not considered. Water use data is provided by Exiobase for both green and blue water. Blue water is water that is withdrawn from aquifers, lakes, and rivers, while green water is mostly from rainfall. All water use data, including water consumption and water withdrawal, were combined into one water use indicator. Land use data provided by Exiobase was directly used with no additional processing.
It must be noted that for the aforementioned seven sectors that were disaggregated into their non-bio- and bio-based shares, ideally new impact factors specific to the bio-based portions are used. However, since impact factors were not specifically available for the newly disaggregated bio-based sectors, these were assumed to be same as those of the respective overall sectors. Therefore, the difference in impacts between disaggregated non-bio- and bio-based sectors are not captured in terms of their emissions intensity, land use intensity or water use intensity, but only in terms of production quantities and trade.

3.4 Monetization of GHG emissions and internalization of costs

We estimate the environmental externalities in terms of monetary values for production- and consumption-based GHG emissions of the bioeconomy of the EU-27 member states. This is done by multiplying the emissions determined in previous steps with a monetization factor, i.e. the price associated with these emissions.
The monetisation factor for the contribution of GHGs to climate change is taken from a report by True Price Foundation[35]. The monetization factor, as defined in the report, is the marginal abatement cost or the carbon price required to restore greenhouse gas levels in the atmosphere to limit temperature increases to the 2°C scenario as specified in the Paris Agreement. The “true price methodology” generally estimates the remediation cost of environmental and social impacts by combining restoration costs, compensation costs, prevention of re-occurrence costs and retribution costs. However, in case of climate change, compensation cost, prevention-of-recurrence and retribution costs do not apply. Only the element of restoration is considered in the “true price methodology”, and the factor is obtained from a meta-analysis of marginal abatement cost models by Kuik et al.[36], adjusted to 2022 price levels. Further,

monetisation factors should ideally be region-specific, however, in absence of more detailed data, the global average from the “true price methodology” (which is based on the global average value from Kuik et al.[36]) is applied in the present study.

The GHG emissions cost calculated in the True Price Foundation report[35] is 0.163 €/ kg CO_2eq (2022 price levels). Another report by CE Delft[37] that also estimated environmental prices, considered the monetisation factor from Kuik et al.[36] for GHG emissions as the upper limit, and also reported a lower limit and an average. In the present study, only the factor calculated with the true price method is chosen as it represents a global average. Moreover, even going by the assumption in the CE Deflt report that 0.163 €/ kg CO_2eq is the upper limit of GHG abatement price in the year 2022, the factor can provide an estimate of the maximum abatement costs. These costs are then compared with the GDPs of respective member states in order to provide an estimate of the size of the EU bioeconomy’s impacts.

We only monetize the GHG emissions and not land use and water use. The latter two can especially differ from region to region and depend upon the specific type of biome. Since the EE-MRIO analysis is not conducted at this level of detail, we do not carry out the monetization of these impacts.

To further contextualize the costs of emissions with respect to an economy, we take the case of the Netherlands and show how a sector’s profits are affected if it were to internalize the production-based GHG emission costs attributed to it. The Netherlands is chosen for illustrating the approach because sector-specific data on operating surplus are readily available. Although not necessarily representative of the EU bioeconomy, this case study on the Netherlands allows testing the approach. In future research, additional countries can be explored to further understand the economic impact of the bioeconomy’s impacts (see also discussion).

To internalize the costs of GHG emissions, costs are calculated for the production-based GHG emissions occurring due to each bio-based sector of the Netherlands meeting the global final demand (i.e., GHG emissions associated with production of bio-based commodities in the Netherlands for domestic consumption and exports). Afterwards, these sector-specific costs are compared to the sector’s profits. A sector’s profits refer to the value “Operating surplus / mixed income (net) by industry” in the national accounts. These values are provisional for the year 2022 in the national accounts.

As sector aggregation in Exiobase is not the same as in the Netherlands, bio-based sectors first need to be mapped onto sectors in the Dutch national accounts. That is, the 46 bio-based sectors can be mapped to three main sectors of the national accounts[38] of the Netherlands, namely, “*Agriculture, forestry and fishing*”, “*Manufacturing*”, and “*Electricity and gas supply*”. “*Manufacturing*” is further sub-divided in the national accounts into 13 sub-sectors, of which six are relevant for the bioeconomy. These are “*Manufacture of food, beverages and tobacco*”, “*Manufacture of textile-, leather products*”, “*Manufacture of paper-, wood products, printing*”, “*Manufacture of chemicals*”, “*Manufacture of plastic and building material*”, and “*Other manufacturing and repair*”.

The national accounts only provide one “Operating surplus / mixed income (net) by industry” provisional value for the whole “*Manufacturing*” sector for the year 2022 (and not individual sub-sector values as for previous years). The growth rate of the operating surplus value for the “*Manufacturing*” sector between 2021 and 2022 was used to estimate the sub-sector operating surplus values in 2022.

4 Results

EU's production of bio-based feedstocks, materials and products accounted for 585 $MtCO_2eq$ of GHG emissions, 193 million ha of land use and 941 billion m^3 of water use in 2022 (Fig. 1). These are 1.3%, 7% and 4% of the global total economy (from all bio and non-bio sectors), respectively. When looking at only bio-based sectors, the EU was responsible for 6%, 7% and 4% of impacts associated with the bioeconomy worldwide, respectively.
In the demand perspective, i.e. considering all impacts associated with consumption of bio-based feedstocks, materials and products, the EU accounted for 762 $MtCO_2eq$ of GHG emissions, 196 million ha of land use and 1338 billion m^3 of water use (Fig. 1). This is 2%, 7% and 6% of the global demand (from all sectors), respectively, and 9-10% of the global demand from bio-based sectors each. Therefore, the EU-27's bio-based consumption-based global footprints are already higher than the production-based impacts.
In the following, the roles of the EU-27 member states as producers and consumers of impacts are discussed first (Section 4.1). Then we focus on the findings in the demand perspective, assessing the shares of bio- and non-bio-based contributions in the total consumption-based impacts (Section 4.2), tracing origins of the bio-based consumption-based impacts (Section 4.3), and looking at the sector-wise drivers of impacts (Section 4.4). Finally, using available pricing data for impacts and focusing on GHG emissions, we estimate the total cost of environmental externalities of the EU-27 (Section 4.5). This latter part of the analysis helps understand the possible financial implications of these impacts determined before.

4.1 EU-27 member states as producers and consumers of environmental impacts

Fig. 1 shows the roles of EU-27 member states as consumption-based drivers of environmental impacts as compared to their roles as direct emitters of GHG, as land users and as water users in the year 2022. Note that these impacts are only related to bio-based sectors. Panels A, B and C show GHG emissions, land use and water use, respectively. States are sorted in descending order of their consumption-based impacts. France (93 $MtCO_2eq$), Germany (79 $MtCO_2eq$), Poland, Spain and Italy (about 50-60 $MtCO_2eq$ each) are the top producers of GHG emissions, together making up 60% of the total production-based emissions of the EU bioeconomy. Spain uses the largest area of land for its production of bio-based commodities at 40 million ha. It is followed by France (23 million ha), and Poland, Italy and Germany at 13-18 million ha each. These countries are together responsible for 57% of the land use associated with production of bio-based products in the EU-27. As for water use, Spain (185 billion m3), Germany (156 billion m3) and France (122 billion m3) are the largest water users. They are followed by Poland, Italy and Romania at about 70-90 billion m3 each. These countries are together responsible for 74% of the water use associated with production of bio-based products in the EU-27.
Countries with high production-based impacts are often also the countries with the biggest consumption-based impacts. For example, Germany has the highest consumption-based GHG emissions (about 160 $MtCO_2eq$) followed by Italy, France and Spain (close to 100 $MtCO_2eq$ each). It is interesting to note that Germany's and Italy's consumption-based emissions are double their production-based emissions

(Fig. 1, panel A). This implies that these countries are also heavily reliant on imports for meeting their demands of bio-based commodities, apart from their domestic production. Note that (part of this production is also exported, i.e., it is not the case that first all domestic production goes towards domestic consumption, and then the demand in excess of that is met through imports.

Spain, Germany, France and Italy have the highest consumption-based land use in 2022 (25-35 million ha each) (Fig. 1, panel B). Spain's production-based land use is slightly higher than its consumption-based use. Poland follows Italy as the fifth largest driver, but like Spain, its production-based emissions are higher. This implies that Spain and Poland produce more bio-based commodities than they consume, this in turn means that they export embodied emissions. Similar to emissions (and water use), Germany's and Italy's consumption-based land use are around double their production-based land use. For the Netherlands and Belgium, the consumption-based land use is four times as high as the production-based land use.

As for water use (Fig. 1, panel C), Germany has the highest consumption-based water use at about 280 billion m^3, followed by Spain and France at about 190 billion m^3 each. Next follows Italy at 150 billion m^3, Poland and Netherlands at 100 billion m^3 each, and Belgium at about 70 billion m^3. The consumption-based water use of Germany, France and Italy is much higher than their production-based water use. The difference is particularly significant in the case of the Netherlands and Belgium, where it is six-fold and eight-fold, respectively.

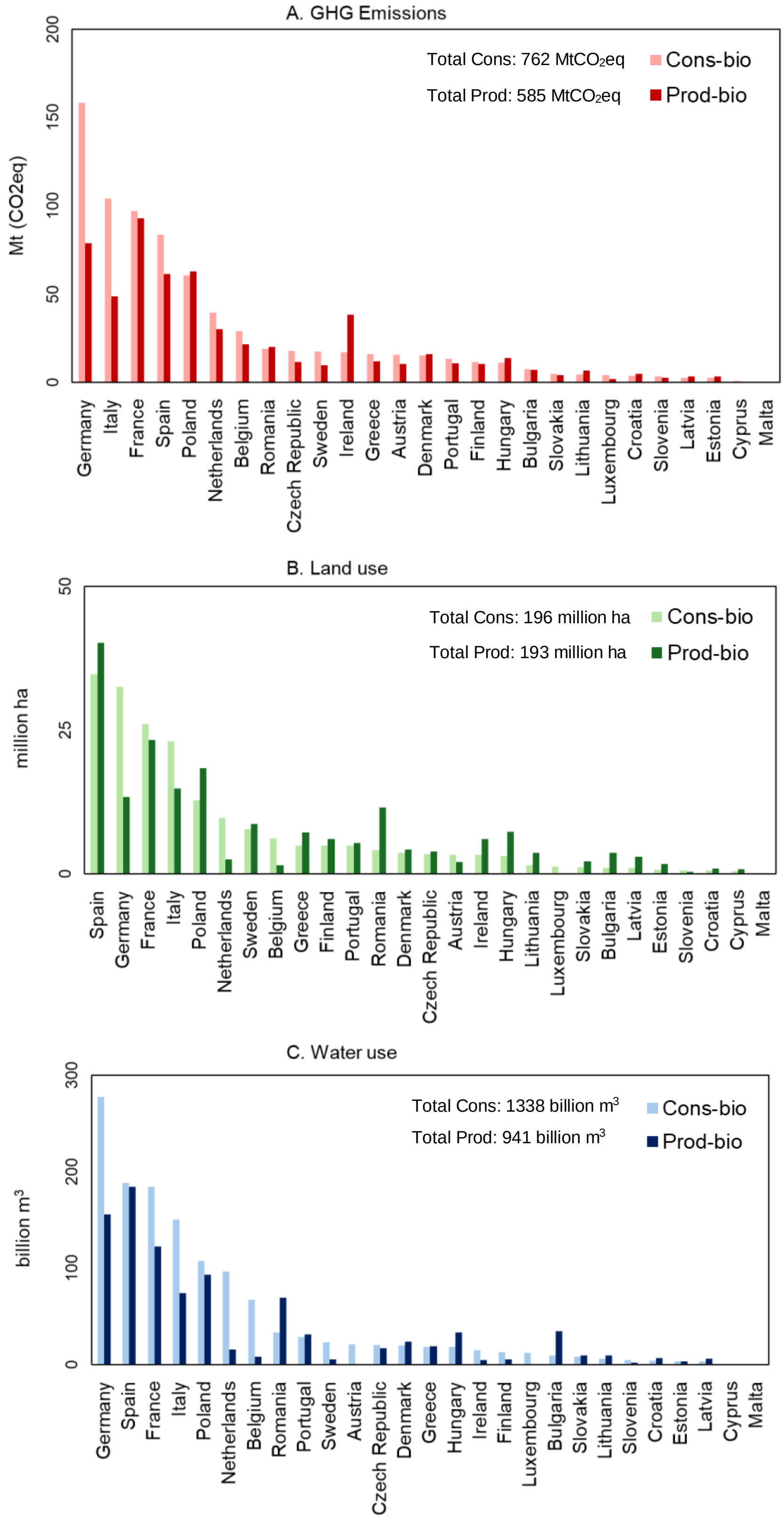


Fig. 1. Environmental impacts of EU's production and consumption of bio-based products. GHG emissions are presented in panel A, land use in panel B, and water use in panel C. Member states are sorted in descending order of their consumption-based impacts in order to allow easy comparison of impacts of one country.

4.2 Consumption-based impacts over time

The consumption-based GHG emissions of 15 selected EU member states over time are shown in Fig. 2. The states are shown in descending order of the consumption-based GHG emissions of their bio-based sectors. The share of bio-based consumption driving global GHG emissions for each of these member states is about 10-20%. This share has so far remained more or less constant over time. A slight decline is observed in total demand-driven GHG emissions in 2022 as compared to 2011. This conforms with the ongoing emissions reduction efforts in the EU and estimated reductions of GHG emissions in recent years.[39]

The consumption-based land use of the 15 EU member states with the highest land use is shown in Fig. 3. The states are shown in descending order of the consumption-based land use of their bio-based sectors. About 60-80% of the impacts are attributed to the consumption of bio-based commodities for all these states. This share remains more or less constant over time. However, contrary to GHG emissions, a relative increase is observed in total land use in 2022.

The consumption-based water use of some EU member states is shown in Fig. 4. The states are shown in descending order of the consumption-based water use of their bio-based sectors. The share of water used for meeting the demand for bio-based commodities remains in the range of about 60 to 80% over time for all states. There is a slight increase in the total water use in 2022 as compared to 2011. In 2015, however, a sharp decrease is observed. While the total global water use increased during both intervals (2011-2015 and 2015-2022) as seen from Exiobase's estimates, the reduction in water use for EU in 2015 could possibly be related to an underlying error of, or difference in, the water use indicator estimation in the Exiobase database for the year 2015 (see also Section 5.3).

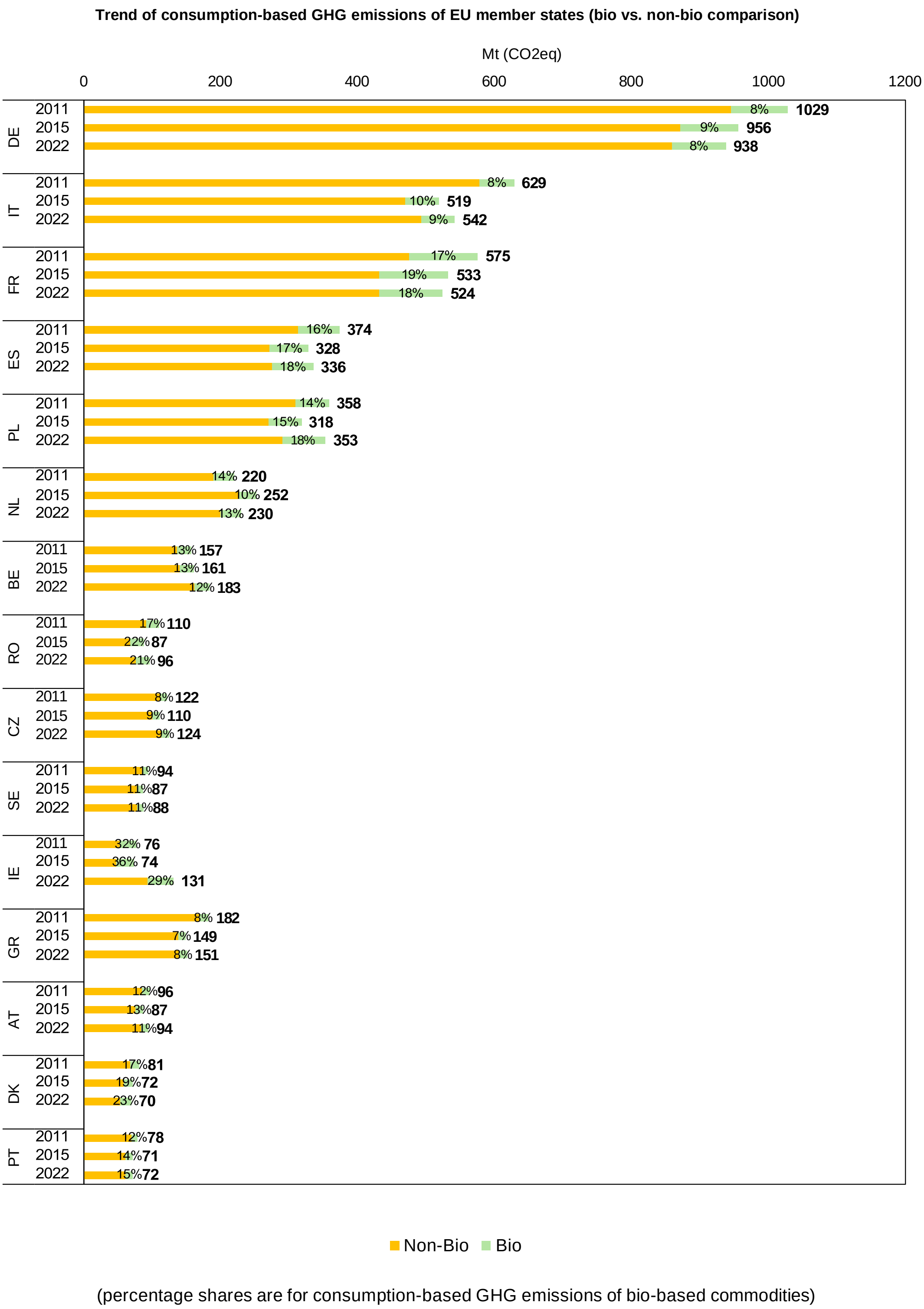


Fig. 2. Consumption-based GHG emissions of 15 EU member states with the largest impacts over time, breakdown for emissions associated with consumption of bio-based products and non-bio-based products. Refer Table A1 in the Appendix for unabbreviated region names.

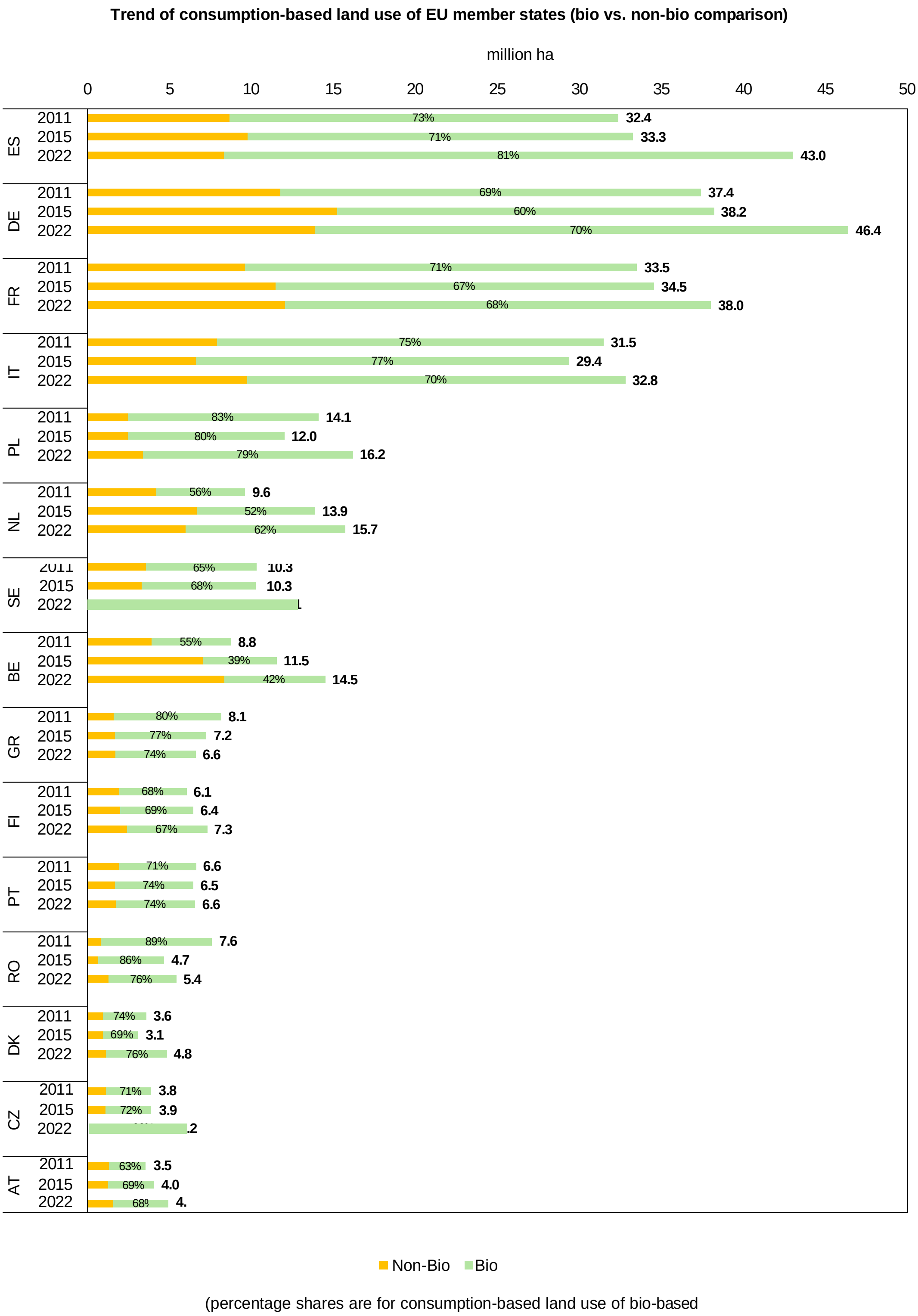


Fig. 3. Consumption-based land use of EU member states, breakdown for land use associated with consumption of bio-based products and non-bio-based products. Refer Table A1 in the appendix for unabbreviated region names.

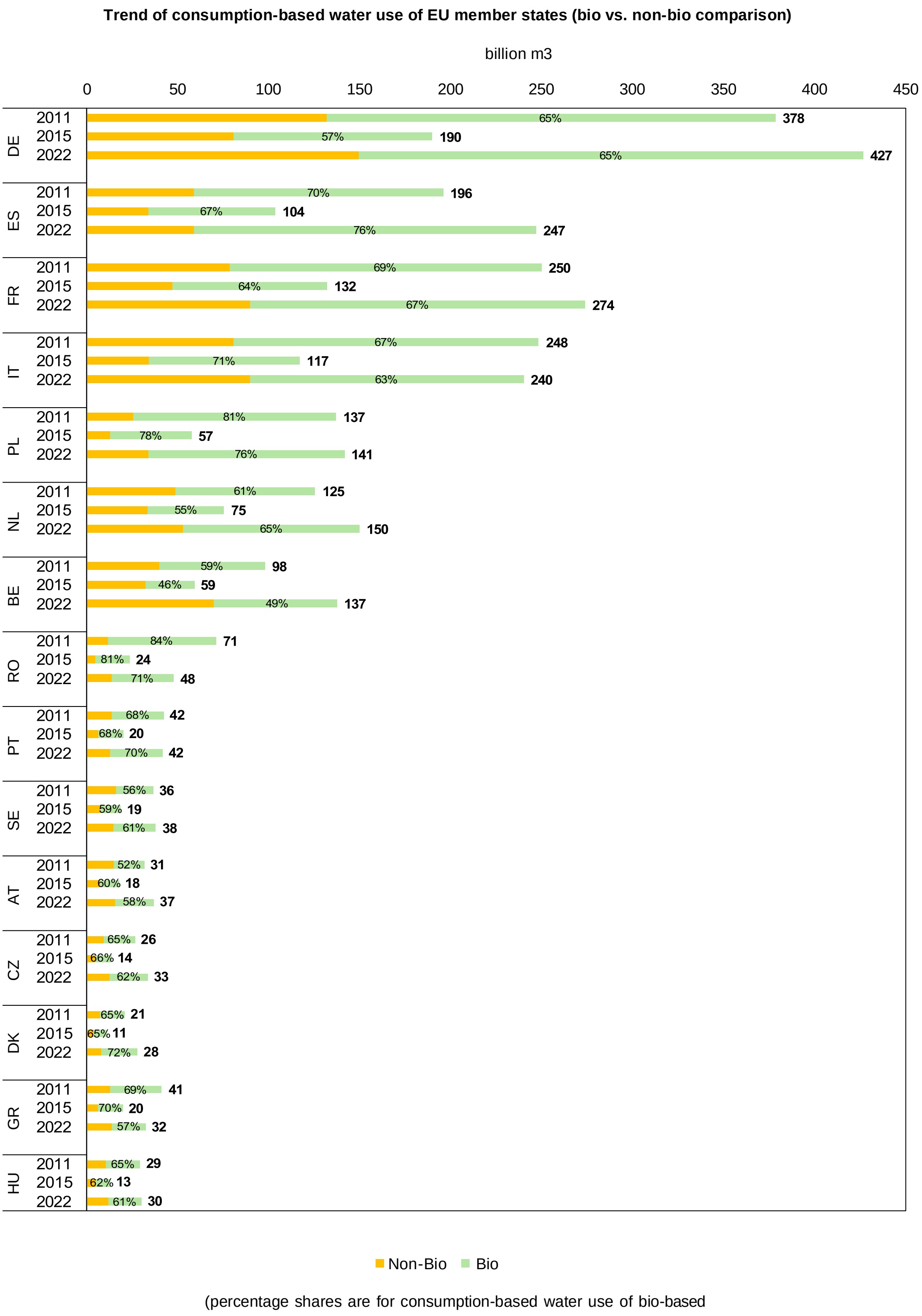


Fig. 4. Consumption-based water use of EU member states, breakdown for water use associated with consumption of bio-based products and non-bio-based products. Refer Table A1 in the appendix for unabbreviated region names.

4.3 Tracing origins of impacts from consumption of bio-based commodities

Fig. 5 shows the footprints of the top consumption-based GHG emitters (EU-27 member states) in the year 2022. It is observed that about 70-85% of emissions driven by the top five consumption-based emitters occur within the EU-27 region itself. Germany is seen to have a relatively high footprint in other world regions as well, such as in the Rest of Europe and the Asia Pacific region. The share of the footprints outside the EU-27 region (or "external footprint") is relatively higher for the Netherlands, Belgium and Ireland as compared to the external footprints of other member states.

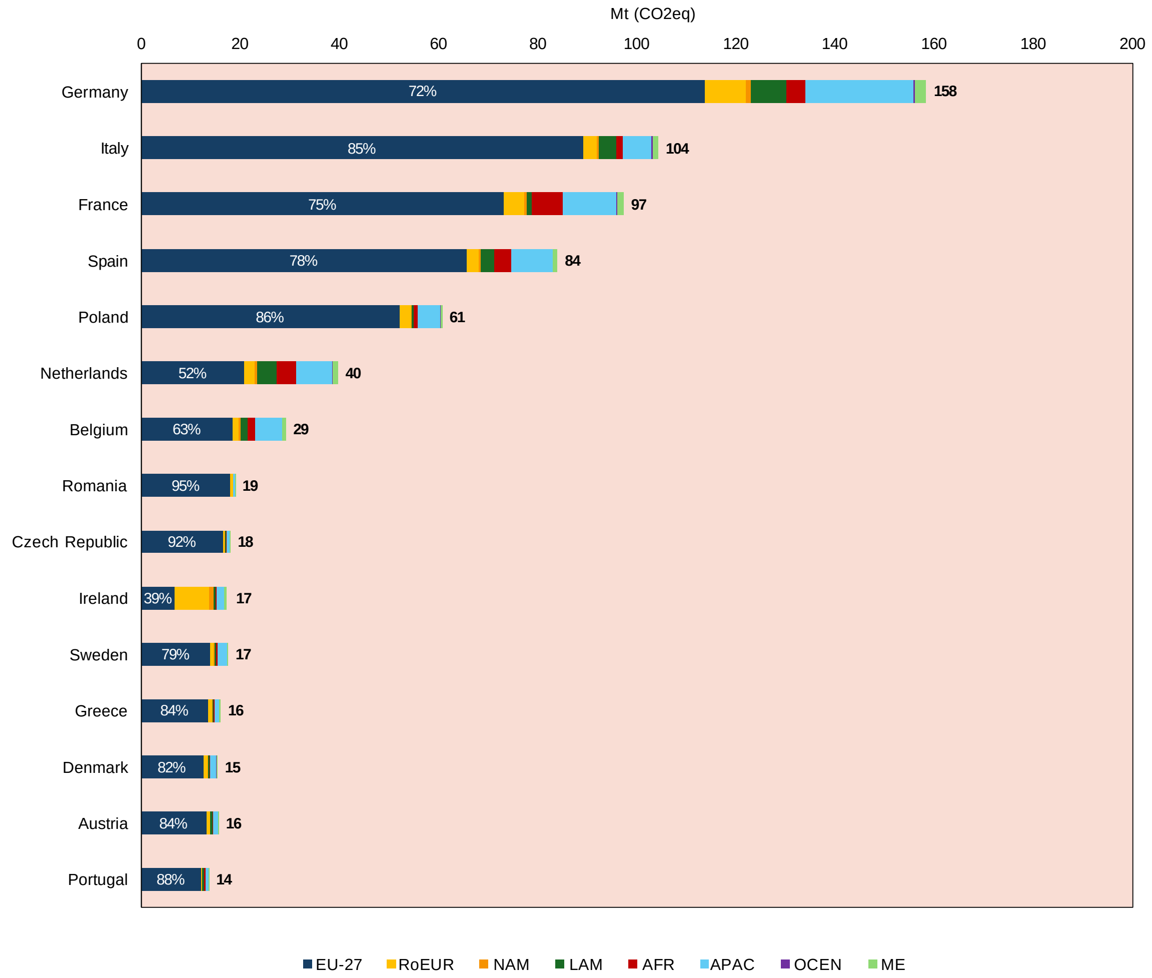


Fig. 5. Consumption-based GHG emission footprints of some EU-27 member states, by country/region where consumption takes place. The footprints within the EU-27 region as well as in other world regions are shown. (RoEUR: Rest of Europe; NAM: North America; LAM: Latin America; AFR: Africa; APAC: Asia Pacific; OCEN: Oceania; ME: Middle East.)

Fig. 6 shows the footprints of the top consumption-based land users (EU-27 member states) in the year 2022. It is observed that about 60-80% of land use driven by the top five consumption-based land users occurs within the EU-27 region itself. Spain and France have a relatively large footprint in the African region. Germany's external footprints are seen in the Rest of Europe, African region and the Asia Pacific region. For the Netherlands and Belgium, it is observed that more than half of their footprints are external to the EU-27 region.

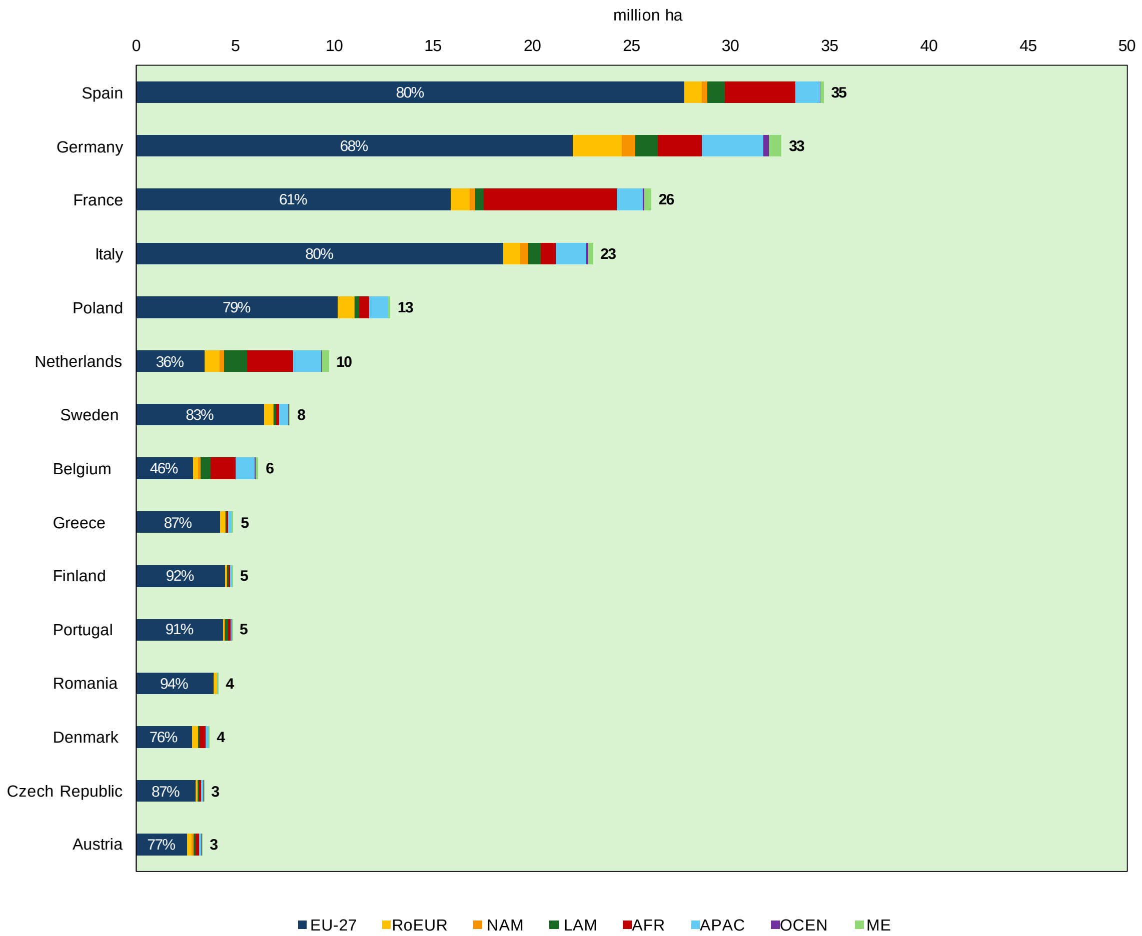


Fig. 6. Consumption-based land use footprints of some EU-27 member states, by country/region where consumption takes place. The footprints within the EU-27 region as well as in other world regions are shown.

Fig. 7 shows the footprints of the top consumption-based water users (EU-27 member states) in the year 2022. It is observed that about 55-75% of water use driven by the top five consumption-based water users, occurs within the EU-27 region itself. Germany, Spain, France, the Netherlands and Belgium have a relatively large footprint in the African region. Germany also has a large external footprint in the Asia Pacific region.

For the Netherlands and Belgium, it is again observed that more than half of their footprints are external to the EU-27. This observation for the Netherlands and Belgium, also seen in GHG emissions and land use, implies that these states are heavily reliant on imports from other regions of the world, particularly the African region, Asia Pacific region and Latin American region.

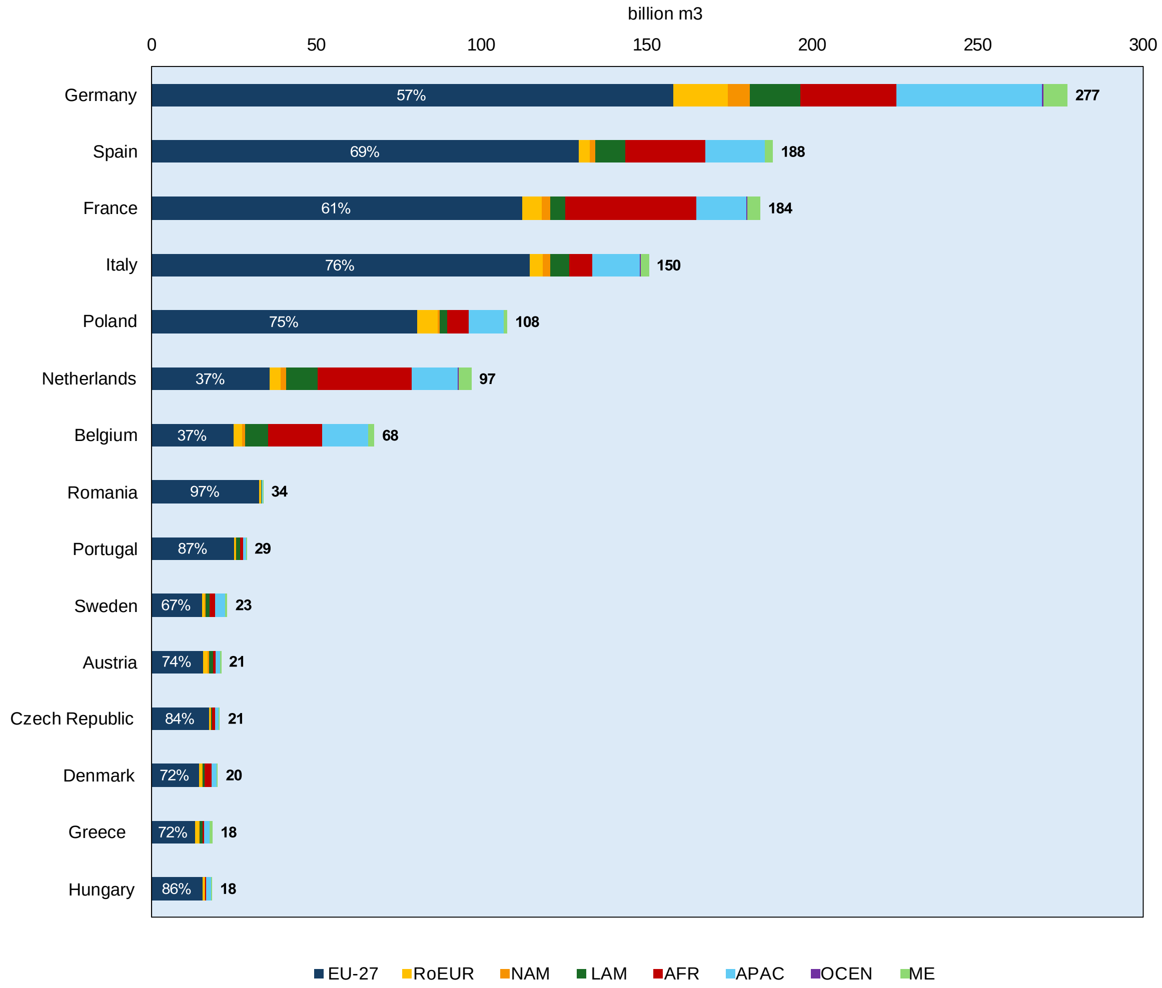


Fig. 7. Consumption-based water emission footprints of some EU-27 member states, by country/region where consumption takes place. The footprints within the EU-27 region as well as in other world regions are shown.

4.4 Sector level drivers of impacts

EU's sectoral level drivers of GHG emissions are shown in Fig. 8 in order to highlight the key sectors driving the emissions. Fig. 8A shows the emissions of EU-27's bio-based sectors from their production activities. Fig. 8B shows the emissions driven due to EU-27's consumption activities from global bio-based sectors (i.e., from sectors of all world regions). In the production perspective, sectors that produce primary agricultural products are critical emitters, particularly *Raw milk* (~160 Mt CO_2eq) and *Cattle* (~120 Mt CO_2eq). From the demand perspective, it is seen that the final demand in the EU-27 for processed foods i.e., from the sectors of *Food products nec*, *Dairy products*, *Products of meat cattle*, and *Meat products nec* (among others), drives more than 300 Mt CO_2eq of GHG emissions globally. This is not surprising, given that these sectors primarily rely on the feedstock production sectors with the highest emissions, i.e. raw milk and cattle. The demand for bio-based products in furniture is estimated to drive 45 Mt CO_2eq of emissions, the demand for Vegetables, fruit, nuts about 40 Mt CO_2eq, and the demand for bio-based products in the textiles sector about 27 Mt

CO_2eq. Together these seven sectors account for about 60% of the EU-27 bioeconomy's consumption-based emissions.

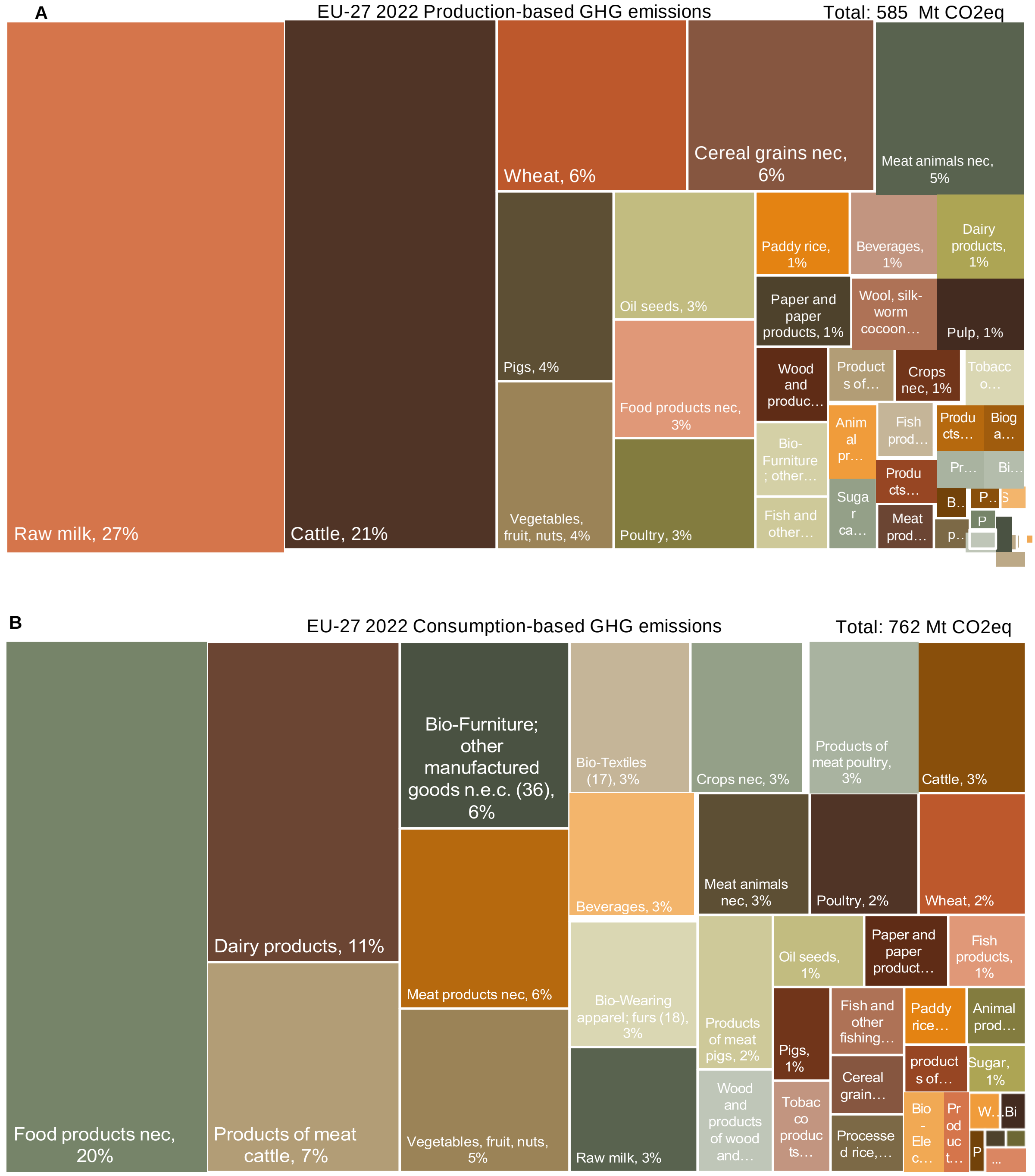


Fig. 8. Production-based emissions of EU-27's bio-based sectors (A); Consumption-based emissions of EU-27's bio-based sectors (B)

As an example of an individual EU member state, Germany's sectoral level drivers of GHG emissions are shown in Fig. 9. In the production perspective, *Raw milk* and *Cattle* are responsible for about half the emissions (40 Mt CO_2eq) associated with the demand for bio-based products in Germany (as is the case for the whole EU-27 region). From the demand perspective, the demand for processed foods i.e., from the sectors of *Food products nec*, *Dairy products*, *Products of meat cattle*, and *Meat* *products nec* (among others) drives about half the consumption-emissions. The demand for bio-based products in furniture is estimated to drive 11 Mt CO_2eq of emissions, and the demand for bio-based products in the vegetables, fruits and nuts sector as well as the textiles sector about 8 Mt CO_2eq each. This is similar to the EU picture shown previously. Together these seven sectors account for about 70% of the German bioeconomy's consumption-based emissions.

EU's sector level drivers (production- and consumption-based) of land use and water use, as well as some examples of individual member states are shown in section A4 of the Appendix.

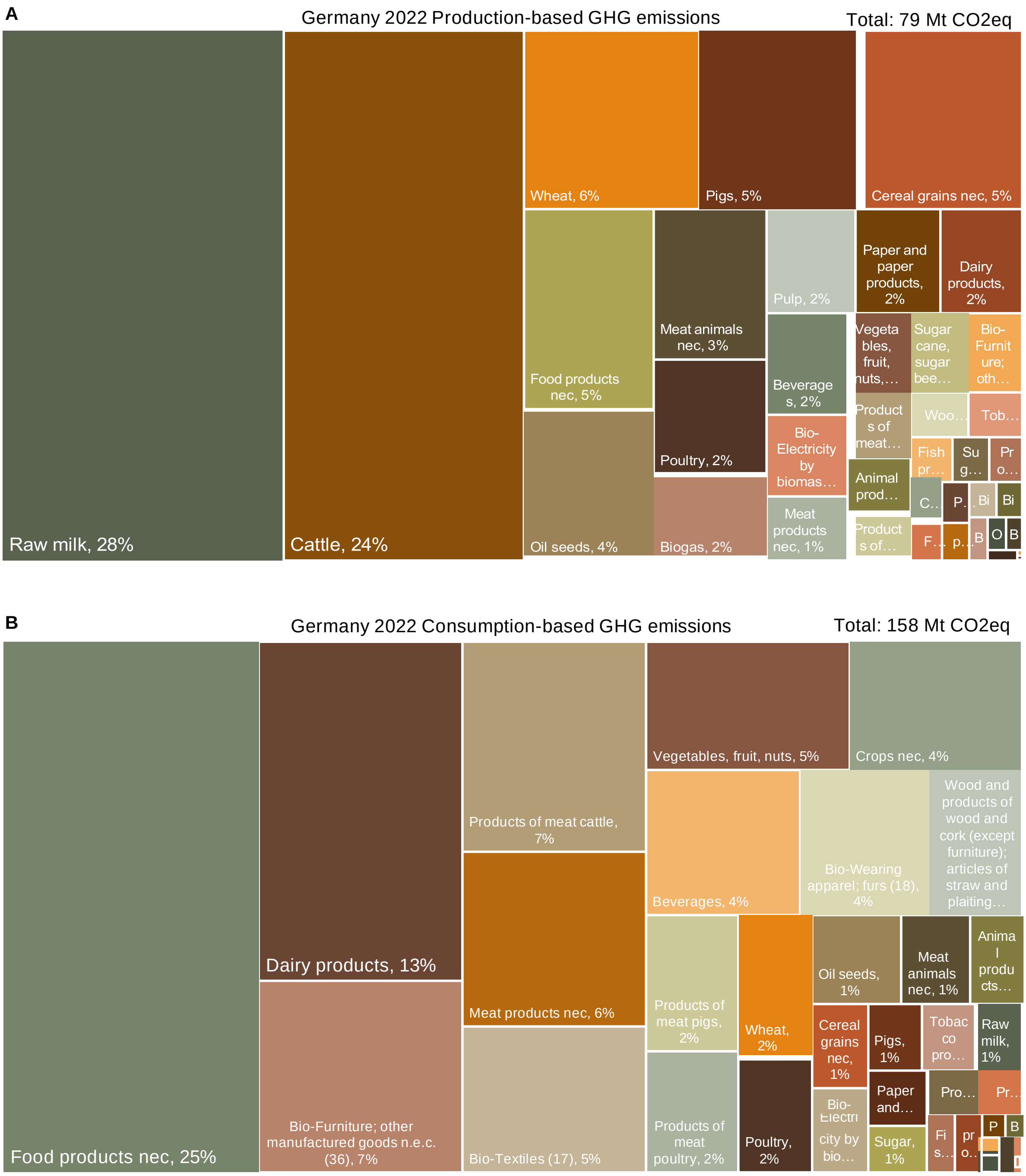


Fig. 9. Production-based emissions of Germany's bio-based sectors (A); Consumption-based emissions of Germany's bio-based sectors (B)

4.5 Pricing of environmental impacts

Table 1 shows the total production- and consumption-based GHG emission costs per EU member state. The total cost attributed to each state itself is proportional to the emissions as discussed in earlier sections. That is, the western European states of Germany, Italy, France, Spain, the Netherlands and Belgium lead to the highest externalities in absolute terms due to their production and consumption activities.
However, when looking at the shares of the total external costs relative to the GDPs of respective states, new patterns emerge. Eastern European states of Poland,

Bulgaria, Latvia, Estonia, Hungary, Lithuania and Romania are at the top of the list of ratios of production- and consumption-based costs to GDP. Greece is also among the top states in the consumption-based accounting list. Eastern European states dominate the list of ratios of production- and consumption-based costs to GDP. For instance, the ratio of production-based cost to GDP is the highest for Estonia, Latvia, Lithuania, Poland, Bulgaria, Hungary and Croatia, all in the range of 1.4% to 1.7%.
Eastern European economies are more reliant on production and heavy industry while western European economies are based more on value addition. This value addition occurs in bioeconomy related sectors such as processed foods and textiles, but also from services and other industries. The GDP of Eastern European states being lower results in larger ratios, even though the absolute emission values are higher for western European states.
While looking at the ratio of consumption-based cost to GDP, Poland, Bulgaria, Latvia, Greece, Estonia, Hungary, Lithuania and Romania dominate the list. Their ratios are in the range of 1.1% to 1.5%. Whereas the absolute consumption-based emissions of eastern European states are lower than western states, their final demands are also lower (meaning their GDPs are lower). Therefore, the ratios are once again higher for the eastern European members.

Next, we contextualized the costs associated with GHG emissions by comparing sector-specific contribution to these costs with sector profits for three sectors, i.e. agriculture, forest and fishing, electricity and gas supply, and manufacturing. Fig. 10A shows the share of the GHG costs of Exiobase agricultural sectors to the total profit of the “Agriculture, forestry and fishing” sector of the Netherlands in 2022. If the “Agriculture, forestry and fishing” sector of the Netherlands were to internalize its GHG emission costs, its annual profit in 2022 would be reduced by 13%. The Exiobase sectors of “Vegetables, fruit, nuts” (4%), “Poultry” (4%), “Pigs” (1.3%) and “Crops nec” (1.2%) would be the largest contributors to the expense.
Fig. 10B shows the share of the GHG costs of Exiobase bio-based electricity and fuel sectors to the total profit of the “Electricity and gas supply” sector of the Netherlands in 2022. Costs of GHG emissions attributed to bio-based electricity and fuels are not yet as high so as to impact the sectors profits significantly, causing only a 0.05% decrease in profits. From the 2022 MRIO table, it is observed that the production of electricity from biomass and waste is 10% of the total production from all electricity sectors including distribution and transmission. This could mean that while the value addition and profits of the overall electricity sector (including fossil-based generation, distribution and transmission) is high, the bio-based share of the sector is not yet significant enough to lead to GHG emissions that affect the profits of the overall electricity sector.

Table 1. Production- and consumption-based GHG emission costs per EU member state

	GDP (million €)		Production-based costs (million €)		Production-based costs/ GDP (%)		Consumption-based costs (million €)		Consumption-based costs/ GDP (%)	
1	Germany	3,953,850	France	15,851	Estonia	1.72%	Germany	27,652	Poland	1.53%
2	France	2,655,435	Germany	14,367	Latvia	1.67%	Italy	17,782	Bulgaria	1.46%
3	Italy	1,997,055	Spain	10,794	Lithuania	1.64%	France	16,923	Latvia	1.32%
4	Spain	1,373,629	Poland	10,547	Poland	1.59%	Spain	14,625	Greece	1.30%
5	Netherlands	993,820	Italy	8,340	Bulgaria	1.43%	Poland	10,118	Estonia	1.17%
6	Poland	661,712	Ireland	6,258	Hungary	1.39%	Netherlands	6,638	Hungary	1.16%
7	Belgium	563,544	Netherlands	5,045	Croatia	1.35%	Belgium	4,824	Lithuania	1.15%
8	Sweden	551,781	Belgium	3,598	Ireland	1.20%	Romania	3,163	Romania	1.12%
9	Ireland	520,935	Romania	3,381	Romania	1.20%	Czech Republic	3,015	Spain	1.06%
10	Austria	448,007	Denmark	2,660	Finland	0.97%	Sweden	2,953	Czech Republic	1.05%
11	Denmark	382,309	Finland	2,593	Greece	0.97%	Ireland	2,896	Slovenia	1.00%
12	Czech Republic	286,977	Hungary	2,343	Portugal	0.85%	Greece	2,693	Croatia	0.96%
13	Romania	281,761	Sweden	2,140	Spain	0.79%	Austria	2,619	Portugal	0.94%
14	Finland	266,124	Portugal	2,063	Slovenia	0.76%	Denmark	2,547	Luxembourg	0.89%
15	Portugal	243,957	Czech Republic	2,025	Czech Republic	0.71%	Portugal	2,303	Italy	0.89%
16	Greece	207,854	Greece	2,020	Denmark	0.70%	Hungary	1,964	Belgium	0.86%
17	Hungary	169,096	Austria	1,913	Slovakia	0.64%	Finland	1,927	Slovakia	0.78%
18	Slovakia	110,089	Bulgaria	1,227	Belgium	0.64%	Bulgaria	1,253	Finland	0.72%
19	Bulgaria	86,082	Lithuania	1,108	France	0.60%	Slovakia	860	Germany	0.70%
20	Luxembourg	77,529	Croatia	911	Netherlands	0.51%	Lithuania	773	Netherlands	0.67%
21	Croatia	67,612	Slovakia	704	Austria	0.43%	Luxembourg	692	Denmark	0.67%
22	Lithuania	67,456	Estonia	627	Luxembourg	0.43%	Croatia	649	France	0.64%
23	Slovenia	56,909	Latvia	602	Italy	0.42%	Slovenia	568	Austria	0.58%
24	Estonia	36,443	Slovenia	431	Sweden	0.39%	Latvia	476	Ireland	0.56%
25	Latvia	36,104	Luxembourg	331	Cyprus	0.37%	Estonia	427	Sweden	0.54%
26	Cyprus	29,416	Cyprus	108	Germany	0.36%	Cyprus	140	Cyprus	0.48%
27	Malta	18,242	Malta	20	Malta	0.11%	Malta	23	Malta	0.12%
	EU-27 total	16,143,728	**EU-27 total**	102,005	**EU-27 total**	0.63%	**EU-27 total**	130,502	**EU-27 total**	0.81%

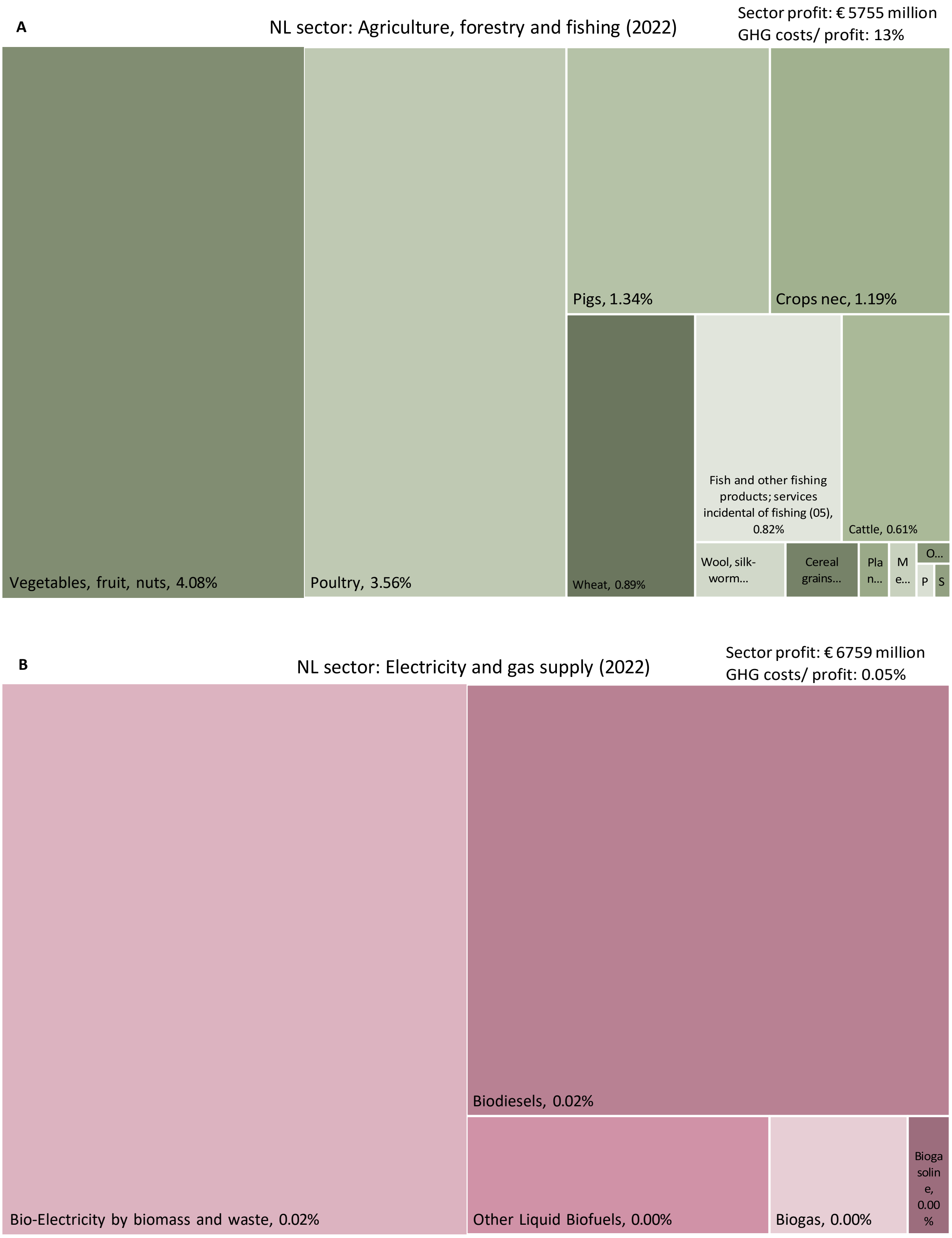
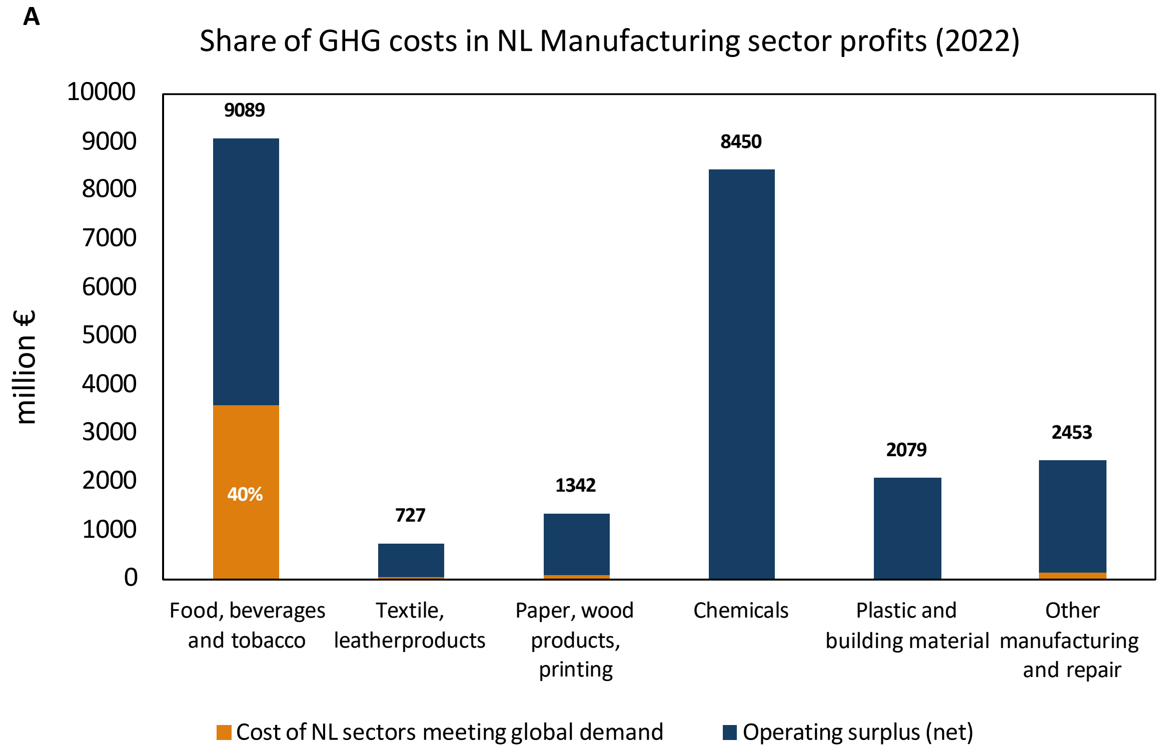


Fig. 10. Shares of the GHG costs of Exiobase agricultural sectors to the Netherlands' "Agriculture, forestry and fishing" sector's profits (A); Shares of the GHG costs of Exiobase bio-based electricity and fuel sectors to the Netherlands' "Electricity and gas supply" sector's profits (B)

Fig. 11A shows the shares of the GHG costs of Exiobase bio-based manufacturing sectors (including processed foods) as a share of the Manufacturing sub-sectors' profits taken from the Netherlands' national accounts. For five of the six manufacturing sub-sectors, the effect of internalizing GHG emission costs is almost negligible. This can again be understood as the bio-based shares of these sectors not being sufficient to significantly impact the profits of the total (bio- and non-bio-based) sectors. For the "Manufacture of food, beverages and tobacco" sector, the GHG emissions from just the bio-based portion are so high that internalizing their abatement costs would affect the profits of the sector by 40%.

Fig. 11B shows the shares of the GHG costs of Exiobase processed food sectors to the total profit of the "Manufacture of food, beverages and tobacco" sector of the Netherlands in 2022. The Exiobase sectors of "Food products nec" (26%), and "Dairy products" (13%) would be the largest contributors to the abatement expense.



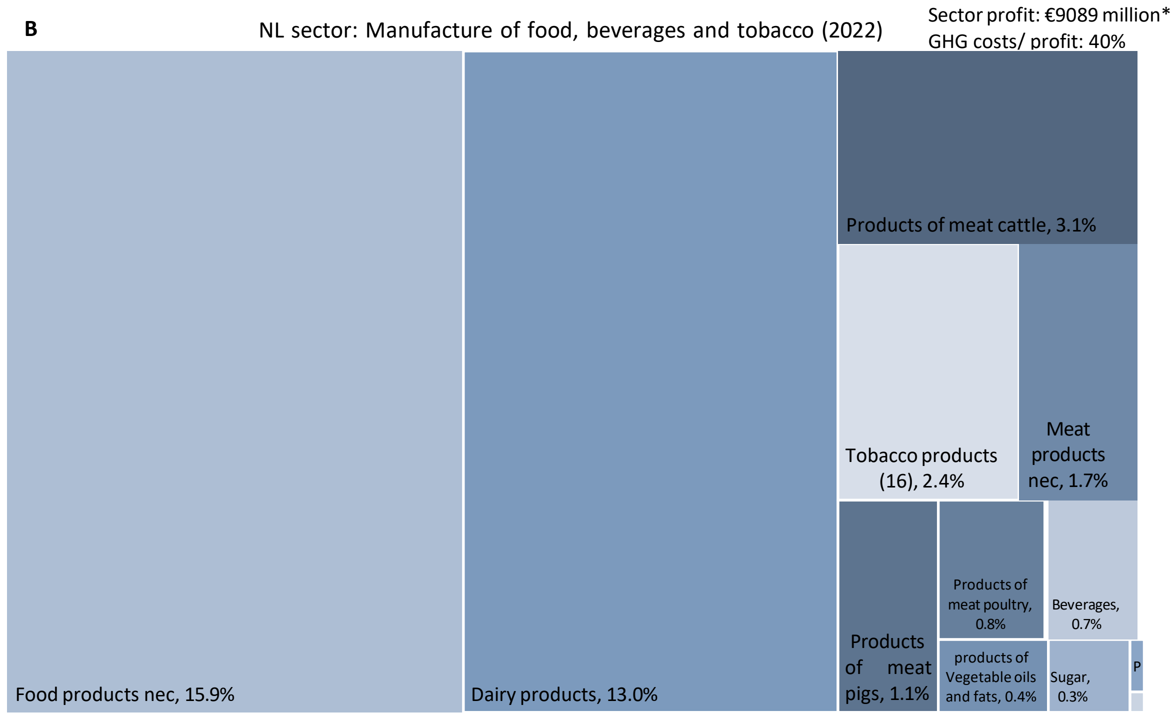


Fig. 11. Shares of the GHG costs of Exiobase bio-based manufacturing sectors to the Netherlands' Manufacturing sub-sectors profits (A); Shares of the GHG costs of Exiobase processed food sectors to the Netherlands' "Manufacture of food, beverages and tobacco" sector's profits (B)

5 Discussion and Conclusions

5.1 Overview of key findings

EU's production of bio-based feedstocks, materials and products accounts for 6%, 7% and 4% of the total GHG emissions, land use and water use attributed to the global production of bio-based commodities, respectively. In the demand perspective, i.e., consumption-based accounting, these shares are about 10% each. In both the accounting perspectives, the impacts attributed to Germany, France, Spain, Italy and Poland are most prominent. The Netherlands and Belgium are also important for GHG emissions (both as producers and consumers) and consumption-based water use.

While consumption-based land use and water use increased for almost all EU member states in 2022 as compared to 2011, consumption-based GHG emissions are seen to have slightly declined in line with the recent emissions reduction efforts in the EU.[39] Over time, the shares of bio-based consumption by each EU member state driving global GHG emissions, land use and water use are observed to remain more or less constant. These shares are 10-20% for GHG emissions, 60-80% for land use, and 60-80% for water use.

While investigating the regions most impacted by the EU-27's consumption of bio-based commodities, it was found that about 70-85% of GHG emissions driven by the top consumers occur within the EU-27 region itself. This figure is 60-80% for land use, and 55-75% for water use. Germany is seen to have a relatively high footprint in other world regions, mainly the Rest of Europe, African region and the Asia Pacific region. Spain, France and the Netherlands also have significant land and water use footprints in the African region. The Netherlands and Belgium have more than half of their footprints in other world regions for all three impacts.

At the EU-27 sector level, primary agricultural products, particularly *Raw milk* and *Cattle*, are critical direct emitters of GHG. From a demand perspective, it is observed that the consumption of processed foods and meat products drive the largest share of emissions as these are based on the biggest directly emitting sectors *Raw milk* and *Cattle*. Similar observations are made when looking at individual member states, in this report illustrated for Germany. Sectors related to furniture and textiles in both Germany and the EU are also relatively significant drivers of GHG emissions due to their demand for bio-based products.

From the estimation of GHG emission costs, it is found that western European states, particularly Germany, Italy, France, Spain, the Netherlands and Belgium, have the highest production- and consumption-based costs in absolute terms. This is because of the large amount of emissions associated with the production and consumption of bio-based products in these countries. The shares of the total external costs relative to GDP are high especially for eastern European states such as Poland, Bulgaria, Latvia, Estonia, Hungary, Lithuania, Romania and Greece.

Taking the Netherlands and its GHG emissions as a test case, it is found that the profits of its "Agriculture, forestry and fishing" sector would be reduced by 13% if it had to bear the costs of its emissions. More strikingly, the "Manufacture of food, beverages and tobacco" sector would stand to lose about 40% of its profits.

5.2 Limitations and future research avenues

To study the direct and indirect environmental impacts of the EU bioeconomy, we applied an environmentally extended multi-regional input output (EE-MRIO) model approach. Using the MRIO tables and environmental impact factors from Exiobase, we quantified production- and consumption-based GHG emissions, land use and water use of the EU bioeconomy in 2011, 2015 and 2022. Several limitations of the analysis are important to recognize and consider in the interpretation of our results.

General limitations to the EE-MRIO approach, such as those related to the level of sector aggregation and assumption of homogeneity in sectors, consistency in data sources for creating the MRIO tables or time lag between MRIO tables and reality, also apply to this study.[40] EE-MRIO still serves as a useful tool for assessing environmental impacts of the EU bioeconomy across the world. In the following we discuss key limitations specific to the present study.

First, this study disaggregated partially bio-based sectors from Exiobase into biobased and non-biobased sectors in order to provide a better representation of the EU bioeconomy in the MRIO tables. This disaggregation was conducted based on literature but was hampered by lack of detailed data on the share of bio-based feedstocks, materials and products versus non-bio-based inputs, and little information on their developments over time. Standard data collection systems are required to record the production, consumption and trade of bio-based feedstocks, materials and products within and among regions. This can greatly improve the accuracy of the findings of such a study in future.

Second, and related to the first, while this study investigated the environmental impacts of the bioeconomy, in the context of the HARMONITOR project, it would have been interesting to estimate the impacts of certified and non-certified bio-based products. As more and more companies introduce bio-based commodities in the market, they also seek to have their products certified for a higher brand value and accessing new markets, among other reasons. However, there are numerous certification systems and no standardisation, which renders the tracking of the certified bioeconomy impractical. Work package 3 of the HARMONITOR project[41] has specifically investigated the level of sustainability certification in the bioeconomy and found that data availability is very limited (see Vis et al. 2024 - HARMONITOR Deliverable D3.4). They were able to make good estimates for biomass feedstocks such as palm oil, wood, sugar cane, and sugar beet, but estimates on the level of certification for bio-based products with a limited number of producers, i.e. bio-based chemicals, were only possible accepting high levels of uncertainty. For wood-based products in many cases only the number of chain-of-custody certificates could be counted, resulting only in a statement on the relative level of certification per country compared to other countries. In addition, there was not enough information available to estimate the share of certification in internationally traded volumes of bio-based feedstocks, materials and products. As a result, in the present study, differentiation for certified and uncertified bio-based feedstocks, materials and products was not possible. If more such information were to be generated in a consistent and systematic manner for all (or at least key) bio-based feedstocks, materials and products across countries and world regions in the future, then it would be possible to also integrate it in the approach taken in the present report. Joint initiatives in the EU-27 region to introduce standard regulations for CSLs can improve data quality and tracking of the bioeconomy. This would allow differentiating the effects of certified and non-certified feedstocks, materials and products in the EU bioeconomy.

Third, in addition to improved tracking of the bioeconomy, studies that investigate and consistently define the environmental impacts specifically of bio-based feedstocks, materials and products across different world regions are required. While many case studies on specific bioeconomy products already exist, the analysis conducted for this study requires a systematic assessment of impacts across sectors and regions applied here. For lack of better data, in this study, the same impact factors are assumed for the bio-based portions of a sector as for the overall sector. Having more specific impact factors will greatly improve the quality of the findings of such a study in the future.

Moreover, the environmental impact factors also require further refinement. Most importantly, for GHG emissions, it is important to include emissions from land use change, which especially outside Europe can make up a significant portion of the emissions of bio-based value chains. In addition, although water use as a combination of green and blue water is a commonly used indicator in the context of MRIO studies, it is a simple metric of water consumption, lacking local and regional differentiation in water stress/scarcity. For example, Germany and Spain are the biggest countries in terms of water use for bio-based feedstock and product production domestically, with Spain using slightly more water than Germany. However, recognizing that Spain has a much higher water exploitation index (i.e. total abstraction per year/long-term renewable resources)[42], it becomes clear that water use for bioeconomy production in Spain will have more impacts than in Germany, especially in the long term. Future research can improve the water use impact factor by combining water use from Exiobase with characterization factors for the impact of water consumption, as proposed in the life cycle assessment community.[43] This allows to scale the Exiobase water use impact factors, and thereby more accurately represent the impacts of the bioeconomy.

It must also be noted that for the year 2015, there is a decrease in EU's water use (both production- and consumption-based) based on data from Exiobase. This is reflected in the results of this study as seen in section 4.2. The global water use, however, increased during both intervals (2011-2015 and 2015-2022). It is unclear if there is an error in estimation of EU's water use indicators for that year or water use of the EU actually reduced in that year. Further analysis of this issue is needed.

Fourth, multilateral initiatives with producer countries in other world regions can facilitate greater sustainability of global supply chains. 17 out of 27 EU member states are seen to have a higher GDP than the total production- or consumption-based GHG emission cost of the EU-27 region. The states with the highest GDPs are also observed to have significant footprints outside the EU-27 region. Consumer countries (i.e., EU member states) could support producer countries with technical know-how and finance for improving the efficiency and sustainability of their production activities.

Fifth, the approach applied in this study is based on *current* feedstock production and product conversion techniques. However, it would also be interesting to monitor national efforts to modernise bioeconomy activities and study their effect on environmental externalities. A recent study found that while other northern and western EU member states are still in the early stages of a bioeconomy transition, Belgium, Denmark, Finland and Ireland are modernising their bioeconomy activities by mobilising structural changes.[6] Future research could focus on assessing how different strategies related to making the bioeconomy more sustainable would actually affect the GHG emissions, land use and water use both in the EU and abroad, such as studying different agricultural management strategies that could help minimize impacts of production.

Sixth, in this study, we also investigated the costs associated with the environmental impacts of the bioeconomy and the effect of internalizing these costs. Due to data availability, we illustrated the approach for a case study of the Netherlands, focusing only on GHG emissions. To conduct such analyses for all EU member states, detailed and standardised sector-wise profits data for all states are required. This is not currently available at the level of detail required here. Moreover, our study illustrated the approach for GHG emissions. Future research can also expand this analysis to other environmental and socio-economic indicators in order to provide a more comprehensive understanding of the costs of externalities of the bioeconomy.

5.3 Conclusions and policy implications

Overall, this study found that the production of bio-based feedstocks, materials and products in the EU in 2022 accounted for 585 $MtCO_2eq$ of GHG emissions, 193 million ha of land use, and 941 billion m^3 of water use. However, consumption-based impacts were higher at 762 $MtCO_2eq$, 196 million ha, and 1338 billion m^3, indicating the EU's reliance on imports to meet its demand for bio-based commodities and products. Several member states cause significantly more impacts outside the EU than inside such as the Netherlands, Belgium and Ireland, or are very large producers and consumers such Germany, Spain, France and Italy. These countries have a particularly important role to play in addressing impacts outside of the EU and supporting countries where impacts occur most. The European Commission has emphasized the importance of a *sustainable* EU bioeconomy, but more efforts to address impacts outside of the EU are needed to achieve that. Therefore, it is recommended to address consumption-based impacts of the EU bioeconomy. This is possible by i) incentivizing imports of sustainable bio-based feedstocks, materials and products in combination with ii) expanding the use and strengthening of certification schemes and labels (CSLs).

Promoting sustainable imports can be achieved by establishing bilateral partnerships with key exporting countries or by executing trade agreements that prioritize sustainably sources bio-based feedstock, materials and products.

To expand and strengthen CSLs, it is essential to first establish clear sustainability criteria for bio-based feedstock, materials and products as defined by the EU. This should be coupled with robust certification mechanisms. These tools can promote sustainable practices across the supply chain, extend their influence beyond EU borders, and support the alignment of global supply chains with EU sustainability goals.

In addition to these recommendations, it is important to consider improved reporting and monitoring of consumption-based footprints by the EU and its member states. This includes advancements in underlying data on bio-based feedstock, materials and products trade so that MRIO tables can increase their representation of bio-based sectors and estimations of the footprints can improve. More detailed monitoring of the level of certification in international trade would also allow specifying MRIO tables and assessing consumption-based impacts of certified vs non-certified production for the bioeconomy. With clear EU guidelines on sustainability criteria as well requirements for certification, CSLs can help ensure that bio-based feedstocks, materials and products entering the EU market fulfil minimum sustainability standards.

A broader measure entails incorporating bioeconomy sectors into the European trading system and the carbon border adjustment mechanism. The potential inclusion of agriculture is already under discussion, aligning well with our study's findings that diary and meat production, along with their processing sectors are particularly significant. More specifically, our study indicates that over 50% of impacts stem from only a few sectors. From a production perspective, the sectors raw milk, cattle, wheat, and other cereals account for 60% of the EU's GHG emissions linked to the bioeconomy. Meanwhile, from a consumption perspective, food products, dairy products, products of meat cattle, bio-based furniture, and other meat products are most important. Given their substantial impact within the EU and beyond, these sectors should be prioritized in mitigation efforts within the bioeconomy. Another option is to integrate consumption-based metrics into the EU's climate and sustainability goals to ensure their recognition in policy planning and decision making.

An additional finding of our research is that the costs associated with these externalities are significant, especially for the sectors causing the highest impacts. The findings of the GHG emission cost internalisation exercise in this study for the Netherlands suggest that there is a need for all member states to examine the environmental externalities arising from their production and consumption of bio-based commodities. It is shown that the consumption of processed foods and meat products is mainly responsible for GHG emissions and associated costs. Policies that mandate the internalisation of these costs, at least in phases, can support this effort. As sectors like furniture, textiles, chemicals, plastics electricity begin to have larger bio-based shares in future years, they should also consider and plan for their external costs to be internalised.

By addressing consumption-driven environmental impacts as outlined above, the EU can reduce its global ecological footprint while maintaining leadership in fostering a sustainable bioeconomy worldwide.

6 References

(1) Miller, R. E.; Blair, P. D. *Input-Output Analysis: Foundations and Extensions*, 2nd ed.; Cambridge University Press: Cambridge, 2009. https://doi.org/10.1017/CBO9780511626982.

(2) Stadler, K.; Wood, R.; Bulavskaya, T.; Södersten, C.-J.; Simas, M.; Schmidt, S.; Usubiaga, A.; Acosta-Fernández, J.; Kuenen, J.; Bruckner, M.; Giljum, S.; Lutter, S.; Merciai, S.; Schmidt, J. H.; Theurl, M. C.; Plutzar, C.; Kastner, T.; Eisenmenger, N.; Erb, K.-H.; de Koning, A.; Tukker, A. EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology* **2018**, *22* (3), 502–515. https://doi.org/10.1111/jiec.12715.

(3) Wesseler, J.; von Braun, J. Measuring the Bioeconomy: Economics and Policies. *Annual Review of Resource Economics*, 2017, *9*, 275–298. https://doi.org/10.1146/annurev-resource-100516-053701.

(4) European Commission: Directorate-General for Research and Innovation. *Innovating for Sustainable Growth – A Bioeconomy for Europe*; Publications Office, 2012. https://doi.org/10.2777/6462.

(5) Bojović, J.; D'Amico, V.; Đukić, D.; Gemović, B.; Goujon, E.; Stanton, B. *Accelerating the Global Transition to a Bio-Based Economy: The Strategic Role of Policy*; World Economic Forum, 2024.

(6) Ronzon, T.; Iost, S.; Philippidis, G. Has the European Union Entered a Bioeconomy Transition? Combining an Output-Based Approach with a Shift-Share Analysis. *Environment, Development and Sustainability* **2022**, *24* (6), 8195–8217. https://doi.org/10.1007/s10668-021-01780-8.

(7) European Commission, Secretariat-General. *The European Green Deal*; 2019.

(8) Ronzon, T.; Piotrowski, S.; Tamosiunas, S.; Dammer, L.; Carus, M.; M'barek, R. Developments of Economic Growth and Employment in Bioeconomy Sectors across the EU. *Sustainability* **2020**, *12* (11). https://doi.org/10.3390/su12114507.

(9) Ronzon, T.; M'Barek, R. Socioeconomic Indicators to Monitor the EU's Bioeconomy in Transition. *Sustainability* **2018**, *10* (6). https://doi.org/10.3390/su10061745.

(10) Cingiz, K.; Gonzalez-Hermoso, H.; Heijman, W.; Wesseler, J. H. H. A Cross-Country Measurement of the EU Bioeconomy: An Input–Output Approach. *Sustainability* **2021**, *13* (6). https://doi.org/10.3390/su13063033.

(11) Porc, O.; Harc, N.; Carus, M.; Carrez, D. *European Bioeconomy in Figures 2008–2019*; Bio-based Industries Constortium, nova-Institute for Ecology and Innovation: Brussels, Belgium, 2022.

(12) Piotrowski, S.; Carus, M.; Carrez, D. European Bioeconomy in Figures. *Industrial Biotechnology* **2016**, *12* (2), 78–82. https://doi.org/10.1089/ind.2016.29030.spi.

(13) European Commission: Joint Research Centre; Kuosmanen, T.; Kuosmanen, N.; El-Meligi, A.; Ronzon, T.; Gurria, P.; Iost, S.; M'barek, R. *How Big Is the Bioeconomy? – Reflections from an Economic Perspective*; Publications Office, 2020. https://doi.org/10.2760/144526.

(14) Heijman, W. How Big Is the Bio-Business? Notes on Measuring the Size of the Dutch Bio-Economy. *NJAS: Wageningen Journal of Life Sciences* **2016**, *77* (1), 5–8. https://doi.org/10.1016/j.njas.2016.03.004.

(15) Efken, J.; Dirksmeyer, W.; Kreins, P.; Knecht, M. Measuring the Importance of the Bioeconomy in Germany: Concept and Illustration. *NJAS: Wageningen Journal of Life Sciences* **2016**, *77* (1), 9–17. https://doi.org/10.1016/j.njas.2016.03.008.
(16) Loizou, E.; Jurga, P.; Rozakis, S.; Faber, A. Assessing the Potentials of Bioeconomy Sectors in Poland Employing Input-Output Modeling. *Sustainability* **2019**, *11* (3). https://doi.org/10.3390/su11030594.
(17) European Commission: Directorate-General for Research and Innovation. *A Sustainable Bioeconomy for Europe – Strengthening the Connection between Economy, Society and the Environment – Updated Bioeconomy Strategy*; Publications Office, 2018. https://doi.org/10.2777/792130.
(18) Bruckner, M.; Häyhä, T.; Giljum, S.; Maus, V.; Fischer, G.; Tramberend, S.; Börner, J. Quantifying the Global Cropland Footprint of the European Union's Non-Food Bioeconomy. *Environmental Research Letters* **2019**, *14* (4), 045011. https://doi.org/10.1088/1748-9326/ab07f5.
(19) Bringezu, S.; Distelkamp, M.; Lutz, C.; Wimmer, F.; Schaldach, R.; Hennenberg, K. J.; Böttcher, H.; Egenolf, V. Environmental and Socioeconomic Footprints of the German Bioeconomy. *Nature Sustainability* **2021**, *4* (9), 775–783. https://doi.org/10.1038/s41893-021-00725-3.
(20) Lazorcakova, E.; Dries, L.; Peerlings, J.; Pokrivcak, J. Potential of the Bioeconomy in Visegrad Countries: An Input-Output Approach. *Biomass and Bioenergy* **2022**, *158*, 106366. https://doi.org/10.1016/j.biombioe.2022.106366.
(21) Brizga, J.; Miceikienė, A.; Liobikienė, G. Environmental Aspects of the Implementation of Bioeconomy in the Baltic Sea Region: An Input-Output Approach. *Journal of Cleaner Production* **2019**, *240*, 118238. https://doi.org/10.1016/j.jclepro.2019.118238.
(22) PRI Association and UNEP Finance Initiative. *Universal Ownership: Why Environmental Externalities Matter to Institutional Investors*; 2011.
(23) Smeets, B.; Schellekens, G.; Bauwens, T.; Wilting, H. *What's the Damage? Monetizing the Environmental Externalities of the Dutch Economy and Its Supply Chain*; Working paper 719; De Nederlandsche Bank, 2021.
(24) Leontief, W. W. Quantitative Input and Output Relations in the Economic Systems of the United States. *The Review of Economics and Statistics* **1936**, *18* (3), 105–125. https://doi.org/10.2307/1927837.
(25) Statistics Division, Department of Economic and Social Affairs, United Nations. UN Comtrade Database, 2024. https://comtradeplus.un.org/TradeFlow.
(26) International Energy Agency. *World Energy Statistics, 2022 Edition.* https://www.iea.org/data-and-statistics/data-product/world-energy-statistics.
(27) Spekreijse, J.; Vikla, K.; Vis, M.; Boysen-Urban, K.; Philippidis, G.; M`barek, R. Bio-Based Value Chains for Chemicals, Plastics and Pharmaceuticals. **2021**, No. KJ-NA-30653-EN-N (online). https://doi.org/10.2760/712499 (online).
(28) Statistics Division, United Nations Secretariat. *Standard Country or Area Codes for Statistical Use (M49) online version*. https://unstats.un.org/unsd/methodology/m49/#geo-regions.
(29) Shen, L.; Worrell, E.; Patel, M. Present and Future Development in Plastics from Biomass. *Biofuels, Bioproducts and Biorefining* **2010**, *4* (1), 25–40. https://doi.org/10.1002/bbb.189.
(30) Plastics Europe AISBL; EPRO. *Plastics – the Facts 2022*; 2022. https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/.

(31) Scarlat, N.; Dallemand, J.-F.; Monforti-Ferrario, F.; Nita, V. The Role of Biomass and Bioenergy in a Future Bioeconomy: Policies and Facts. *Environmental Development* **2015**, *15*, 3–34. https://doi.org/10.1016/j.envdev.2015.03.006.

(32) Stone, R. Input-Output and National Accounts. *Organization for European Economic Cooperation* **1961**.

(33) Malik, A.; Lenzen, M.; Ely, R. N.; Dietzenbacher, E. Simulating the Impact of New Industries on the Economy: The Case of Biorefining in Australia. *Ecological Economics* **2014**, *107*, 84–93. https://doi.org/10.1016/j.ecolecon.2014.07.022.

(34) IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Geneva, Switzerland, 2014.

(35) Galgani, P.; Kanidou, D.; van Veen, B.; Westrik, H. *Monetisation Factors for True Pricing Version 3.0.0*; True Price Foundation: Amsterdam, The Netherlands, 2023.

(36) Kuik, O.; Brander, L.; Tol, R. S. J. Marginal Abatement Costs of Greenhouse Gas Emissions: A Meta-Analysis. *Energy Policy* **2009**, *37* (4), 1395–1403. https://doi.org/10.1016/j.enpol.2008.11.040.

(37) de Bruyn, S.; Bijleveld, M.; de Graaff, L.; Schep, E.; Schroten, A.; Vergeer, R.; Ahdour, S. *Environmental Prices Handbook EU28 Version*; CE Delft: Delft, The Netherlands, 2018.

(38) CBS Statistics Netherlands. National Accounts 2022 Tables, 2023. https://www.cbs.nl/en-gb/custom/2023/27/national-accounts-2022-tables.

(39) European Commission. *Report from the Commission to the European Parliament and the Council: EU Climate Action Progress Report 2024*; Brussels, 2024.

(40) Wiedmann, T. A Review of Recent Multi-Region Input–Output Models Used for Consumption-Based Emission and Resource Accounting. *Ecological Economics* **2009**, *69* (2), 211–222. https://doi.org/10.1016/j.ecolecon.2009.08.026.

(41) HARMONITOR. *Harmonisation and monitoring platform for certification schemes and labels to advance the sustainability of bio-based systems (HARMONITOR)*. https://www.harmonitor.eu/.

(42) European Environment Agency. Water Exploitation Index (WEI), 2024. https://www.eea.europa.eu/en/analysis/maps-and-charts/water-exploitation-index-wei-2?activeTab=6fbd444d-c422-4a78-8492-fd496bd61b7a.

(43) Pfister, S.; Scherer, L.; Boulay, A.-M.; Motoshita, M.; Núñez, M.; Damiani, M.; Manzardo, A.; Huang, J.; Link, A.; Bunsen, J.; Berger, M. Letter to the Editor Re: “The Scarcity-Weighted Water Footprint Provides Unreliable Water Sustainability Scoring” by Vanham and Mekonnen, 2021. *Science of The Total Environment* **2022**, *825*, 154108. https://doi.org/10.1016/j.scitotenv.2022.154108.

Appendix

A1. Region and commodity classification

Table A1. Exiobase countries/ regions

	Country/ Region		Regional classification
1	AT	Austria	EU-27
2	BE	Belgium	EU-27
3	BG	Bulgaria	EU-27
4	CY	Cyprus	EU-27
5	CZ	Czech Republic	EU-27
6	DE	Germany	EU-27
7	DK	Denmark	EU-27
8	EE	Estonia	EU-27
9	ES	Spain	EU-27
10	FI	Finland	EU-27
11	FR	France	EU-27
12	GR	Greece	EU-27
13	HR	Croatia	EU-27
14	HU	Hungary	EU-27
15	IE	Ireland	EU-27
16	IT	Italy	EU-27
17	LT	Lithuania	EU-27
18	LU	Luxembourg	EU-27
19	LV	Latvia	EU-27
20	MT	Malta	EU-27
21	NL	Netherlands	EU-27
22	PL	Poland	EU-27
23	PT	Portugal	EU-27
24	RO	Romania	EU-27
25	SE	Sweden	EU-27
26	SI	Slovenia	EU-27
27	SK	Slovakia	EU-27
28	GB	United Kingdom	RoEUR
29	US	United States	NAM
30	JP	Japan	APAC
31	CN	China	APAC
32	CA	Canada	NAM
33	KR	South Korea	APAC
34	BR	Brazil	LAM
35	IN	India	APAC
36	MX	Mexico	LAM
37	RU	Russia	RoEUR
38	AU	Australia	OCEN
39	CH	Switzerland	RoEUR
40	TR	Turkey	RoEUR
41	TW	Taiwan	APAC
42	NO	Norway	RoEUR
43	ID	Indonesia	APAC
44	ZA	South Africa	AFR
45	RoW APAC	RoW Asia and Pacific	APAC
46	Row Europe	RoW America	LAM
47	RoW Africa	RoW Europe	RoEUR
48	RoW America	RoW Africa	AFR
49	RoW Middle East	RoW Middle East	ME

RoEUR: Rest of Europe; NAM: North America; LAM: Latin America; AFR: Africa; APAC: Asia Pacific; OCEN: Oceania; ME: Middle East.

Table A2. Exiobase sectors classified as Fully/ Partially/ Non- bio-based

	Product	Fully/ Partially/ Non- bio-based (FB/PB/NB)
1	Paddy rice	FB
2	Wheat	FB
3	Cereal grains nec	FB
4	Vegetables, fruit, nuts	FB
5	Oil seeds	FB
6	Sugar cane, sugar beet	FB
7	Plant-based fibers	FB
8	Crops nec	FB
9	Cattle	FB
10	Pigs	FB
11	Poultry	FB
12	Meat animals nec	FB
13	Animal products nec	FB
14	Raw milk	FB
15	Wool, silk-worm cocoons	FB
16	Manure (conventional treatment)	FB
17	Manure (biogas treatment)	FB
18	Products of forestry, logging and related services (02)	FB
19	Fish and other fishing products; services incidental of fishing (05)	FB
20	Anthracite	NB
21	Coking Coal	NB
22	Other Bituminous Coal	NB
23	Sub-Bituminous Coal	NB
24	Patent Fuel	NB
25	Lignite/Brown Coal	NB
26	BKB/Peat Briquettes	NB
27	Peat	NB
28	Crude petroleum and services related to crude oil extraction, excluding surveying	NB
29	Natural gas and services related to natural gas extraction, excluding surveying	NB
30	Natural Gas Liquids	NB
31	Other Hydrocarbons	NB
32	Uranium and thorium ores (12)	NB
33	Iron ores	NB
34	Copper ores and concentrates	NB
35	Nickel ores and concentrates	NB
36	Aluminium ores and concentrates	NB
37	Precious metal ores and concentrates	NB
38	Lead, zinc and tin ores and concentrates	NB
39	Other non-ferrous metal ores and concentrates	NB
40	Stone	NB
41	Sand and clay	NB
42	Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.	NB
43	Products of meat cattle	FB
44	Products of meat pigs	FB
45	Products of meat poultry	FB
46	Meat products nec	FB
47	products of Vegetable oils and fats	FB
48	Dairy products	FB
49	Processed rice	FB
50	Sugar	FB

	Product	Fully/ Partially/ Non-bio-based (FB/PB/NB)
51	Food products nec	FB
52	Beverages	FB
53	Fish products	FB
54	Tobacco products (16)	FB
55	Textiles (17)	PB
56	Wearing apparel; furs (18)	PB
57	Leather and leather products (19)	NB
58	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	FB
59	Wood material for treatment, Re-processing of secondary wood material into new wood material	NB
60	Pulp	FB
61	Secondary paper for treatment, Re-processing of secondary paper into new pulp	NB
62	Paper and paper products	FB
63	Printed matter and recorded media (22)	NB
64	Coke Oven Coke	NB
65	Gas Coke	NB
66	Coal Tar	NB
67	Motor Gasoline	NB
68	Aviation Gasoline	NB
69	Gasoline Type Jet Fuel	NB
70	Kerosene Type Jet Fuel	NB
71	Kerosene	NB
72	Gas/Diesel Oil	NB
73	Heavy Fuel Oil	NB
74	Refinery Gas	NB
75	Liquefied Petroleum Gases (LPG)	NB
76	Refinery Feedstocks	NB
77	Ethane	NB
78	Naphtha	NB
79	White Spirit & SBP	NB
80	Lubricants	NB
81	Bitumen	NB
82	Paraffin Waxes	NB
83	Petroleum Coke	NB
84	Non-specified Petroleum Products	NB
85	Nuclear fuel	NB
86	Plastics, basic	PB
87	Secondary plastic for treatment, Re-processing of secondary plastic into new plastic	NB
88	N-fertiliser	NB
89	P- and other fertiliser	NB
90	Chemicals nec	PB
91	Charcoal	FB
92	Additives/Blending Components	NB
93	Biogasoline	FB
94	Biodiesels	FB
95	Other Liquid Biofuels	FB
96	Rubber and plastic products (25)	PB
97	Glass and glass products	NB
98	Secondary glass for treatment, Re-processing of secondary glass into new glass	NB
99	Ceramic goods	NB
100	Bricks, tiles and construction products, in baked clay	NB

	Product	Fully/Partially/Non-bio-based (FB/PB/NB)
101	Cement, lime and plaster	NB
102	Ash for treatment, Re-processing of ash into clinker	NB
103	Other non-metallic mineral products	NB
104	Basic iron and steel and of ferro-alloys and first products thereof	NB
105	Secondary steel for treatment, Re-processing of secondary steel into new steel	NB
106	Precious metals	NB
107	Secondary preciuos metals for treatment, Re-processing of secondary preciuos metals into new preciuos metals	NB
108	Aluminium and aluminium products	NB
109	Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium	NB
110	Lead, zinc and tin and products thereof	NB
111	Secondary lead for treatment, Re-processing of secondary lead into new lead	NB
112	Copper products	NB
113	Secondary copper for treatment, Re-processing of secondary copper into new copper	NB
114	Other non-ferrous metal products	NB
115	Secondary other non-ferrous metals for treatment, Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	NB
116	Foundry work services	NB
117	Fabricated metal products, except machinery and equipment (28)	NB
118	Machinery and equipment n.e.c. (29)	NB
119	Office machinery and computers (30)	NB
120	Electrical machinery and apparatus n.e.c. (31)	NB
121	Radio, television and communication equipment and apparatus (32)	NB
122	Medical, precision and optical instruments, watches and clocks (33)	NB
123	Motor vehicles, trailers and semi-trailers (34)	NB
124	Other transport equipment (35)	NB
125	Furniture; other manufactured goods n.e.c. (36)	PB
126	Secondary raw materials	NB
127	Bottles for treatment, Recycling of bottles by direct reuse	NB
128	Electricity by coal	NB
129	Electricity by gas	NB
130	Electricity by nuclear	NB
131	Electricity by hydro	NB
132	Electricity by wind	NB
133	Electricity by petroleum and other oil derivatives	NB
134	Electricity by biomass and waste	PB
135	Electricity by solar photovoltaic	NB
136	Electricity by solar thermal	NB
137	Electricity by tide, wave, ocean	NB
138	Electricity by Geothermal	NB
139	Electricity nec	NB
140	Transmission services of electricity	NB
141	Distribution and trade services of electricity	NB
142	Coke oven gas	NB
143	Blast Furnace Gas	NB
144	Oxygen Steel Furnace Gas	NB
145	Gas Works Gas	NB
146	Biogas	FB
147	Distribution services of gaseous fuels through mains	NB
148	Steam and hot water supply services	NB
149	Collected and purified water, distribution services of water (41)	NB
150	Construction work (45)	NB

	Product	Fully/Partially/Non-bio-based (FB/PB/NB)
151	Secondary construction material for treatment, Re-processing of secondary construction material into aggregates	NB
152	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	NB
153	Retail trade services of motor fuel	NB
154	Wholesale trade and commission trade services, except of motor vehicles and motorcycles (51)	NB
155	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52)	NB
156	Hotel and restaurant services (55)	NB
157	Railway transportation services	NB
158	Other land transportation services	NB
159	Transportation services via pipelines	NB
160	Sea and coastal water transportation services	NB
161	Inland water transportation services	NB
162	Air transport services (62)	NB
163	Supporting and auxiliary transport services; travel agency services (63)	NB
164	Post and telecommunication services (64)	NB
165	Financial intermediation services, except insurance and pension funding services (65)	NB
166	Insurance and pension funding services, except compulsory social security services (66)	NB
167	Services auxiliary to financial intermediation (67)	NB
168	Real estate services (70)	NB
169	Renting services of machinery and equipment without operator and of personal and household goods (71)	NB
170	Computer and related services (72)	NB
171	Research and development services (73)	NB
172	Other business services (74)	NB
173	Public administration and defence services; compulsory social security services (75)	NB
174	Education services (80)	NB
175	Health and social work services (85)	NB
176	Food waste for treatment: incineration	NB
177	Paper waste for treatment: incineration	NB
178	Plastic waste for treatment: incineration	NB
179	Intert/metal waste for treatment: incineration	NB
180	Textiles waste for treatment: incineration	NB
181	Wood waste for treatment: incineration	NB
182	Oil/hazardous waste for treatment: incineration	NB
183	Food waste for treatment: biogasification and land application	NB
184	Paper waste for treatment: biogasification and land application	NB
185	Sewage sludge for treatment: biogasification and land application	NB
186	Food waste for treatment: composting and land application	NB
187	Paper and wood waste for treatment: composting and land application	NB
188	Food waste for treatment: waste water treatment	NB
189	Other waste for treatment: waste water treatment	NB
190	Food waste for treatment: landfill	NB
191	Paper for treatment: landfill	NB
192	Plastic waste for treatment: landfill	NB
193	Inert/metal/hazardous waste for treatment: landfill	NB
194	Textiles waste for treatment: landfill	NB
195	Wood waste for treatment: landfill	NB
196	Membership organisation services n.e.c. (91)	NB
197	Recreational, cultural and sporting services (92)	NB
198	Other services (93)	NB
199	Private households with employed persons (95)	NB
200	Extra-territorial organizations and bodies	NB

A2. Bio-based shares for the seven partially bio-based sectors

Table A3: Bio-based shares for the seven partially bio-based sectors, for all regions and all years. These shares are related to export data and are used to disaggregate the rows.

Region	Textiles			Wearing apparel; furs			Plastics, basic			Chemicals nec			Rubber and plastic products			Furniture; other manufactured goods n.e.c.			Electricity by biomass and waste		
	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022
AT	0.67	0.72	0.79	0.67	0.72	0.79	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.34	0.42	0.50	0.93	0.90	0.88
BE	0.29	0.23	0.13	0.29	0.23	0.13	0.01	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.55	0.49	0.43	0.83	0.84	0.80
BG	0.36	0.45	0.30	0.36	0.45	0.30	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00		0.37	0.33	0.51	1.00	1.00	1.00
CY	0.47	0.32	0.19	0.47	0.32	0.19	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.48	0.73	0.88	0.89	0.91	0.93
CZ	0.53	0.34	0.26	0.53	0.34	0.26	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.11	0.11	0.18	0.97	0.97	0.97
DE	0.41	0.36	0.34	0.41	0.36	0.34	0.01	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.41	0.39	0.47	0.76	0.74	0.74
DK	0.42	0.41	0.43	0.42	0.41	0.43	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.68	0.70	0.58	0.84	0.83	0.91
EE	0.43	0.22	0.11	0.43	0.22	0.11	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.73	0.73	0.80	1.00	0.92	0.95
ES	0.54	0.48	0.38	0.54	0.48	0.38	0.01	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.46	0.46	0.47	0.83	0.86	0.89
FI	0.64	0.54	0.44	0.64	0.54	0.44	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.31	0.27	0.51	0.98	0.97	0.97
FR	0.32	0.25	0.19	0.32	0.25	0.19	0.03	0.00	0.00	0.02	0.02	0.02	0.03	0.00	0.00	0.34	0.34	0.42	0.65	0.70	0.75
GR	0.89	0.85	0.79	0.89	0.85	0.79	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.49	0.54	0.58	0.89	1.00	1.00
HR	0.27	0.26	0.18	0.27	0.26	0.18	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.30	0.25	0.47	1.00	1.00	1.00
HU	0.40	0.34	0.25	0.40	0.34	0.25	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.23	0.26	0.27	0.93	0.95	0.95
IE	0.11	0.03	0.02	0.11	0.03	0.02	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.32	0.33	0.52	1.00	0.79	0.72
IT	0.45	0.37	0.33	0.45	0.37	0.33	0.01	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.53	0.54	0.65	0.68	0.73	0.75
LT	0.18	0.17	0.13	0.18	0.17	0.13	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.70	0.70	0.84	1.00	0.89	0.77
LU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.63	0.48	0.29	0.38	0.49	0.82
LV	0.35	0.13	0.12	0.35	0.13	0.12	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.69	0.64	0.82	1.00	1.00	1.00
MT	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.71	0.76	0.17	0.89	0.91	0.93
NL	0.23	0.21	0.20	0.23	0.21	0.20	0.01	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.40	0.39	0.39	0.78	0.71	0.84
PL	0.18	0.17	0.18	0.18	0.17	0.18	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.53	0.51	0.78	1.00	1.00	0.93
PT	0.70	0.58	0.62	0.70	0.58	0.62	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.40	0.42	0.57	0.90	0.91	0.93
RO	0.22	0.20	0.22	0.22	0.20	0.22	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.55	0.48	0.63	1.00	1.00	1.00
SE	0.38	0.56	0.35	0.38	0.56	0.35	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.50	0.47	0.54	0.90	0.90	0.89
SI	0.06	0.11	0.09	0.06	0.11	0.09	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.24	0.27	0.44	1.00	1.00	1.00
SK	0.16	0.23	0.02	0.16	0.23	0.02	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.45	0.46	0.48	0.98	0.99	0.97
GB	0.22	0.22	0.24	0.22	0.22	0.24	0.01	0.00	0.00	0.03	0.03	0.03	0.01	0.00	0.00	0.23	0.19	0.29	0.87	0.89	0.88
US	0.86	0.76	0.87	0.86	0.76	0.87	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.28	0.24	0.33	0.86	0.87	0.85
JP	0.23	0.21	0.14	0.23	0.21	0.14	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.04	0.08	0.81	0.84	0.95
CN	0.48	0.45	0.29	0.48	0.45	0.29	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.48	0.48	0.40	1.00	1.00	1.00
CA	0.05	0.06	0.07	0.05	0.06	0.07	0.09	0.00	0.00	0.01	0.01	0.01	0.09	0.00	0.00	0.33	0.36	0.41	0.99	0.99	0.99
KR	0.19	0.17	0.13	0.19	0.17	0.13	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.08	0.08	0.08	0.89	0.91	0.93
BR	0.91	0.88	0.94	0.91	0.88	0.94	0.01	0.00	0.00	0.04	0.04	0.04	0.01	0.00	0.00	0.63	0.72	0.80	1.00	1.00	1.00
IN	0.70	0.74	0.72	0.70	0.74	0.72	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.78	0.69	0.63	0.97	0.97	0.96
MX	0.55	0.52	0.61	0.55	0.52	0.61	0.09	0.00	0.00	0.01	0.01	0.01	0.09	0.00	0.00	0.10	0.09	0.22	1.00	1.00	1.00
RU	0.43	0.44	0.44	0.43	0.44	0.44	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.48	0.50	0.51	1.00	1.00	1.00
AU	0.99	0.99	0.99	0.99	0.99	0.99	0.00	0.00	0.00	0.13	0.13	0.13	0.00	0.00	0.00	0.22	0.31	0.20	1.00	1.00	1.00
CH	0.45	0.47	0.40	0.45	0.47	0.40	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.33	0.33	0.40	0.55	0.54	0.60
TR	0.57	0.53	0.54	0.57	0.53	0.54	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.47	0.56	0.56	1.00	1.00	1.00
TW	0.48	0.45	0.29	0.48	0.45	0.29	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.48	0.48	0.40	0.53	0.53	0.52
NO	0.44	0.70	0.63	0.44	0.70	0.63	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.64	0.54	0.44	0.80	0.51	0.55
ID	0.36	0.43	0.47	0.36	0.43	0.47	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.70	0.83	0.87	0.93	0.98	1.00
ZA	0.53	0.39	0.57	0.53	0.39	0.57	0.00	0.00	0.00	0.13	0.13	0.13	0.00	0.00	0.00	0.25	0.42	0.52	1.00	1.00	1.00
RoW APAC	0.42	0.40	0.31	0.42	0.40	0.31	0.00	0.00	0.00	0.04	0.04	0.04	0.00	0.00	0.00	0.37	0.35	0.32	0.91	0.92	0.95
Row Europe	0.36	0.32	0.26	0.36	0.32	0.26	0.08	0.00	0.00	0.09	0.09	0.09	0.08	0.00	0.00	0.46	0.46	0.53	0.84	0.85	0.85
RoW Africa	0.90	0.85	0.03	0.90	0.85	0.03	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.69	0.91	0.36	1.00	1.00	1.00
RoW America	0.49	0.45	0.52	0.49	0.45	0.52	0.00	0.00	0.00	0.13	0.13	0.13	0.00	0.00	0.00	0.24	0.23	0.32	0.89	0.90	0.88
RoW Middle East	0.16	0.16	0.25	0.16	0.16	0.25	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.43	0.57	0.58	0.89	0.91	0.93

Table A4: Bio-based shares for the seven partially bio-based sectors, for all regions and all years. These shares are related to import data and are used to disaggregate the columns.

Region	Textiles			Wearing apparel; furs			Plastics, basic			Chemicals nec			Rubber and plastic products			Furniture; other manufactured goods n.e.c.			Electricity by biomass and waste		
	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022	2011	2015	2022
AT	0.51	0.53	0.57	0.51	0.53	0.57	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.55	0.54	0.53	0.93	0.90	0.88
BE	0.32	0.23	0.16	0.32	0.23	0.16	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.00	0.00	0.44	0.45	0.49	0.83	0.84	0.80
BG	0.55	0.48	0.42	0.55	0.48	0.42	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.45	0.36	0.50	1.00	1.00	1.00
CY	0.34	0.31	0.36	0.34	0.31	0.36	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.66	0.61	0.64	0.89	0.91	0.93
CZ	0.41	0.31	0.28	0.41	0.31	0.28	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.28	0.17	0.26	0.97	0.97	0.97
DE	0.43	0.36	0.34	0.43	0.36	0.34	0.00	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.36	0.35	0.43	0.76	0.74	0.74
DK	0.36	0.30	0.25	0.36	0.30	0.25	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.48	0.47	0.52	0.84	0.83	0.91
EE	0.46	0.36	0.31	0.46	0.36	0.31	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.61	0.60	0.54	1.00	0.92	0.95
ES	0.45	0.37	0.30	0.45	0.37	0.30	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.00	0.00	0.34	0.27	0.37	0.83	0.86	0.89
FI	0.33	0.24	0.21	0.33	0.24	0.21	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.50	0.40	0.47	0.98	0.97	0.97
FR	0.37	0.31	0.31	0.37	0.31	0.31	0.00	0.00	0.00	0.03	0.05	0.08	0.00	0.00	0.00	0.46	0.44	0.52	0.65	0.70	0.75
GR	0.55	0.42	0.32	0.55	0.42	0.32	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.56	0.47	0.51	0.89	1.00	1.00
HR	0.49	0.39	0.30	0.49	0.39	0.30	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.59	0.51	0.58	1.00	1.00	1.00
HU	0.41	0.31	0.26	0.41	0.31	0.26	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.28	0.19	0.25	0.93	0.95	0.95
IE	0.33	0.25	0.17	0.33	0.25	0.17	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.57	0.55	0.55	1.00	0.79	0.72
IT	0.48	0.40	0.36	0.48	0.40	0.36	0.00	0.00	0.00	0.01	0.02	0.03	0.00	0.00	0.00	0.41	0.38	0.41	0.68	0.73	0.75
LT	0.40	0.32	0.22	0.40	0.32	0.22	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.35	0.42	0.51	1.00	0.89	0.77
LU	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.70	0.69	0.71	0.38	0.49	0.82
LV	0.38	0.28	0.25	0.38	0.28	0.25	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.49	0.46	0.56	1.00	1.00	1.00
MT	0.37	0.12	0.04	0.37	0.12	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.72	0.71	0.69	0.89	0.91	0.93
NL	0.24	0.17	0.16	0.24	0.17	0.16	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.00	0.00	0.49	0.50	0.48	0.78	0.71	0.84
PL	0.42	0.35	0.28	0.42	0.35	0.28	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.24	0.20	0.39	1.00	1.00	0.93
PT	0.58	0.56	0.58	0.58	0.56	0.58	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.30	0.26	0.37	0.90	0.91	0.93
RO	0.43	0.35	0.28	0.43	0.35	0.28	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.38	0.38	0.45	1.00	1.00	1.00
SE	0.44	0.46	0.29	0.44	0.46	0.29	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.46	0.47	0.50	0.90	0.90	0.89
SI	0.21	0.20	0.26	0.21	0.20	0.26	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.27	0.31	0.49	1.00	1.00	1.00
SK	0.48	0.38	0.13	0.48	0.38	0.13	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.25	0.16	0.23	0.98	0.99	0.97
GB	0.30	0.25	0.25	0.30	0.25	0.25	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.00	0.00	0.47	0.45	0.54	0.87	0.89	0.88
US	0.32	0.28	0.25	0.32	0.28	0.25	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.41	0.41	0.50	0.86	0.87	0.85
JP	0.47	0.37	0.36	0.47	0.37	0.36	0.00	0.00	0.00	0.01	0.02	0.03	0.00	0.00	0.00	0.47	0.42	0.44	0.81	0.84	0.95
CN	0.75	0.72	0.73	0.75	0.72	0.73	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.26	0.39	0.47	1.00	1.00	1.00
CA	0.32	0.28	0.25	0.32	0.28	0.25	0.00	0.00	0.00	0.09	0.17	0.30	0.00	0.00	0.00	0.41	0.41	0.50	0.99	0.99	0.99
KR	0.64	0.51	0.49	0.64	0.51	0.49	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.54	0.56	0.47	0.89	0.91	0.93
BR	0.39	0.12	0.06	0.39	0.12	0.06	0.00	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.05	0.05	0.04	1.00	1.00	1.00
IN	0.25	0.31	0.41	0.25	0.31	0.41	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.56	0.47	0.25	0.97	0.97	0.96
MX	0.32	0.28	0.25	0.32	0.28	0.25	0.00	0.00	0.00	0.09	0.17	0.30	0.00	0.00	0.00	0.41	0.41	0.50	1.00	1.00	1.00
RU	0.56	0.48	0.39	0.56	0.48	0.39	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.39	0.41	0.43	1.00	1.00	1.00
AU	0.18	0.18	0.18	0.18	0.18	0.18	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.42	0.44	0.51	1.00	1.00	1.00
CH	0.45	0.47	0.44	0.45	0.47	0.44	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.60	0.62	0.61	0.55	0.54	0.60
TR	0.61	0.49	0.60	0.61	0.49	0.60	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.36	0.37	0.29	1.00	1.00	1.00
TW	0.75	0.72	0.73	0.75	0.72	0.73	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.26	0.39	0.47	0.53	0.53	0.52
NO	0.28	0.30	0.24	0.28	0.30	0.24	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.51	0.52	0.57	0.80	0.51	0.55
ID	0.72	0.62	0.52	0.72	0.62	0.52	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.27	0.22	0.29	0.93	0.98	1.00
ZA	0.62	0.54	0.49	0.62	0.54	0.49	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.53	0.64	0.51	1.00	1.00	1.00
RoW APAC	0.57	0.53	0.55	0.57	0.53	0.55	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.42	0.44	0.42	0.91	0.92	0.95
Row Europe	0.40	0.32	0.27	0.40	0.32	0.27	0.00	0.00	0.00	0.08	0.15	0.27	0.00	0.00	0.00	0.45	0.42	0.48	0.84	0.85	0.85
RoW Africa	0.62	0.54	0.49	0.62	0.54	0.49	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.53	0.64	0.51	1.00	1.00	1.00
RoW America	0.32	0.28	0.25	0.32	0.28	0.25	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.41	0.41	0.50	0.89	0.90	0.88
RoW Middle East	0.23	0.22	0.20	0.23	0.22	0.20	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.49	0.56	0.54	0.89	0.91	0.93

A3. Comtrade commodity codes

A3.1 Textiles, and Wearing apparels

In Comtrade, the entire *Textiles, and Wearing apparels* sector data was identified as commodity codes 50, 52, 53, and 54, where 52 is cotton. 50 is silk, 53 is textile fibers and 54 is man-made filaments.

The following assumptions were made:

- Data for Canada and Mexico were missing; USA's data was used for these regions.
- For Australia, 2011 and 2015 data were missing; 2022 data was used also for these two years.
- Data for Taiwan was missing; China's data was used.
- Data for South Africa was missing, RoW Africa's data was used.
- For Russia, 2022 data was missing; 2011 and 2015 were used to calculate a trend to obtain 2022 data;
- Values for RoW Asia are averages of the following countries: Taiwan, India, South Korea, China, and Japan.
- Values for Row Europe are averages of all the EU countries for which data was available.
- USA's values are used for RoW America.

A3.2 Furniture

The *furniture* sector was identified as Comtrade commodity codes 9401 (seats), 9402 (furniture for businesses), and 9403 (furniture and parts thereof).

The following subsectors of commodity codes in Comtrade were identified as bio-based for the furniture sector:
940131, 940141, 940152, 940153, 940159, 940161, 940169, 940191, 940330, 940340, 940350, 940360, 940381, 940380, 940391, 940389, 940382, 940383.

The following assumptions were made:

- Data for Canada and Mexico were missing; USA's data was used for these regions.
- For Australia, 2011 and 2015 data were missing; 2022 data was used also for these two years.
- Data for Taiwan was missing; China's data was used.
- Data for South Africa was missing, RoW Africa's data was used.
- For Russia, 2022 data was missing; 2011 and 2015 were used to calculate a trend to obtain 2022 data;
- Values for RoW Asia are averages of the following countries: Taiwan, India, South Korea, China, and Japan.
- Values for Row Europe are averages of all the EU countries for which data was available.
- USA's values are used for RoW America.

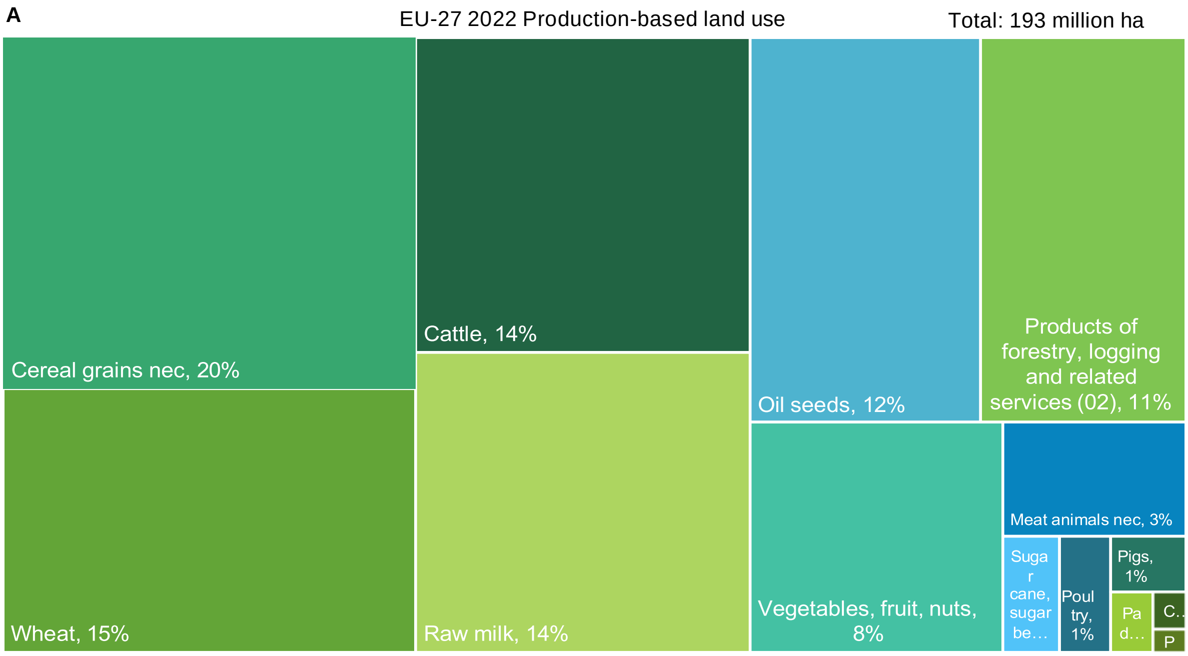
A3.3 Electricity from biomass and waste

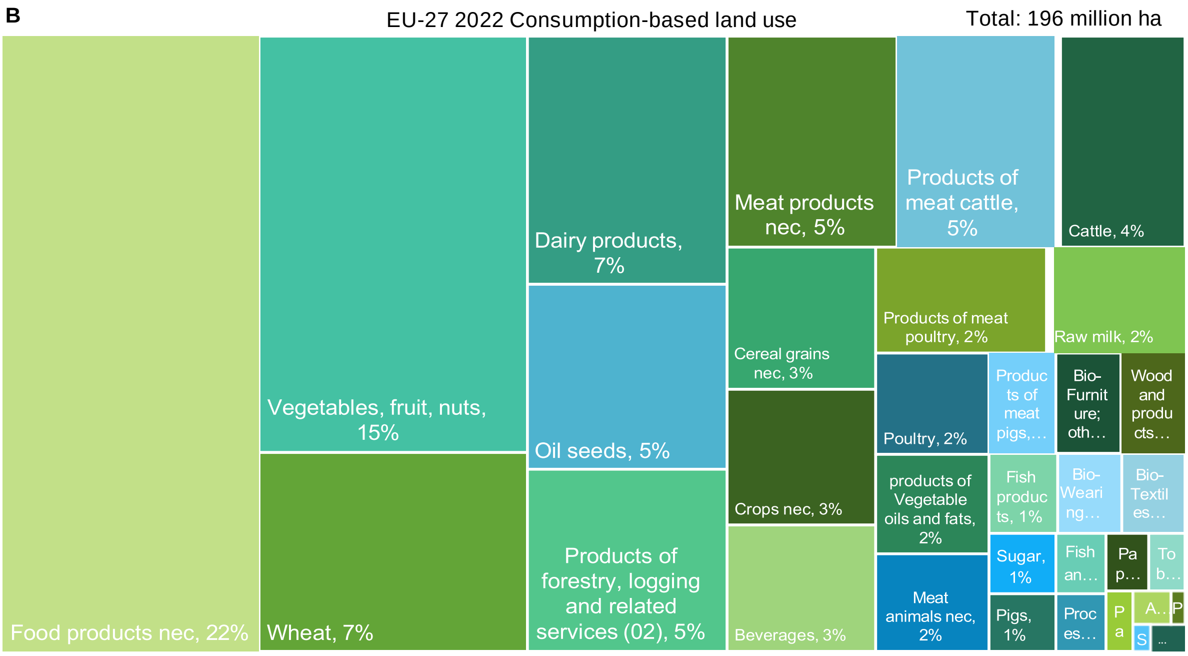
The sources relevant for this sector are municipal waste (renewable), municipal waste (non-renewable), and primary solid biofuels. The definitions of these sectors (from IEA[26]) are given below.

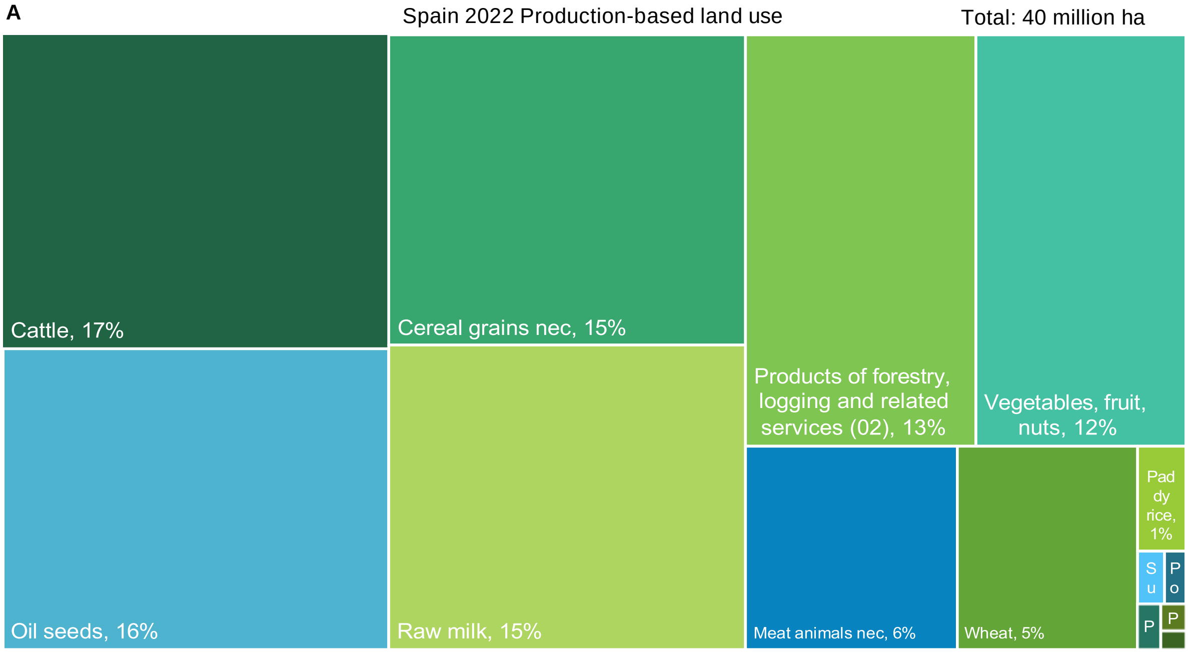
Definition of *Municipal waste*:
Municipal waste consists of products that are combusted directly to produce heat and/or power and comprises wastes produced by households, industry, hospitals, and the tertiary sector that are collected by local authorities for incineration at specific installations. Municipal waste is split into renewable and non-renewable.

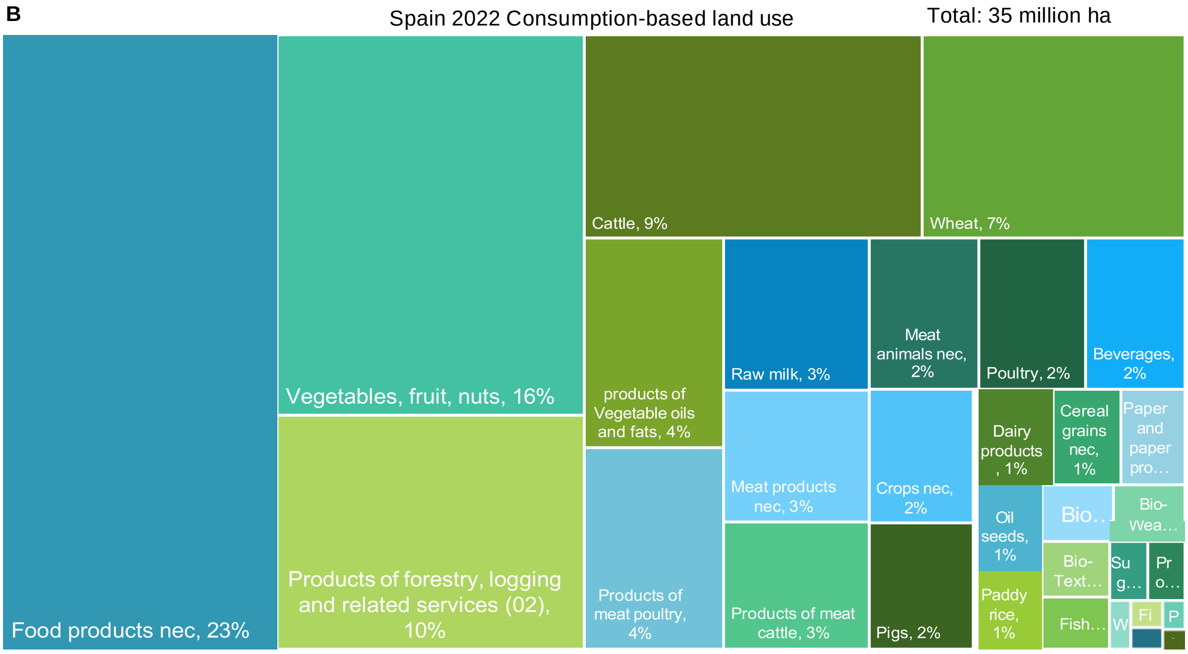
Definition of *Primary solid biofuels*:
Primary solid biofuels are defined as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes, and other solid biofuels). Note that for biofuels, only the amounts of biomass specifically used for energy purposes (a small part of the total) are included in the energy statistics. Therefore, the non-energy use of biomass is not taken into consideration, and the quantities are null by definition.

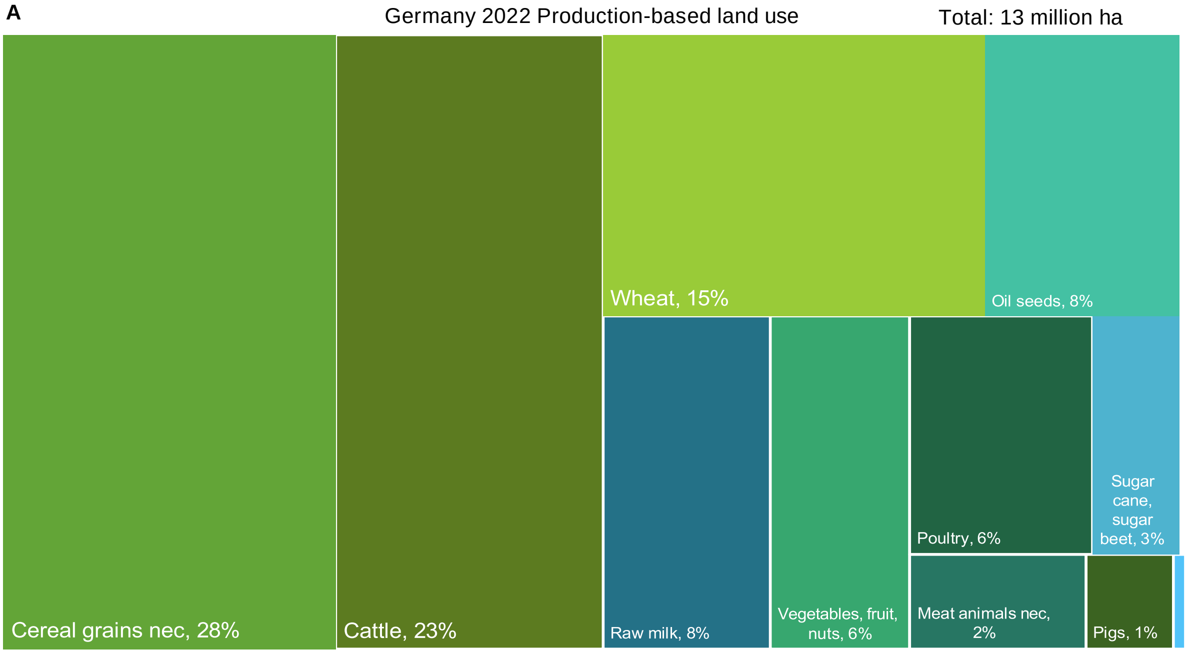
A4. Sector level drivers (production- and consumption-based) of land use and water use

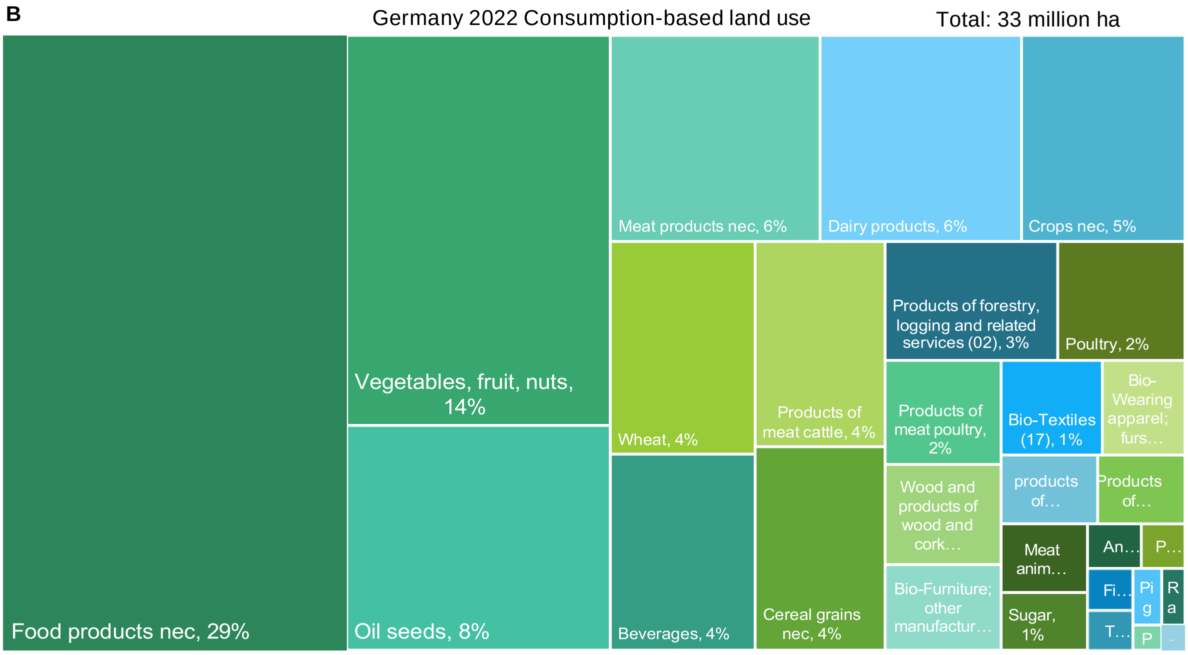


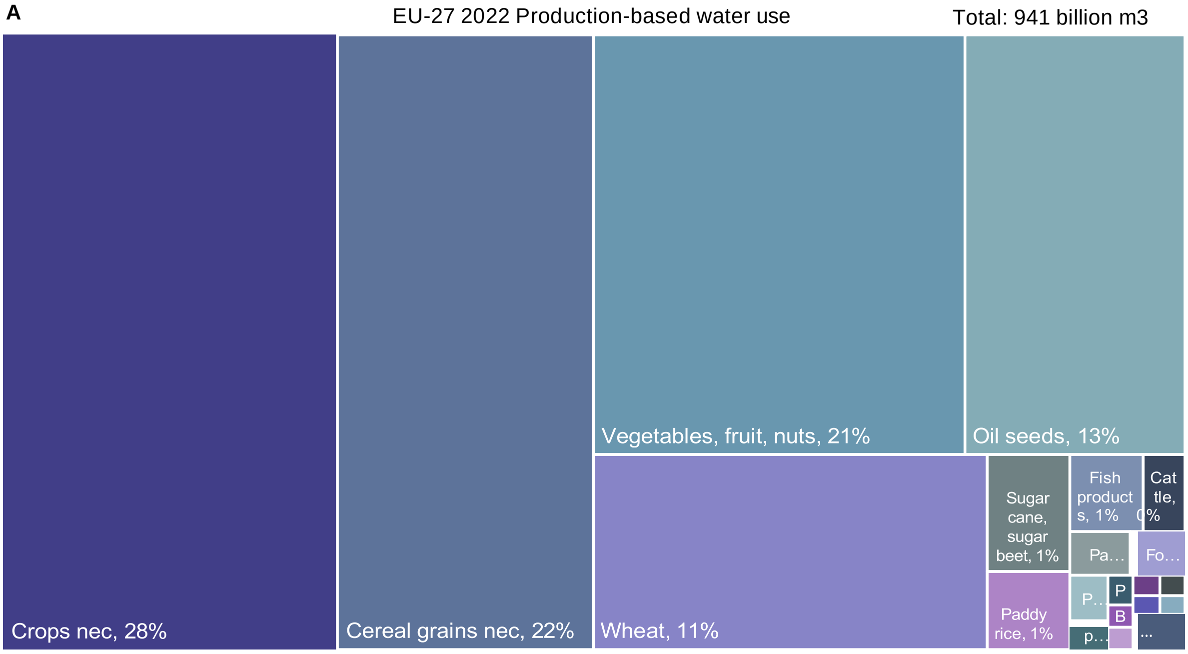


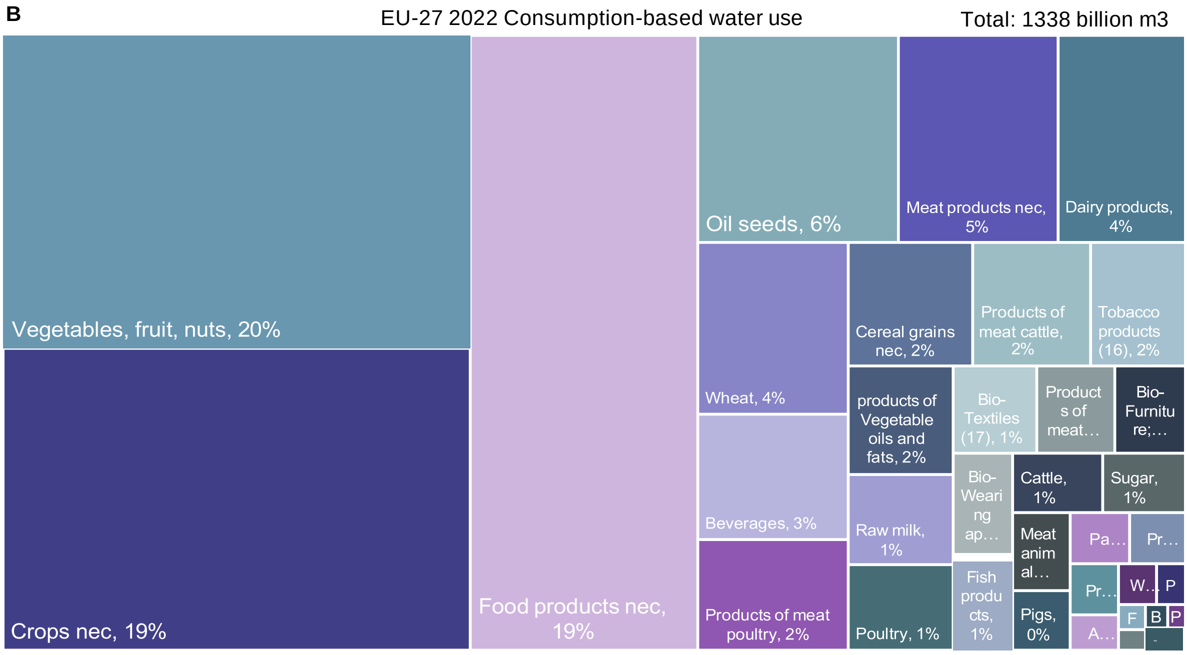

A
Spain 2022 Production-based land use
Total: 40 million ha
Cattle, 17%
Cereal grains nec, 15%
Products of forestry, logging and related services (02), 13%
Vegetables, fruit, nuts, 12%
Oil seeds, 16%
Raw milk, 15%
Meat animals nec, 6%
Wheat, 5%
Paddy rice, 1%


B
Spain 2022 Consumption-based land use
Total: 35 million ha
Food products nec, 23%
Vegetables, fruit, nuts, 16%
Products of forestry, logging and related services (02), 10%
Cattle, 9%
Wheat, 7%
products of Vegetable oils and fats, 4%
Raw milk, 3%
Meat animals nec, 2%
Poultry, 2%
Beverages, 2%
Products of meat poultry, 4%
Meat products nec, 3%
Crops nec, 2%
Products of meat cattle, 3%
Pigs, 2%
Dairy products , 1%
Cereal grains nec, 1%
Paper and paper pro…
Oil seeds, 1%
Paddy rice, 1%
Bio-Wea…
Bio-Text…
Fish…


A
Germany 2022 Production-based land use
Total: 13 million ha
Cereal grains nec, 28%
Cattle, 23%
Wheat, 15%
Oil seeds, 8%
Raw milk, 8%
Vegetables, fruit, nuts, 6%
Poultry, 6%
Sugar cane, sugar beet, 3%
Meat animals nec, 2%
Pigs, 1%


B
Germany 2022 Consumption-based land use
Total: 33 million ha
Food products nec, 29%
Vegetables, fruit, nuts, 14%
Oil seeds, 8%
Meat products nec, 6%
Dairy products, 6%
Crops nec, 5%
Wheat, 4%
Products of meat cattle, 4%
Products of forestry, logging and related services (02), 3%
Poultry, 2%
Products of meat poultry, 2%
Bio-Textiles (17), 1%
Bio-Wearing apparel; furs…
Wood and products of wood and cork…
products of…
Products of…
Beverages, 4%
Cereal grains nec, 4%
Bio-Furniture; other manufactur…
Meat anim…
An…
P…
Fi…
Pi g
R a
Sugar, 1%
T…
P


A
EU-27 2022 Production-based water use
Total: 941 billion m3
Crops nec, 28%
Cereal grains nec, 22%
Vegetables, fruit, nuts, 21%
Oil seeds, 13%
Wheat, 11%
Sugar cane, sugar beet, 1%
Fish products, 1%
Cattle, 0%
Pa…
Fo…
Paddy rice, 1%
P…
P
B
p…
...


B
EU-27 2022 Consumption-based water use
Total: 1338 billion m3
Vegetables, fruit, nuts, 20%
Crops nec, 19%
Food products nec, 19%
Oil seeds, 6%
Meat products nec, 5%
Dairy products, 4%
Wheat, 4%
Cereal grains nec, 2%
Products of meat cattle, 2%
Tobacco products (16), 2%
Beverages, 3%
products of Vegetable oils and fats, 2%
Bio-Textiles (17), 1%
Products of meat…
Bio-Furniture;…
Raw milk, 1%
Bio-Wearing ap…
Cattle, 1%
Sugar, 1%
Meat animal…
Pa…
Pr…
Products of meat poultry, 2%
Poultry, 1%
Fish products, 1%
Pigs, 0%
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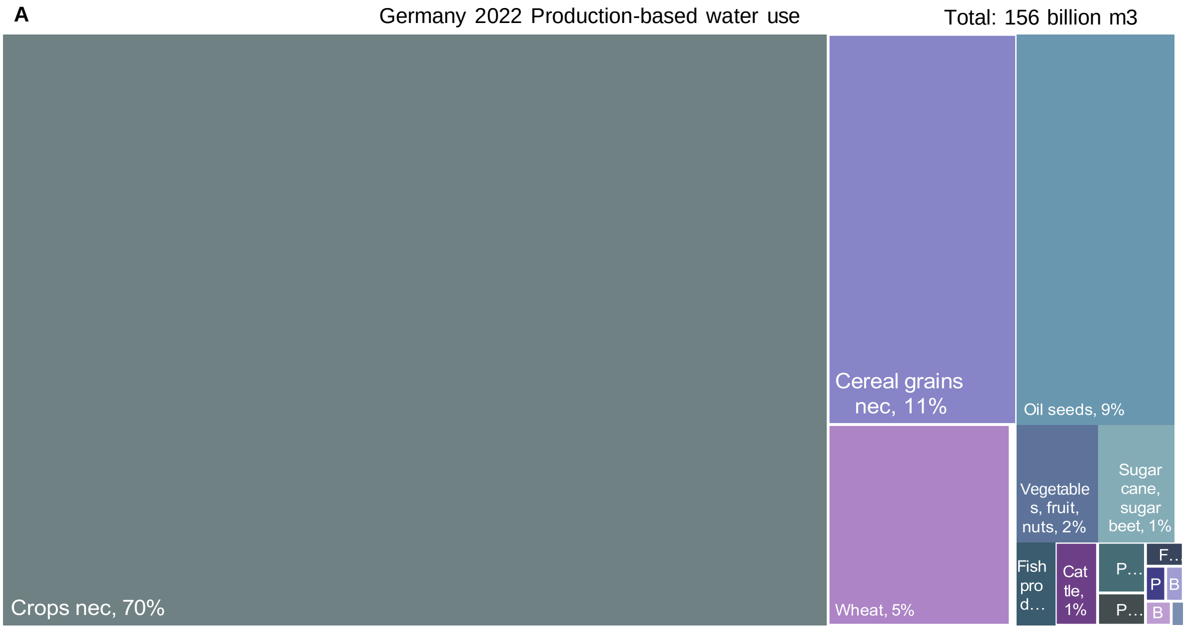
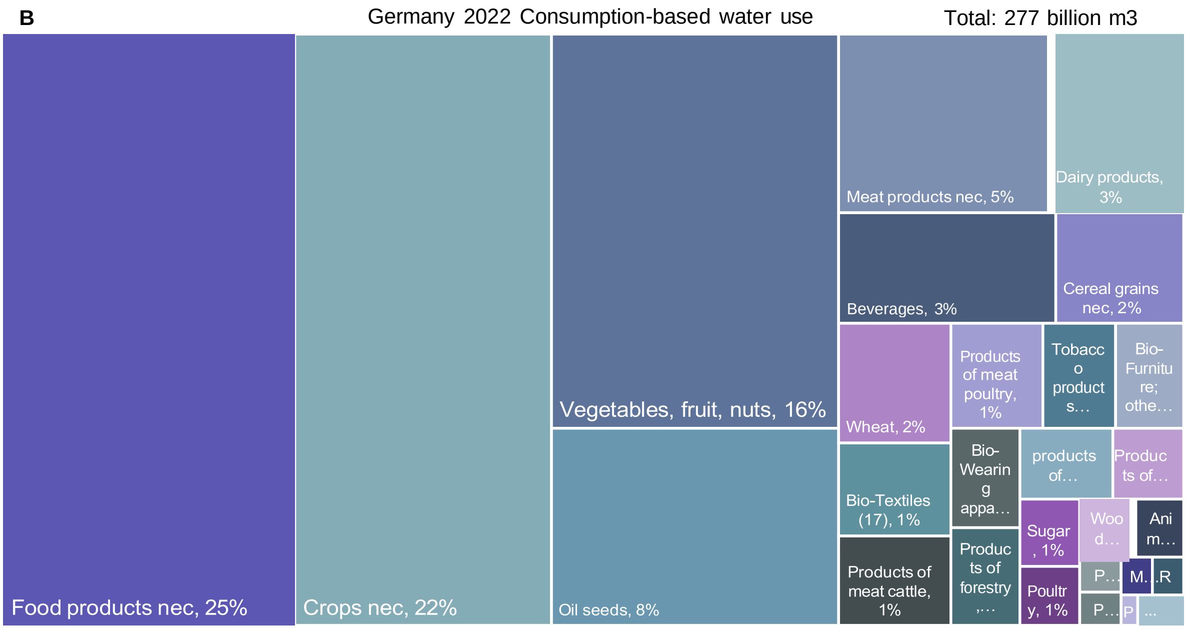

A
Germany 2022 Production-based water use
Total: 156 billion m3
Crops nec, 70%
Cereal grains nec, 11%
Oil seeds, 9%
Wheat, 5%
Vegetables, fruit, nuts, 2%
Sugar cane, sugar beet, 1%
Fish prod…
Cattle, 1%


B
Germany 2022 Consumption-based water use
Total: 277 billion m3
Food products nec, 25%
Crops nec, 22%
Vegetables, fruit, nuts, 16%
Oil seeds, 8%
Meat products nec, 5%
Dairy products, 3%
Beverages, 3%
Cereal grains nec, 2%
Wheat, 2%
Products of meat poultry, 1%
Tobacco products…
Bio-Furniture; othe…
Bio-Textiles (17), 1%
Bio-Wearing appa…
products of…
Products of…
Products of meat cattle, 1%
Products of forestry, …
Sugar, 1%
Wood…
Anim…
Poultry, 1%