# Making globalisation and trade work for people and planet: International spillovers embodied in EU's food supply chains

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# Contents

# SUMMARY

Human demand for agri-food products contributes to environmental degradation in the form of land-use impacts and emissions into the atmosphere. Development and implementation of suitable policy instruments to mitigate these impacts requires robust and timely statistics at sectoral, regional, and global levels. In this study, we quantify emissions (carbon dioxide, particulate matter, sulphur dioxide, nitrous oxide), land use, employment, and income-related impacts embodied in European Union's (EU's) demand for agri-food products. We trace these environmental and social impacts across EU's trading partners to identify specific sectors and regions as hotspots of international spillovers embodied in EU's food supply chains and find that these hotspots are wide-ranging in all continents. EU's food demand is responsible for 5% of the EU's total $CO_2$ consumption-based footprint, 9% of the total $NO_X$ footprint, 16% of the total PM footprint, 6% of the total $SO_2$ footprint, 46% of the total land-use footprint, 13% of the total employment footprint, and 5% of the total income footprint. Our results serve to inform future reforms in the EU for aligning policies and strategies with the SDGs and the objectives of the Paris Climate Agreement.

# INTRODUCTION

## The SDGs and Agri-food systems

The global agricultural industry faces a major challenge: the production of sufficient food to feed a growing population whilst ensuring that negative environmental impacts are addressed. This comes at the back of a growing demand for food, which is projected to increase by 35% to 56% by 2050, compared to 2010 levels (van Dijk et al. 2021).

Food is a necessity, hence it lies at the heart of many Sustainable Development Goals (SDGs). Food production and consumption are linked to SDG2 (Zero hunger) on ending hunger and achieving food security; SDG3 (Good health and well-being) on addressing overnutrition and malnutrition; SDG12 (Responsible Production and Consumption) on addressing the negative unintended consequences such as food waste, emissions, land-use, which in-turn link indirectly to SDG6 (Clean water and sanitation), SDG13 (Climate action) for reducing carbon dioxide and air pollution, SDG15 (Life on land) for accounting for biodiversity threats, SDG8 (Decent work and economic growth) on employment in the agricultural sector, and much more. Food is a common thread that directly or indirectly links all 17 SDGs. Considering the interconnected environmental, social, and economic dimensions of food systems, access to food supply and managing the associated negative impacts of food production (e.g., emissions and land-use) are major societal challenges.

Food systems are responsible for about a third of global greenhouse gas emissions (Crippa et al. 2021a). These emissions are due to the production of primary food commodities (e.g., crops, livestock for meat, fisheries, animal feed) and further processing and transport of food, waste management, and industrial processes (Poore and Nemecek 2018; Crippa et al. 2021a). It is well documented that plant-based foods emit about 10–50 times less carbon dioxide than animal-based foods (Ritchie and Roser 2020). An integrated assessment of food production and consumption, and the associated impacts on the environment and human health by Malley et al. (2021), highlight the intricacies of the interconnected system – food is vital for good health and well-being; however, emissions resulting from food production indirectly impact human health via exposure to harmful agricultural pollutants. This clearly shows that any policy directed at transforming food systems will have follow-on effects on other SDGs.

Multiple studies have been undertaken at regional, national, and global scales to assess the environmental and socio-economic impacts associated with food production and consumption (Foster et al. 2007; Sala et al. 2017; Eberle and Fels 2016; Usva et al. 2009; Mosier et al. 2013; Tonini et al. 2018; Kastner et al. 2012), and specifically in relation to diets (Baroni et al. 2007). Crippa et al. (2021a) developed a comprehensive food emissions database at a global level for assessing the contribution of food systems to anthropogenic greenhouse gas emissions, including temporal trends. With expansion of agriculture, there has also been a drastic increase in irrigated land area and cropland area

(Tilman 1999). Nearly half of the world's habitable land is used for agriculture (Ritchie and Roser 2020).

## Agri-food systems and the EU context

Quantification of impacts of food production and consumption is typically undertaken using bottom-up methods, such as life-cycle assessment-based techniques, or top-down approaches, such as input-output analysis. Assessments that cover supply chain impacts tend to utilise input-output analysis, as the technique offers the ability to account for hidden hotspots in upstream interconnected economic networks. This technique has particularly been used for assessing environmental and socio-economic impacts embodied in international supply chains (Wiedmann and Lenzen 2018). More recently, Boylan et al. (2020) showcased the use of input-output analysis in measuring not just the sustainability of food systems, but also nutrition, diets, resilience, and vulnerability. The Global Commons Stewardship (GCS) Index, measures countries' domestic and spillover impacts on the Global Commons (SDSN et al. 2021).

In this study, we assess international spillover impacts embodied in the European Union's (EU) food supply chains, i.e., impacts that take place in other countries because of the EU's demand for food products, with key insights from publications by the European Commission (2020a, 2020b, 2021a – 2021i), global reports, and academic works. Trade, including that of food products, is a major source of income and a driver of prosperity in many low and middle-income countries. At the same time, negative cross-border impacts, known as spillovers, can undermine the ability of the global community to achieve the SDGs (Sachs et al. 2021a). The EU is the third largest importer of food products in the world. In 2020, the region imported 122 billion € of agri-food products (European Commission 2021a). Out of the 20 top performers in the SDG Index, 19 are European countries. However, European countries perform poorly on the subset of indicators used to compile the International Spillover Index, which covers impacts embodied into trade. Strengthening policy coherence, as emphasized under SDG17 (Partnerships for the Goals), calls for robust indicator frameworks and ambitious policy measures to clean-up unsustainable supply chains to align them with the SDGs and the Paris Climate Agreement.

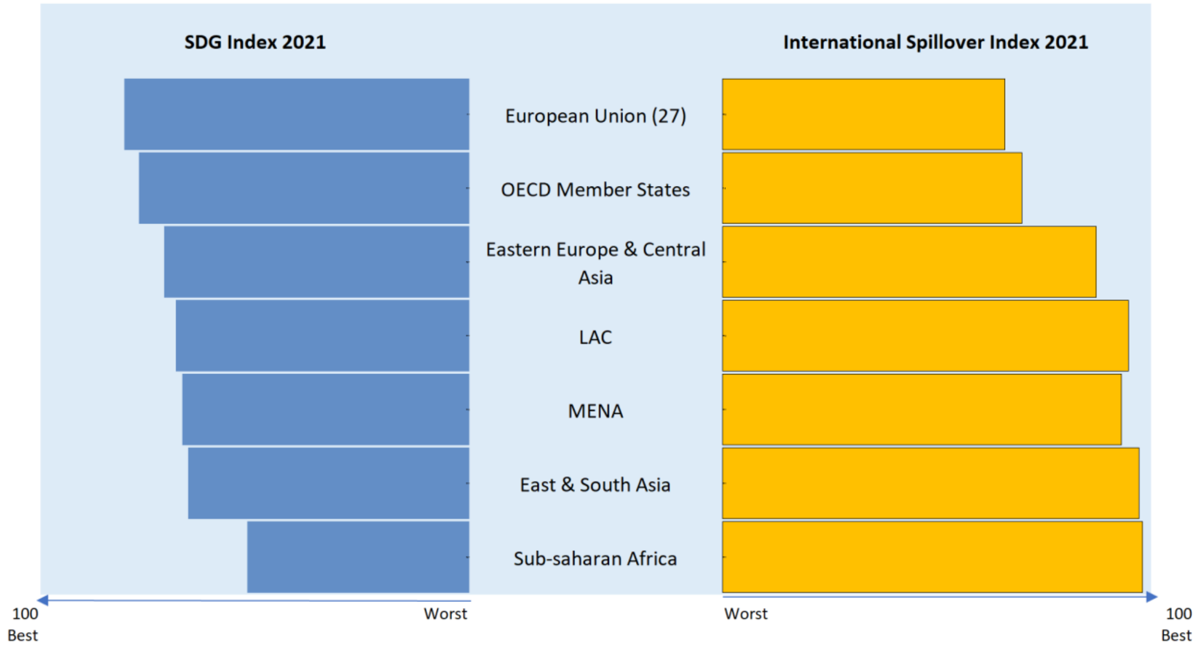


**Figure 1. EU27 performance on the 2021 Sustainable Development Goals Index and International Spillover Index compared with other world regions and OECD Member States**

*Note: The Spillover Index measures transboundary impacts generated by one country that affect the ability of other countries to achieve the SDGs. The Spillover Index incorporates environmental and social impacts embodied in trade and consumption (negative spillovers include $CO_2$ emissions, biodiversity threats, and accidents at work), financial spillovers (such as financial secrecy and profit shifting), and security/development cooperation spillovers (Official Development Assistance and weapons exports). ODA is an example of a positive spillover. Scores should be interpreted in the same way as the SDG Index, ranging from 0 (worst performance/significant negative spillovers) to 100 (best possible performance/no significant negative spillovers). To allow for international comparisons, most spillover indicators are expressed on a per capita basis. The Spillover Index scores and ranks are available online at www.sdgindex.org. Source: Figure and legend taken verbatim from Sachs et al. (2021a).*

## Objectives

For gaining insights on the sustainability aspects of EU's food demand, we first provide an overview of the magnitude of consumption-based environmental impacts in the EU food supply chain, focusing on carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), nitrous oxide ($NO_X$), particulate matter (PM), and land use. We also present estimates of income and employment generated globally to satisfy EU's consumption of food products. We then quantify intra-EU spillovers and spillovers generated outside of the EU's border. Finally, by focusing on spillovers generated outside of the EU, we identify the regions and countries most affected and specific commodities that drive these negative impacts. The discussion section highlights some of the challenges and priorities for the EU leadership, governments, businesses, and consumers to monitor and address negative food-related spillovers. We also emphasise the need to accelerate the transition towards more sustainable food production, supply chains, and diets.

# MEASURING SPILLOVERS

Measurement of spillovers involves quantifying impacts embodied in international supply chains. This quantification can be carried out using a technique called input-output analysis, which was first formulated by the Nobel Prize Laureate Wassily Leontief (Leontief 1936) for the United States. Over the years, there have been numerous innovations in the application of this technique – one of which is the development of multi-regional input-output (MRIO) databases.

As the name suggests, MRIO databases offer coverage of more than one region (a true advancement from the first national table that Wassily Leontief created for the US economy). Global MRIO databases provide detail on imports and exports between different countries, and hence are ideal for assessments related to spillover impacts. It is worth noting that the term 'spillover impacts' refers to any environmental, social, or economic impacts that are embodied in supply chains that connect producers with consumers at an international level. With an increase in globalisation and international trade, global imports/exports have been rising, as well as the associated impacts. Such assessments have been undertaken for a number of indicators, such as emissions (Kanemoto et al. 2014; Malik and Lan 2016), water use (Lenzen et al. 2013; Soligno et al. 2019), land use (Moran et al. 2013), nitrogen (Oita et al. 2016), child labour (Gómez-Paredes et al. 2016), employment (Alsamawi et al. 2014a), inequality (Alsamawi et al. 2014b), corruption (Xiao et al. 2018), occupational hazards (Alsamawi et al. 2017), and much more (Wiedmann and Lenzen 2018). In the case of the European Union (EU), social spillover impacts are embodied in textile supply chains (Malik et al. 2020). The 2021 GCS Index offers an overview of environmental impacts generated by the EU on the Global Commons, with an in-depth contribution analysis of five impacts: GHG emissions, black carbon emissions, land use biodiversity loss, nitrogen surplus, and water stress of crops (SDSN et al, 2021).

MRIO-based quantification of spillover impacts for the EU involves unravelling international supply chains to identify which regions and sectors produce commodities that are eventually destined for consumption in the EU – and what impacts (environmental/social/economic) are embodied in the supply chains. This requires an MRIO database with specific detail on each of the 27 EU member states: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden (Europa EU 2020), as well as details on the rest-of-the-world (RoW). The regional and sectoral composition of the RoW region varies across MRIO databases (Tukker and Dietzenbacher 2013). In this study, we choose an MRIO database that features specific details on 27 EU states and 137 other individual countries, with 97 sectors for each country (Lenzen et al. 2021). This allows for a comprehensive assessment of spillover impacts stemming from EU consumption, and application of input-output equations to quantifying the environmental (e.g., emissions, land use), social (e.g., employment), and economic (e.g., income) impacts of EU's demand for food. The mathematical formulation for measuring spillovers is presented in the Supplementary Information.

We analyse seven distinct indicators: carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), nitrous oxide ($NO_X$), particulate matter (PM), land, employment, and income, taken from SCP-HAT (2021). Specifically, SCP-HAT features data on air pollutants ($SO_2$, $NO_X$, and PM) and $CO_2$ from the EDGAR database (Crippa et al. 2021b; Crippa et al. 2020). Emissions were allocated to the MRIO sectors by developing row- and column-normalised-mapping-matrices (Lenzen et al. 2012). Such mapping matrices convert sector classification using a suitable proxy variable to map an aggregated sector in EDGAR to several disaggregated sectors in SCP-HAT. Data on land-use feature six land use classes related to agriculture and forestry only - annual crops, permanent crops, pasture, extensive forestry, intensive forestry, and urban. For annual crops and permanent crops, data from the FAOSTAT land use database are used to normalise and allocate land use to sectors. Intensive and extensive forests' land use and evolving forests with extractive use is calculated using data from the Global Forest Resources Assessment (FAO 2020). Other land use classes (pasture and urban) are established based on the FAOSTAT land use database for land under permanent meadows and urban. Employment data are sourced from the International Labour Organization (ILO 2018).

# FINDINGS

## Overview at EU-27 level: *wide-ranging spillover effects*

The EU's demand for food products leads to significant environmental, social, and economic consumption-based impacts both domestically and abroad. Figure 2 presents these combined effects (impacts embodied in imports and due to domestic production) to highlight the relative contribution of EU's final consumption of food to environmental and social impacts. The EU's final demand for agriculture- and food-related commodities is responsible for 5% of the EU's total $CO_2$ footprint, 9% of the total $NO_X$ footprint, 16% of the total PM footprint, 6% of the total $SO_2$ footprint, 46% of the total land-use footprint, 13% of the total employment footprint, and 5% of the total income footprint[1]. When calculating these percentages, the 'total' footprint refers to the combined impacts of the EU's expenditure for all primary, secondary, and tertiary sectors. A time-series analysis of EU's food-related $CO_2$ footprint reveals that the total consumption-based emissions (domestic and imports) have decreased over time, however the import-component of the footprint has remained constant (Figure S2). An analysis of the import-component on a per-capita basis, along with a comparison with two key economies (USA and Russia) is presented in Table S1.

The EU is responsible for negative impacts in the form $CO_2$, $SO_2$, $NO_X$ emissions, and PM. These result from activities related to agriculture, burning of fossil fuels, energy use, industrial processes, and the transport sector, the use of land for agricultural production. EU's food demand also contributes to positive impacts such as job creation and income. These spillovers take place both within and outside the EU. We breakdown the consumption-based impacts of the EU's food demand into three components: direct impacts, first-order impacts, and indirect supply chain impacts. Here, direct impacts refer to those caused *directly* by sectors that link with suppliers of food commodities to the final consumers in the EU; first-order impacts are caused by food sectors' immediate suppliers. The impacts caused by suppliers of suppliers and all indirect supply chains are captured as the third band for every indicator in Figure 2. A notable finding is that the EU's food supply chains are not regionally concentrated: there are direct and first-order impacts, but most importantly there are significant impacts embodied in the EU's upstream supply chains and these originate in countries worldwide (Figure 4), for example export of Argentinian beef to the European Union.

The EU's demand for food causes environmental and social impacts ranging between 4 and 17% for the indicators considered in this study, except for the indicator land-use, where the impacts from food consumption are responsible for about 46% of the EU's total land-use impacts. Food systems are directly connected to global and social changes. For

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[1] *EU's final demand for agriculture- and food-related commodities is responsible for 6% of EU's import-only $CO_2$ spillovers, 7% of the total NOx import-only footprint, 13% of the PM footprint, 6% of the $SO_2$ footprint, 39% of the land-use footprint, 22% of the employment footprint and 7% of the income footprint*

example, the use of land for food production supports livelihoods and income to people. However, negative effects include the degradation of land and depletion of resources, which in turn undermines global food production. It is therefore paramount to recognize impacts embodied in supply chains from a regional and sectoral perspective (Figure 3, Figure S1) to understand trade-offs across the indicator suite for implementing appropriate strategies for safeguarding the food systems and the environment whilst ensuring social welfare.

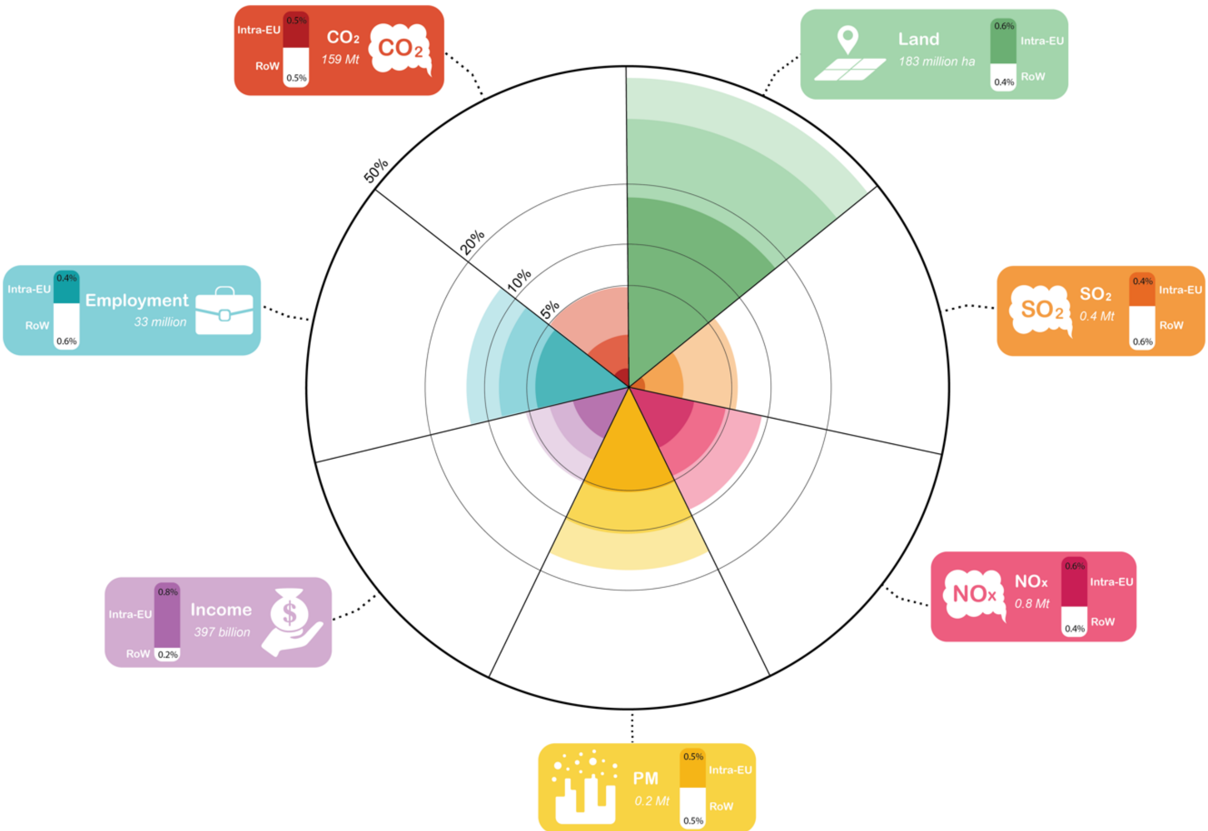



**Figure 2. Environmental, social and economic footprint of the EU's demand for food.** The total footprint of EU's expenditure on food-related sectors is broken down into direct (darkest shade), first-order (middle shade), and supply chain impacts (lightest shade) for all seven indicators analysed in the study. For example, the EU's food demand is responsible for about 5% of direct emissions of particulate matter (PM), 5% of PM emissions in the first-order and the remaining (16%) in upstream supply chains. The bar graphs represent the contribution of domestic production (intra-EU trade) or imports to the overall consumption-based footprint for the EU's food demand (Source: Authors' illustration). *Note: carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$), nitrous oxide ($NO_X$), particulate matter (PM) in Megatonnes (Mt); land in '000 hectares (ha); employment in million people; income in billion US$.*

## Overview at EU-27 level: *intra-EU impacts*

Intra-EU trade is a key feature of the EU's food production and consumption system. About two-thirds of food produced in the EU is consumed within the EU. The impacts are shown as a percentage in Figure 2 (see bar graphs for each indicator, categorised into impacts from domestic production and from imports). Germany, Netherlands, France, Italy, Belgium, and Spain are key EU countries that account for most of the intra-EU trade. Out of these economies, Germany constitutes 25% of total food imports from non-EU countries. Germany also imports food from EU nations, notably spending 23 billion US$ on food products from Netherlands in 2019. This included vegetables, dairy products, bakery products, seeds, and other agriculture-related products (ATLAS 2021). Pigłowski (2021) and Alatriste-Contreras (2015) provide a detailed assessment of intra-EU trade relationships, including commodity-level detail on traded products. Since the focus of this study is to quantify international impacts embodied in EU's food supply chains, the following sections feature findings on environmental impacts that take place outside of the EU for satisfying the EU's demand for food.

## International spillovers: *regional level*

We perform a production layer decomposition for quantifying impacts embodied in up-stream food supply chains of the EU, with a specific focus on supply chains that originate in regions outside of the EU (Figure 3). To this end, we decompose the total impacts of EU's food consumption into the domestic and imports-component over eight upstream layers of production and plot the imports-component at a regional level in Figure 3. We consider demand for fruits, vegetables, meat and fish products, dairy products, oil and fats, and other food products. The methodology for quantification of spillover effects allows for the analysis of direct and total requirements of these sectors. In other words, we appraise the direct and indirect inputs required by the food sectors by subjecting the MRIO database to input-output calculus (See section '*Measuring spillovers*).

Despite EU's well-established food production industry, considerable negative spillover impacts take place in international supply chains when satisfying the food demand of EU residents. Countries in Latin America, Asia-Pacific, Africa, and Eastern Europe and Central Asia experience environmental impacts associated with agri-food systems that produce exports for the EU market. International trade has been shown to be a growing driver of environmental degradation in developing and emerging economies, particularly for ful-filling the demands of the developed world (Wiedmann and Lenzen 2018). The impacts related to the indicators captured in this study have further flow-on effects. For example, land use leads to biodiversity threats due to livestock rearing and production (Marques et al. 2019) and particulate matter deteriorates air quality leading to health impacts on respiratory and cardiovascular systems, among others (Kim et al. 2015).

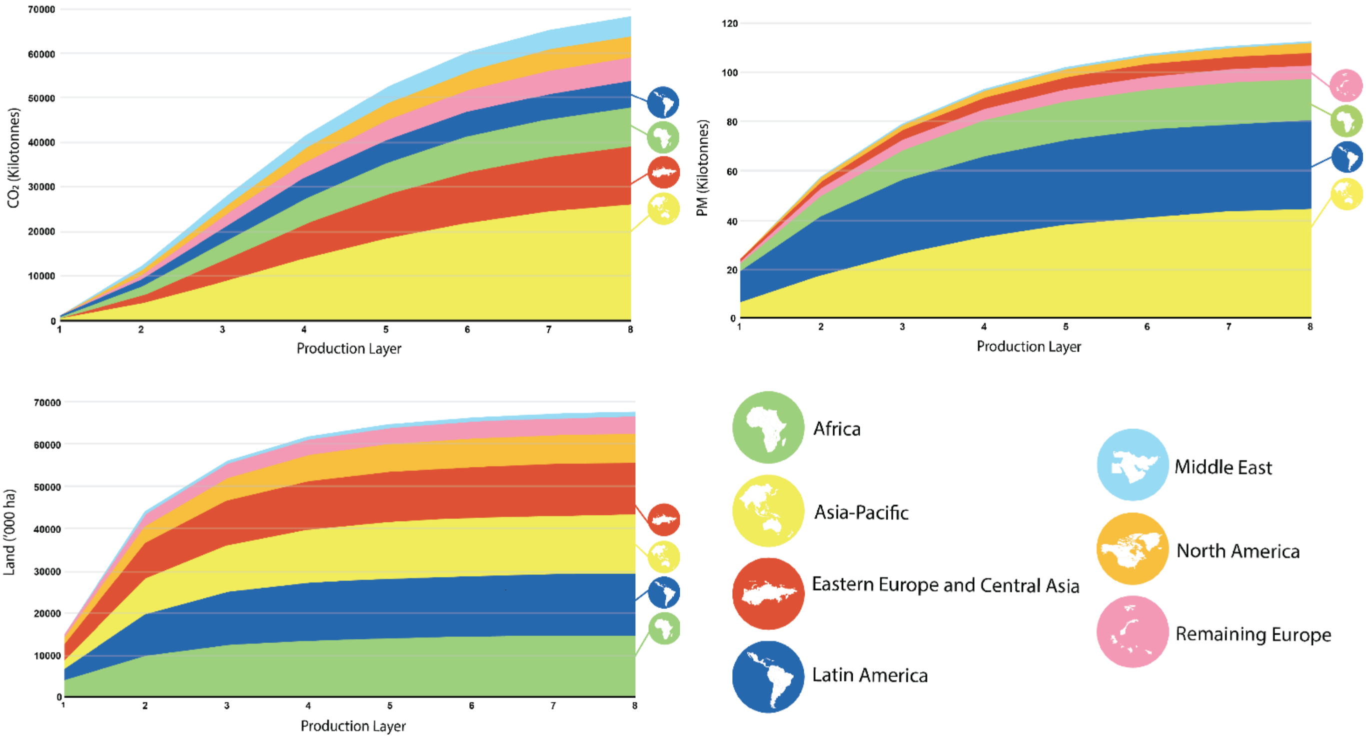



**Figure 3. Production Layer Decomposition showing supply chain impacts for selected indicators: carbon dioxide, particulate matter, and land use** (Source: Authors' illustration).

## International spillovers: *country and sector level*

EU's international trade links originate in countries worldwide (Figure 3). China and the EU trade over 1 billion € worth of goods every day, ranging from industrial and consumer goods to machinery and equipment (European Commission 2021f), alongside some food products. Vietnam exported about 53 million US$ worth of coconuts, brazil nuts, and cashew nuts to France in 2019 (ATLAS 2021). India's exports to the European Union include coffee, tea, rice, tobacco, and oils (European Commission 2021g).

In Latin America, Brazil is an exporter of soybeans and related products to the EU member states. This has been linked to illegal deforestation in the Amazon and Cerrado, with evident policy implications for the EU (Rajão et al. 2020). Argentina exports beef to the EU, with Germany the top destination (Federal Foreign Office 2021). Italy imports Molluscs from Peru and bananas and plantains from Columbia (ATLAS 2021). The EU is the second largest export market of Mexico, with fruits (e.g., avocados, pineapples, mangoes) making up the key export food commodity (European Commission 2021h). The EU also trades with Africa: Germany imports about 50 million US$ worth of cocoa butter, 30 million US$ of cocoa beans, and about 26 million US$ of cocoa paste from Ghana; France imports vegetables (27 million US$), legumes (21 million US$), and fruits from Kenya; Italy imports 89 million US$ worth of coffee from Uganda; additionally, Germany imports tobacco, tea, and vegetables from Zimbabwe. These are some of many international transactions that take place in the world economy for satisfying EU's demand for food, in turn resulting in spillover impacts (Figure 3, Figure 4).

From a sector-wise perspective, it is worth noting that spillover impacts do not just take place in agri-food sectors when satisfying EU's demand for food; instead, these happen across a range of primary, secondary, and tertiary sectors in EU's trading partners during agri-food production for the EU. Figure 5 shows the environmental spillover impacts for ten broad sectors of non-EU countries for producing agri-food products. Evidently, a considerable percentage of impacts happen in fuel, energy, and transport sectors. Electricity and gas are used as inputs in manufacturing and food processing industries for producing cereals, mixed foods, sugar refining, vegetable oils and fats, dairy products, beverages, and tobacco products. Production of fuels and electricity in-turn requires input of coal mining, which relies on the construction sector for sourcing large-scale mining equipment, and so forth. Evidently, industry sectors are inter-related – the footprint for German demand for non-EU meat includes impacts at various links of the beef supply chains, from the purchase of electricity for running cattle farms to cattle handling equipment, water storage tanks, production of shipping crates, and much more (Foster and Stephenson 1922).

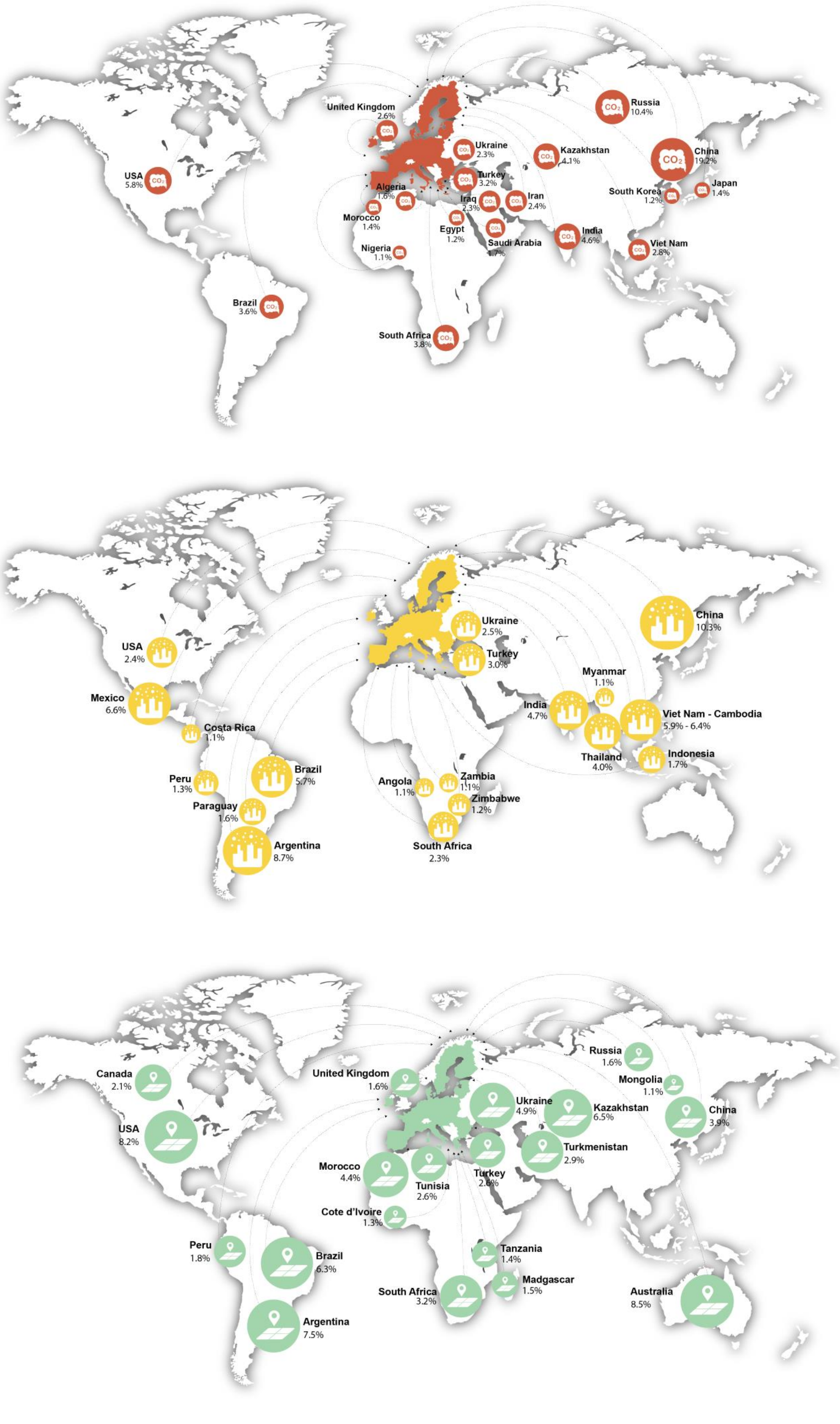



**Figure 4. Tracing spillovers for the European Union by country of origin of imports (indicators, in order: carbon dioxide, Particulate Matter and Land)** (Source: Authors' illustration).

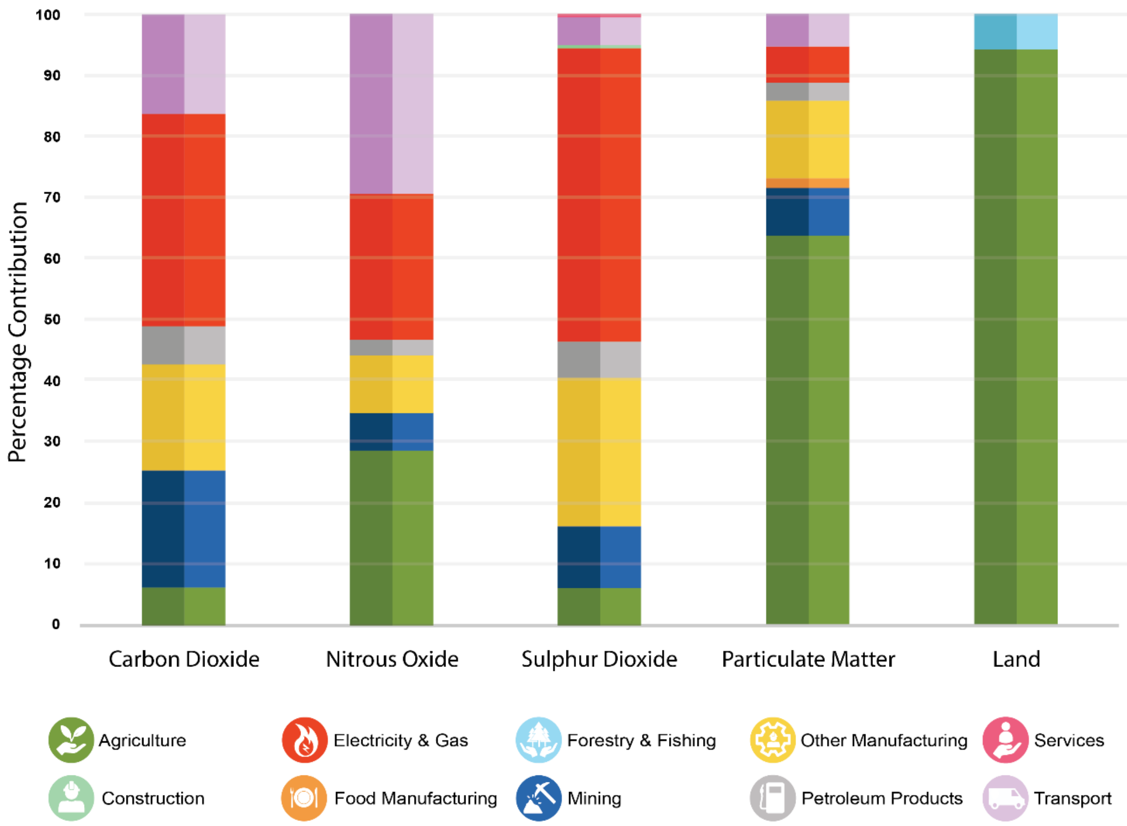



**Figure 5. Sector-level spillover impacts for environmental indicators, according to producing sectors that feed into EU's food supply chains** (Source: Authors' illustration).

## International spillovers: *countries responsible*

Breaking down the total footprint for the EU into constituents from respective EU member states reveals that Germany, France, and Italy are responsible for the bulk of the environmental spillover impacts outside of the EU (Figure 6). This is because of the size of these economies and the high volume of imports into them (ATLAS 2021). The high volume of imports from non-EU countries is taken as the final demand stressor in the footprint equation for calculating spillovers. Since the Leontief input-output model is a demand-pull model, the higher the demand for fruits, vegetables, beverages, meat, and other products from outside the EU, the higher the value of imports and associated land-use impacts and emissions. Identification of EU nations that are responsible for these impacts is essential for targeted action, as outlined in the following section.

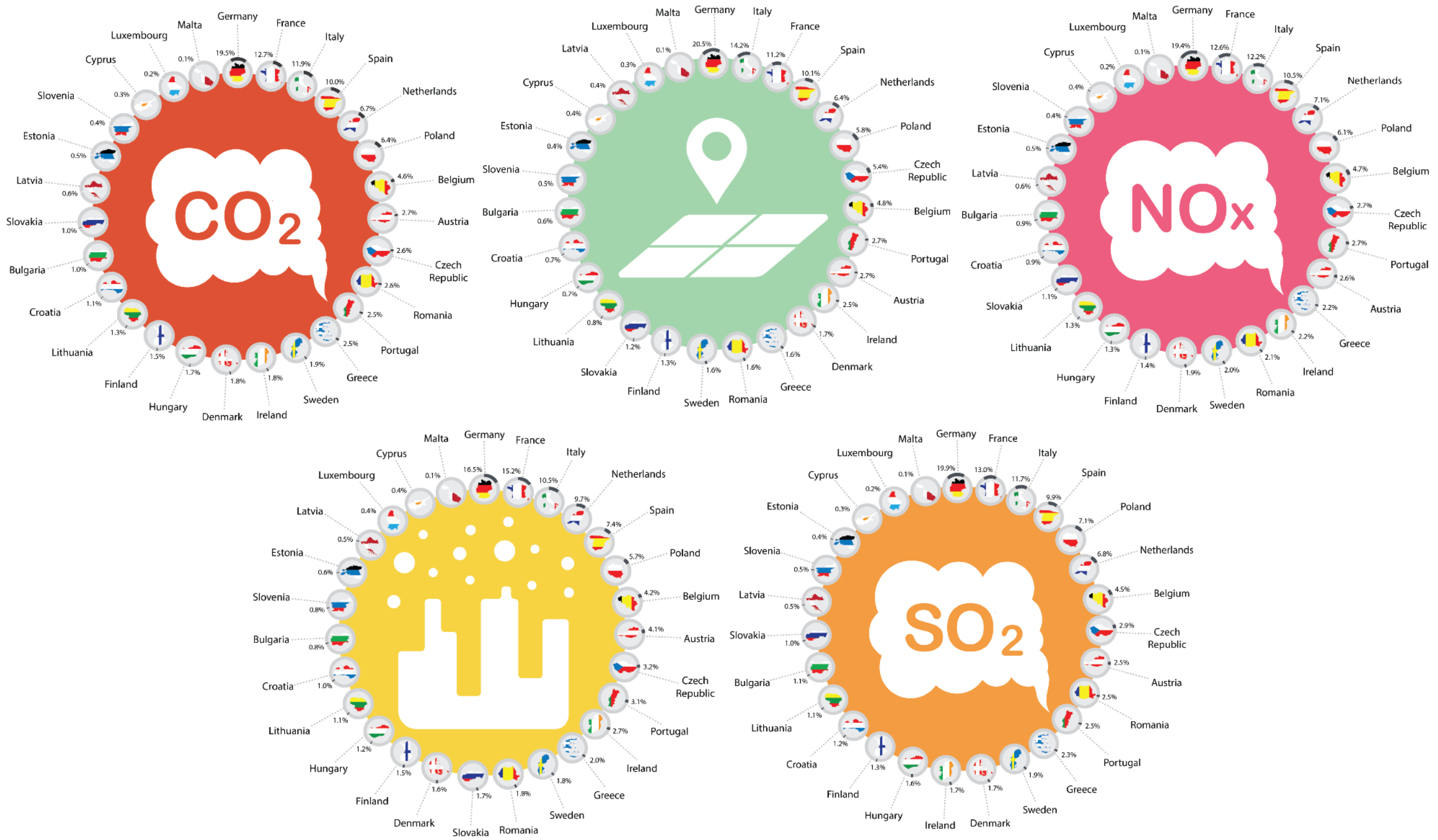



**Figure 6. Contribution of 27 European Union Member states to international spillover effects. The percentages reflect the role of EU states in driving spillover effects in countries outside of the EU** (Source: Authors' illustration).

# DISCUSSION

The previous section highlights that the negative environmental impacts ($CO_2$, PM, land-use, $SO_2$, and $NO_X$) embodied into EU's imports of food products are significant and related in particular to imports of "Meat and Fish", "Livestock Farming", and "Crop Growing". Such impacts take place primarily in the Asia-Pacific (including China), Eastern Europe and Central Asia, Africa, and Latin America (in particular Argentina and Brazil). We underline the importance of addressing spillovers in the context of the SDGs and the Paris Climate Agreement. This section discusses priorities to address the effects on food supply chains that take place abroad to satisfy the EU's consumption. It is beyond the scope of this study to review in detail the level of ambition and implementation of all strategies, directives, and policies related to strengthening the productivity and sustainability of the agri-food system in the EU (such as the Farm To Fork strategy or the Common Agricultural Policy). Instead, we pinpoint high-level priorities for strengthening the sustainability of food supply chains for three major constituencies: (1) The European Commission and individual Member States; (2) Food industry and companies; and (3) Consumers to reduce negative spillovers embodied into the food supply chain. Focus is placed on imported air pollutants and $CO_2$ emissions and on biodiversity threats (including through land-use and deforestation (Marques et al. 2019)). Note that we do not intend to present *embodied land area* as a proxy for *embodied biodiversity impacts* (see (Chaudhary and Kastner 2016) for a detailed analysis).

## European Commission and individual EU Member States

Since 2019, the leadership of the European Union has repeatedly voiced its ambition to promote open, fair, and sustainable trade policies and to promote European values through trade. Trade policy is an exclusive EU competence. In February 2021, the European Commission published its 'Trade Policy Review - An Open, Sustainable and Assertive Trade Policy' (European Commission 2021i). It notably suggests that "*for future trade agreements, the Commission will propose a* ***chapter on sustainable food systems***". It identifies as a headline action the need to "*seek commitments from G20 partners on climate neutrality, strengthen cooperation on other aspects of the green deal such as biodiversity,* ***sustainable food policy****, pollution and the circular economy, and propose to make the respect of the Paris agreement an essential element in all future agreements*." In July 2021, the European Commission adopted the new EU Forest strategy where it reaffirms its full commitment to ensure that products, both from the EU and from third countries, sold on the EU market do not contribute to global deforestation (European Commission 2021b). Consultations on the "*Trade and Sustainable Development (TSD)*" were terminated in November 2021. Tailor-made TSD chapters with partners, supported by robust indicator frameworks, timelines, targets, and ratchet-up mechanisms, can help align trade partnerships and policies with the specific environmental challenges of each country or region (IEEP 2021).

The adoption of the 'European Green Deal' and 'Fit for 55 Package' clarified the climate ambitions of the EU but also propelled the debates around policy coherence for sustainable development and the risks of carbon leakages at the forefront of EU policy debates. Among the policy measures considered, the proposal from the European Commission, published in July 2021, was to apply a carbon border adjustment mechanism (CBAM) to a few selected products first (possibly cement, electricity, fertilisers, iron & steel, and aluminium products) and gradually extend the number of products covered in compliance with the WTO rules (European Commission 2021c). As of this writing, it remains unclear how emissions from deforestation and land use will be accounted in the final version of the CBAM. The French Government, which will have the Presidency of the EU Council as of January 2022, has already stated publicly that they will make it a priority to "*tighten controls on agricultural imports of the EU27 in order to impose European environmental standards*" (agence Europe 2021). EU farmers and food producers have long complained about the unfair competition with imported products from countries with lower environmental, food safety, and animal welfare regulation.

EU trade reforms and new mechanisms, such as the CBAM and mirror clauses to deal with imported deforestation, might help with addressing some of the negative environmental impacts embodied into EU's trade and strengthen policy coherence. However, they must go hand in hand with **clear communications and measures to support the transformation of energy and production systems in partner countries**. This will help prevent accusations of "*protectionism*". The EU is already the largest provider of Official Development Assistance (ODA) (European Commission 2020b), although many individual Member States have still not achieved the target of dedicating 0.7% of their Gross National Income (GNI) to ODA. The EU is also the largest provider of aid for trade (European Commission 2021d). Yet, rich countries, including several EU Member States, fell short in delivering on their commitment to mobilize US$100 billion each year by 2020, to help poorer countries adapt to climate change and mitigate further rises in temperature. France has transferred more than its fair share, but it is mostly in the form of repayable loans and not grants (Timperley 2021). Channelling parts of the revenues generated by the CBAM (and other border adjustment measures) to the green transition worldwide could potentially be an effective way to avoid the protectionist trap (OXFAM 2021).

Besides ODA and financial instruments, and as emphasized in the Farm to Fork Strategy (European Commission 2021e), SDG/Green Deal Diplomacy (SDSN and IEEP 2020) and strengthening technical cooperation, including via the transfer of green technologies to partner countries can also help partner countries move towards more sustainable production and agri-food systems. Finally, the EU should continue to promote the global transition to sustainable food systems in international standard setting bodies and fora and strengthen regional and bilateral partnerships, especially with China, Africa, and Latin America, to support the transition to more sustainable food systems globally.

## Food industry and companies

Agri-food companies engaged at various stages of the food supply chains (production, trade, processing, final sale) have a major role to play to promote a more sustainable food system. A review conducted in 2021 by SDSN and partners of the 100 largest food companies (including many European companies and companies operating in the EU) highlighted major gaps in companies' commitments, measures, and contributions to the transition towards more sustainable food systems. In particular, the review revealed significant variations in the scope and coverage of sustainability reporting and ambitions and an absence of relevant Key Performance Indicators (KPIs) and timelines for monitoring and addressing impacts generated by business partners/suppliers across the supply chains. Only 5% of the companies surveyed, disclosed targets, years, and timelines for 'Sustainable Management of the Supply Chain' in their sustainability reports. 10% of the companies have KPIs to monitor deforestation and disqualify suppliers for non-compliance with basic sustainability criteria (Sachs et al. 2021b). Focusing on one specific food commodity – soy products – responsible for a significant share of the EU's imported GHG emissions and deforestation, Climate Focus and SDSN also highlighted the lack of meaningful indicators and targets in companies' sustainability reports to address adverse impacts on climate and biodiversity across the supply chain (Streck et al. 2019).

The SDSN and partners published its Four Pillar Framework to support the transformation of the food sector and companies' reporting aligned with the SDGs (Box 1). The Framework aims to offer practical steps for companies to align their business activities and operations with the SDGs and can also be used by investors and for informing corporate benchmarks.

The forthcoming EU Due Diligence regulation may help strengthen the sustainability of EU's trade including environmental impacts embodied into the food supply chains. Initially announced for the summer 2021, the adoption of the final text has been delayed. In March 2021, the European Parliament adopted a resolution setting out recommendations to the European Commission (EC) on corporate due diligence and accountability, including a draft directive. Aligned with the findings of many studies (for instance (European Commission 2020a)), the resolution notably underlines the need to go beyond voluntary requirements and move towards mandatory requirements for businesses to prevent, report, and address on a comprehensive set of environmental and social impacts. This may help promote the right "level-playing field" at the industry and company level.

Member States are also strengthening their legal instruments to target companies' negative impacts generated abroad, yet implementation and enforcement remain major challenges. Germany adopted its "Act on Corporate Due Diligence in Supply Chains" in June 2021, including binding obligations to report and address environmental and human rights impacts generated throughout supply chains. It covers companies with their registered office or principal place of business in Germany, as well as foreign companies that have a branch office in the country. The supply chain covers actions of a company in its own business sector, actions of a direct supplier and actions of an indirect supplier. The Act will come into force in January 2023. France adopted in 2017 a comprehensive Duty of Vigilance Law ("Devoir de vigilance"), yet, four years after its adoption some studies underline the lack of compliance by many companies. It is recommended to strengthen enforcement mechanisms (Sherpa 2021), including possibly through the creation of a dedicated supervisory authority.

Efforts to beef up the legislative arsenal in the EU to combat imported climate and biodiversity impacts (including deforestation) must be accompanied by further efforts by policy leaders, experts, and other stakeholders to support companies' efforts to report and take actions, including small and medium size companies, and to scale-up innovative solutions to address such impacts for companies inside and outside the EU.

**Box 1. The Four Pillar Framework for food companies' alignment with the SDGs**

The Four Pillar Framework published by SDSN and partners emphasizes the importance of four major pillars to monitor and address negative environmental (and social) impacts of food companies:

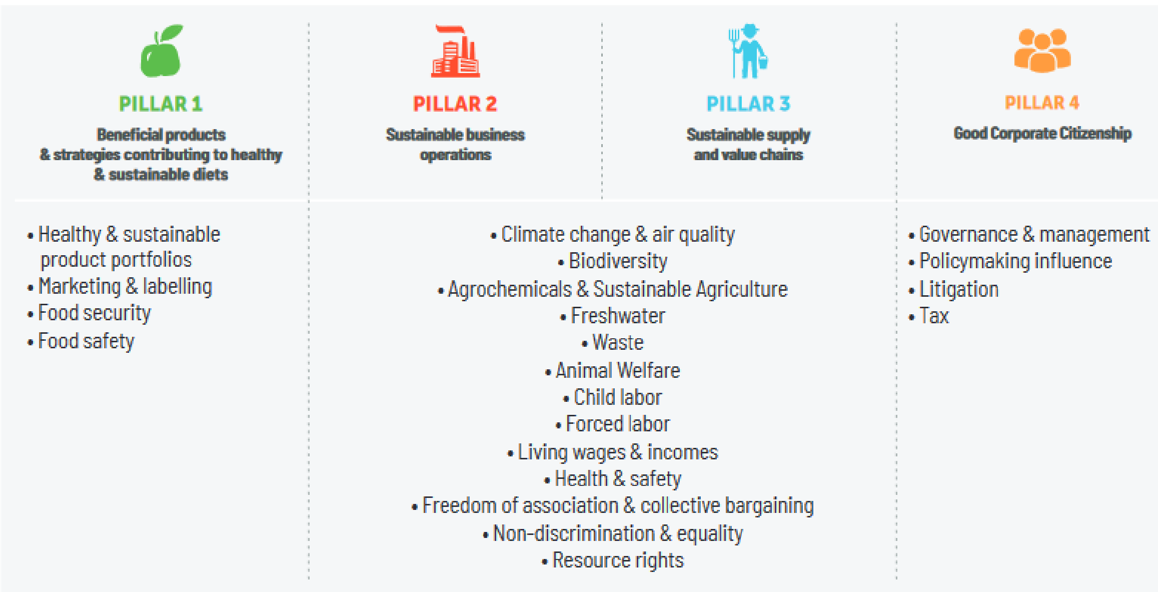
(1) Pillar 1 highlights the impact of a **company's products**, services, and strategies on human wellbeing and the planet's sustainability. For the food processing companies, this Pillar helps bring into focus the contributions to healthy and sustainable dietary patterns through their products and strategies. This includes whether food products are healthful, whether product marketing promotes health, and whether product use is conducive to well-being and supportive of improved living standards

(2) Pillar 2 includes the environmental and social impacts of **business operations** and the responsibility of companies to respect human rights, which improves the livelihoods of communities, workers, producers, and their families.

(3) Pillar 3 highlights the company's role in and responsibility to drive sustainable development across its **value chain**, including suppliers, producers, clients, and other business relationships, and in the broader ecosystems of which it is part. This Pillar focuses on company activities to support the realization of the SDGs through interactions with these actors, and collaboration to promote, incentivize, and ensure more sustainable practices and better livelihoods within its own value chain as well as within the relevant industries, sectors, and communities that its operations and business relationships influence.

(4) Pillar 4 brings into focus how companies are governed and how they engage with the systems and rules that govern them. **Good corporate citizenship** is the foundation for the holistic changes in corporate practices needed to align with the SDGs. This pillar highlights company strategies that contribute to or diminish social goods or societal well-being, and activities that support or undermine the crafting and effective deployment of law and policy that advances sustainable development. It considers company engagement in responsible tax and litigation practices, and the extent to which corporate governance and management systems are geared towards incentivizing SDG-aligned conduct.

Figure B1. The four-pillar framework for agri-food companies' alignment with the SDGs




Source: Sachs J. et al., 2021. "Fixing the Business of Food 2021: Aligning food company practices with the SDGs", Barilla Center for Food & Nutrition, UN Sustainable Development Solutions Network, Columbia Center on Sustainable Investment, Santa Chiara Lab University of Siena.

## Consumers and sustainable diets

The transition towards more sustainable diets in the EU is essential for achieving the SDGs domestically and at the global scale. This would not only be beneficial for addressing the obesity "epidemic" in the EU which leads to chronic diseases, increased health care costs and impacts negatively other aspects covered under SDG3 (Good Health and Well-Being), but also to address negative environmental impacts (including $CO_2$, methane emissions and deforestation) domestically and internationally. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) emphasizes the need to shift towards more plant-based and less meat-based diets to achieve the objectives of the Paris Climate Agreement (IPBES 2019; IPCC 2019). Soy imports from the EU, notably to feed cattle, is a major driver of deforestation in the Amazon region, and especially in Brazil (Streck et al. 2019). This study emphasizes the impacts generated abroad via EU's imports of "meat and fish", "crop growing", and "livestock farming".

Integrated pathways can highlight system-wide implications of dietary shifts and help countries prepare for this transition. In the EU-27 the average national calorie intake is above 3,000 kcal/cap/day, and the average diet is characterized by a low share of cereals (about one quarter of total calories), high share of animal sourced foods (almost a third), and high sugar and fat consumption. On average, fruits and vegetables barely make up 6% of daily calorie intake. Using the FABLE modelling framework that connects 20 countries' national food and land use system models (including the Germany, Finland and Sweden and the rest of the EU-27 as one group) and 6 rest-of-the-world regions through international trade, a recent policy brief highlighted that shifts towards healthier diets could cut global GHG emissions from Agriculture, Forestry and Other Land Use (AFOLU) by half and reduce forest loss by 20% over the period 2030-2050 compared to Current Trends (FABLE 2021). The "Sustainable" scenario combines efforts to shift towards healthier diets (consumption-side) and further actions towards sustainable production of food products (production-side).

Policy levers to support diet shifts must go hand in hand with careful assessments of the winners and losers from this transition. The Farm to Fork Strategy "*aims to improve the availability and price of sustainable food and to promote adoption of healthy and sustainable diets by consumers*". The EU also launched various initiatives to promote healthier diets, labelling, and education, mobilizing the Horizon Europe programme to identify dietary solutions and innovations. As emphasized by the Food Policy Coalition, a fair transition in food systems and diets will require closer integration with social, labour and economic policies. The coalition identifies "Seven Entry-Points for Action on Food Environments" (food characteristic, labelling, promotion, provision, retail, prices, and international agreements) that could be further leveraged to accelerate diet shifts in Europe (Food Policy Coalition 2021).

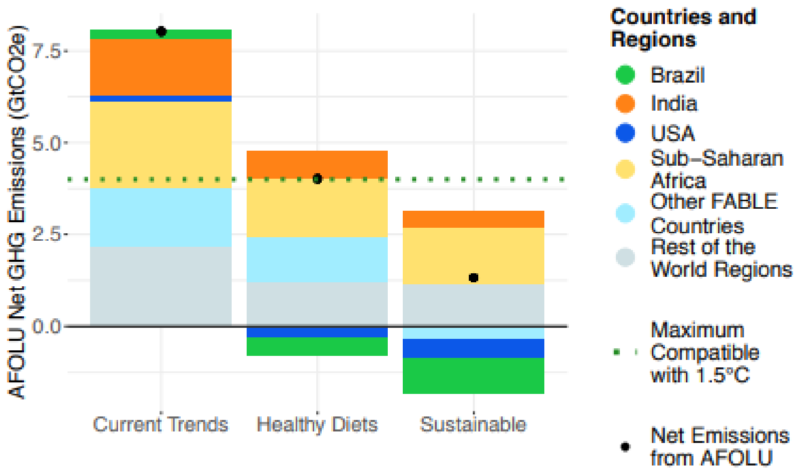



**Figure 7. GHG emissions from agriculture and land use change under each pathway** (Source: FABLE (2021))

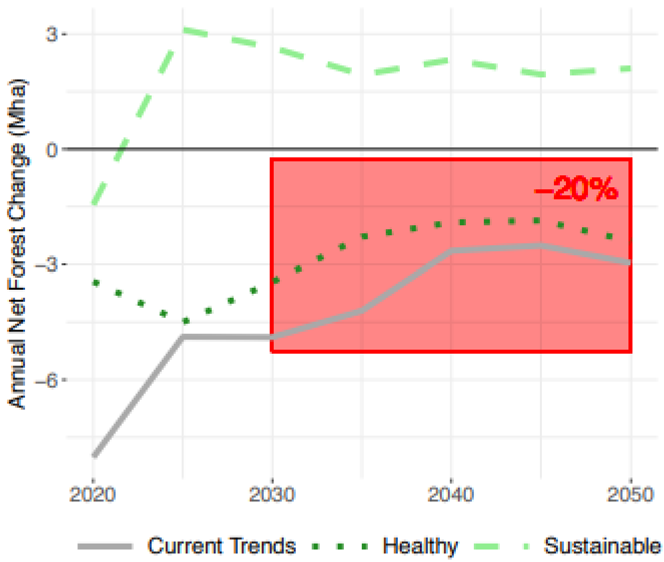



**Figure 8. Evolution of net forest change per year under each pathway** (Source: FABLE (2021))

# CONCLUSION

Discussions and side-events at COP26 in Glasgow underlined the need for systemic approaches in addressing climate change that focus on the convergence of climate, biodiversity and living standards. This study emphasized that the consumption of agri-food commodities in the EU generates significant negative impacts abroad, in terms of carbon emissions, soil and air pollution, and biodiversity threats (using land-use as a proxy). It also highlighted that many workers inside and outside the EU depend on food exports and production. By providing granular assessments of where in the world those negative environmental impacts take place and which specific agri-food commodities are responsible for such impacts (e.g., meat and fish, crop growing, cocoa, livestock farming etc.) we hope that this study provides a useful contribution to help inform policies that aim to align specific supply chains with the objectives of the Sustainable Development Goals and the Paris Climate Agreement.

Policy reforms and actions by governments, businesses, and consumers to transform the agri-food system and reduce their impacts on climate and biodiversity abroad must promote a "Just Transition". The transformation of food and land systems is very complex. Border adjustment mechanisms and mirror clauses might help strengthen policy coherence and reduce carbon leakages and imported deforestation. Yet, they must go hand-in-hand with further efforts to support the transformation of energy, land-use and agricultural systems in partner countries. Some recent announcements made at COP26 go in the right direction including the US and EU pledge to slash methane and the €1 billion EU pledge to protect world forests. Besides financial investments, technical cooperation can help in supporting greater sustainability in producing countries. The Just Transition for South Africa announced at COP26 by the UK, United States, France, Germany, and the EU may pave the way for new forms of development cooperation and partnerships between developed and developing countries.

Strengthening sustainability in food supply chains also requires robust and timely statistics at the global, national, industry, and company level.

Recent work led by the European Commission Joint-Research Centre (JRC), Eurostat and the European Environmental Agency (EEA) endorses the development of more robust and timely consumption-based statistics disaggregated by sectors and supply chains and provide a more comprehensive assessment of the true footprint of the EU. The ability to put precise numbers on *consumption-based impacts* and impacts generated by specific industries and companies abroad is crucial for policy coherence and for aligning international supply chains, including the agri-food system, with the SDGs and objectives of the Paris Climate Agreement.

# REFERENCES

agence Europe. 2021. *Reciprocity in trade and 'mirror clauses', priorities of future French Presidency of EU Council:* https://agenceurope.eu/en/bulletin/article/12785/5.

Alatriste-Contreras, M. G. 2015. The relationship between the key sectors in the european union economy and the intra-European Union trade. *Journal of Economic Structures* 4(1): 1-24.

Alsamawi, A., J. Murray, and M. Lenzen. 2014a. The Employment Footprints of Nations. *Journal of Industrial Ecology* 18(1): 59-70.

Alsamawi, A., J. Murray, M. Lenzen, and R. C. Reyes. 2017. Trade in occupational safety and health: Tracing the embodied human and economic harm in labour along the global supply chain. *Journal of Cleaner Production* 147: 187-196.

Alsamawi, A., J. Murray, M. Lenzen, K. Kanemoto, and D. Moran. 2014b. A novel approach to quantitative accounting of income inequality. *PloS one* 9(10): e110881.

ATLAS. 2021. *The Atlas of Economic Complexity:* http://atlas.cid.harvard.edu/. Vol. 2021.

Baroni, L., L. Cenci, M. Tettamanti, and M. Berati. 2007. Evaluating the environmental impact of various dietary patterns combined with different food production systems. *European journal of clinical nutrition* 61(2): 279-286.

Boylan, S., A.-M. Thow, E. K. Tyedmers, A. Malik, J. Salem, R. Alders, D. Raubenheimer, and M. Lenzen. 2020. Using Input-Output Analysis To Measure Healthy, Sustainable Food Systems. *Frontiers in Sustainable Food Systems* 4: 93.

Chaudhary, A. and T. Kastner. 2016. Land use biodiversity impacts embodied in international food trade. *Global Environmental Change* 38: 195-204.

Crippa, M., E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F. Tubiello, and A. Leip. 2021a. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food* 2(3): 198-209.

Crippa, M., D. Guizzardi, E. Schaaf, E. Solazzo, M. Muntean, F. Monforti-Ferrario, J. G. J. Olivier, and E. Vignati. 2021b. *Fossil CO2 and GHG emissions of all world countries - 2021 Report*.

Crippa, M., E. Solazzo, G. Huang, D. Guizzardi, E. Koffi, M. Muntean, C. Schieberle, R. Friedrich, and G. Janssens-Maenhout. 2020. High resolution temporal profiles in the Emissions Database for Global Atmospheric Research. *Scientific Data* 7(1): 1-17.

Eberle, U. and J. Fels. 2016. Environmental impacts of German food consumption and food losses. *The International Journal of Life Cycle Assessment* 21(5): 759-772.

Europa EU. 2020. *The 27 member countries of the EU:* https://europa.eu/european-union/about-eu/countries_en. Vol. 2020.

European Commission. 2020a. *Study on due diligence requirements through the supply chain:* https://op.europa.eu/en/publication-detail/-/publication/8ba0a8fd-4c83-11ea-b8b7-01aa75ed71a1/language-en#.

European Commission. 2020b. *The European Union remains world's leading donor of Official Development Assistance with €75.2 billion in 2019:* https://ec.europa.eu/commission/presscorner/detail/en/IP_20_674.

European Commission. 2021a. *Agri-food trade in 2020:* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/trade/documents/map-2021-2_en.pdf.

European Commission. 2021b. *New EU forest strategy for 2030:* https://ec.europa.eu/environment/strategy/forest-strategy_fr.

European Commission. 2021c. *Carbon Border Adjustment Mechanism:* https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_fr.

European Commission. 2021d. *Aid for Trade: European Union remains the world's leading provider with €17.9 billion:* https://ec.europa.eu/commission/presscorner/detail/en/IP_21_5641.

European Commission. 2021e. *Farm to Fork strategy for a fair, healthy and environmentally-friendly food system:* https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en.

European Commission. 2021f. *Countries and regions: China:* https://ec.europa.eu/trade/policy/countries-and-regions/countries/china/.

European Commission. 2021g. *Agri-food trade statistical factsheet - European Union and India:* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/agrifood-india_en.pdf.

European Commission. 2021h. *Agri-food trade statistical factsheet - European Union and Mexico:* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/agrifood-mexico_en.pdf.

European Commission. 2021i. *Communication from the Commission to the European Parliament, The Council, The European economic and social committee and the committee of the regions: Trade Policy Review - An Open, Sustainable and Assertive Trade Policy:* https://trade.ec.europa.eu/doclib/docs/2021/february/tradoc_159438.pdf

FABLE. 2021. *Environmental and agricultural impacts of dietary shifts at global and national scales FABLE Policy Brief:* https://irp.cdn-website.com/be6d1d56/files/uploaded/210726_FABLEDietBrief_cor%20%281%29.pdf. Paris: Sustainable Development Solutions Network (SDSN).

FAO. 2020. *Gobal Forest Resources Assessment:* https://fra-data.fao.org/WO/fra2020/home/.

Federal Foreign Office. 2021. *Germany and Argentina: bilateral relations:* https://www.auswaertiges-amt.de/en/aussenpolitik/laenderinformationen/argentinien-node/argentina/229576.

Food Policy Coalition. 2021. *Food Environments & EU Food Policy: Discovering the role of food environments for Sustainable Food Systems:* https://foodpolicycoalition.eu/wp-content/uploads/2021/10/Food-Environments-for-SFS_EU-FPC.pdf.

Foster, C., K. Green, and M. Bleda. 2007. Environmental impacts of food production and consumption: final report to the Department for Environment Food and Rural Affairs.

Foster, W. and R. Stephenson. 1922. Beef Cattle Equipment: Feeding Equipment for Cattle.

Gómez-Paredes, J., A. Alsamawi, E. Yamasue, H. Okumura, K. N. Ishihara, A. Geschke, and M. Lenzen. 2016. Consuming childhoods: An assessment of child labor's role in Indian production and global consumption. *Journal of Industrial Ecology* 20(3): 611-622.

IEEP. 2021. *IEEP's response to the consultation on the Trade and Sustainable Development review:* https://ieep.eu/news/ieep-s-response-to-the-consultation-on-the-trade-and-sustainable-development-review.

ILO. 2018. *Employment by sex and economic activity:* https://ilostat.ilo.org/topics/employment/.

IPBES. 2019. *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors):* https://doi.org/10.5281/zenodo.3831673. IPBES secretariat, Bonn, Germany.

IPCC. 2019. *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems:* https://www.ipcc.ch/report/srccl/.

Kanemoto, K., D. Moran, M. Lenzen, and A. Geschke. 2014. International trade undermines national emission reduction targets: New evidence from air pollution. *Global Environmental Change* 24: 52-59.

Kastner, T., M. J. I. Rivas, W. Koch, and S. Nonhebel. 2012. Global changes in diets and the consequences for land requirements for food. *Proceedings of the National Academy of Sciences* 109(18): 6868-6872.

Kim, K.-H., E. Kabir, and S. Kabir. 2015. A review on the human health impact of airborne particulate matter. *Environment international* 74: 136-143.

Lenzen, M., K. Kanemoto, D. Moran, and A. Geschke. 2012. Mapping the structure of the world economy. *Environmental Science & Technology* 46: 8374-8381.

Lenzen, M., D. Moran, A. Bhaduri, K. Kanemoto, M. Bekchanov, A. Geschke, and B. Foran. 2013. International trade of scarce water. *Ecological Economics* 94: 78-85.

Lenzen, M., A. Geschke, J. West, J. Fry, A. Malik, S. Giljum, L. Milà i Canals, P. Pinero, S. Lutter, T. Wiedmann, M. Li, M. Sevenster, K. Nansai, J. Potočnik, I. Teixeira, M. Van Voore, and H. Schandl. 2021. Implementing the Material Footprint to measure progress towards SDGs 8 and 12. *Nature Sustainability, accepted*.

Leontief, W. W. 1936. Quantitative input and output relations in the economic systems of the United States. *The Review of Economics and Statistics* 18(3): 105-125.

Malik, A. and J. Lan. 2016. The role of outsourcing in driving global carbon emissions. *Economic Systems Research* 28(2): 168-182.

Malik, A., G. Lafortune, S. Carter, M. Li, and M. Lenzen. 2020. *Social spillover effects in the EU's textile supply chains:* https://resources.unsdsn.org/social-spillover-effects-in-the-eu-s-textile-supply-chains.

Malley, C., K. Hicks, J. Kuylenstierna, E. Michalopoulou, A. Molotoks, J. Slater, C. Heaps, S. Ulloa, J. Veysey, and D. Shindell. 2021. Integrated assessment of global climate, air pollution, and dietary, malnutrition and obesity health impacts of food production and consumption between 2014 and 2018. *Environmental Research Communications* 3(7): 075001.

Marques, A., I. S. Martins, T. Kastner, C. Plutzar, M. C. Theurl, N. Eisenmenger, M. A. Huijbregts, R. Wood, K. Stadler, and M. Bruckner. 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature ecology and evolution* 3(4): 628-637.

Moran, D. D., M. Lenzen, K. Kanemoto, and A. Geschke. 2013. Does ecologically unequal exchange occur? *Ecological Economics* 89: 177-186.

Mosier, A., J. K. Syers, and J. R. Freney. 2013. *Agriculture and the nitrogen cycle: assessing the impacts of fertilizer use on food production and the environment*. Vol. 65: Island Press.

Oita, A., A. Malik, K. Kanemoto, A. Geschke, S. Nishijima, and M. Lenzen. 2016. Substantial nitrogen pollution embedded in international trade *Nature Geoscience* 9(2): 111-115.

OXFAM. 2021. *Fit for 55 Package: Not fit to tackle climate emergency says Oxfam:* https://www.oxfam.org/fr/node/17129.

Pigłowski, M. 2021. The Intra-European Union Food Trade with the Relation to the Notifications in the Rapid Alert System for Food and Feed. *International journal of environmental research and public health* 18(4): 1623.

Poore, J. and T. Nemecek. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360(6392): 987-992.

Rajão, R., B. Soares-Filho, F. Nunes, J. Börner, L. Machado, D. Assis, A. Oliveira, L. Pinto, V. Ribeiro, and L. Rausch. 2020. The rotten apples of Brazil's agribusiness. *Science* 369(6501): 246-248.

Ritchie, H. and M. Roser. 2020. *Environmental impacts of food production:* https://ourworldindata.org/environmental-impacts-of-food#environmental-impacts-of-food-and-agriculture.

Sachs, J., G. Traub-Schmidt, C. Kroll, G. Lafortune, and G. Fuller. 2021a. *Sustainable Development Report 2021: The Decade of Action for the Sustainable Development Goals:* https://sdgindex.org/reports/sustainable-development-report-2021/. Cambridge: Cambridge University Press.

Sachs, J., U. Agarwal, G. Espinosa, Mardirossian, A. O. D. Nora; Marrero, Erin; Plekenpol, Regan; Rincón Rico, Diana , and J. D. a. S. Marcela; Sachs, Lisa E. 2021b. *Fixing the business of food:* https://www.fixing-food.com/wp-content/uploads/2021/09/ALIGNING_FOOD_COMPANY_PRACTICES_WITH_THE_SDGs.pdf.

Sala, S., S. J. McLaren, B. Notarnicola, E. Saouter, and U. Sonesson. 2017. In quest of reducing the environmental impacts of food production and consumption. *Journal of Cleaner Production* 140: 387-398.

SCP-HAT. 2021. *Hotspot analysis tool for sustainable consumption and production:* http://scp-hat.lifecycleinitiative.org/.

SDSN and IEEP. 2020. The 2020 Europe Sustainable Development Report: Meeting the Sustainable Development Goals in the face of the COVID-19 pandemic. Sustainable Development Solutions Network and Institute for European Environmental Policy: Paris and Brussels.

SDSN, Yale Center for Environmental Law & Policy, and Center for Global Commons at the University of Tokyo. 2021. *Global Commons Stewardship Index 2021*, *and* Paris; New Haven, CT; and Tokyo.

Sherpa. 2021. *Creating a Public Authority to Enforce the Duty of Vigilance Law: A Step Backward?* https://www.asso-sherpa.org/wp-content/uploads/2021/05/2021.05-Position-Paper-DV-Public-Enforcement.pdf.

Soligno, I., A. Malik, and M. Lenzen. 2019. Socio-economic drivers of global blue water use. *Water Resources Research* 55(7): 5650:5664.

Streck, C., B. Hermann, S. C. Cabezas, G. Lafortune, and H. Bellfield. 2019. *Towards more sustainability in the soy supply chain: How can EU actors support zero-deforestation and SDG efforts?:* https://www.climatefocus.com/publications/towards-more-sustainability-soy-supply-chain-how-can-eu-actors-support-zero.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences* 96(11): 5995-6000.

Timperley, J. 2021. *The broken $100-billion promise of climate finance — and how to fix it, Nature News Feature,* https://www.nature.com/articles/d41586-021-02846-3.

Tonini, D., P. F. Albizzati, and T. F. Astrup. 2018. Environmental impacts of food waste: Learnings and challenges from a case study on UK. *Waste Management* 76: 744-766.

Tukker, A. and E. Dietzenbacher. 2013. Global multiregional input–output frameworks: an introduction and outlook. *Economic Systems Research* 25(1): 1-19.

Usva, K., M. Saarinen, and J.-M. Katajajuuri. 2009. Supply chain integrated LCA approach to assess environmental impacts of food production in Finland. *Agricultural Food Science* 18(3-4): 460-476.

van Dijk, M., T. Morley, M. L. Rau, and Y. Saghai. 2021. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food* 2(7): 494-501.

Wiedmann, T. and M. Lenzen. 2018. Environmental and social footprints of international trade. *Nature Geoscience* 11(5): 314-321.

Xiao, Y., M. Lenzen, C. Benoît-Norris, G. A. Norris, J. Murray, and A. Malik. 2018. The corruption footprints of nations. *Journal of Industrial Ecology* 22(1): 68-78.

# SUPPLEMENTARY INFORMATION

## Mathematical formulation – measuring spillovers

The starting point for quantification of spillover impacts is a set of MRIO matrices – intermediate demand ($\mathbf{T}$), final demand ($\mathbf{Y}$) and value-added ($\mathbf{v}$). The intermediate demand matrix captures intra-industry and inter-industry transactions between regions; the value-added matrix contains information on primary inputs needed for the production of goods and services (e.g., labour input); and the final demand matrix captures expenses related to the final consumption of goods and services. The $\mathbf{T}$ and $\mathbf{Y}$ matrices of a MRIO database harbour data on imports and exports by region and sector, for example if any of the EU member states import food from an Asian economy for further processing, then this transaction is captured in the $\mathbf{T}$ matrix; and final consumption of a processed food item imported from the USA is captured directly in the $\mathbf{Y}$ matrix. MRIO databases therefore capture supply chains that originate in the RoW and feed into supply chains in the EU, before finally ending up with final consumers in the EU; and also supply chains that originate and form part of further processing in the RoW and end up in the EU.

Input-output calculations proceed by calculating the total output $\mathbf{x}$ of an MRIO database by using row summation operators (i.e., summing all elements in a row to obtain a column vector): $\mathbf{x} = \mathbf{T}\mathbf{1}^{\mathrm{T}} + \mathbf{y}\mathbf{1}^{\mathrm{y}}$ , where $\mathbf{1}^{\mathrm{T}}$ is the row summation operator for the matrix $\mathbf{T}$, and $\mathbf{1}^{\mathrm{y}}$ the row summation operator for matrix $\mathbf{y}$. Next, the direct coefficients matrix $\mathbf{A}$ (inputs needed to produce 1$ of output of a sector) is calculated using $\mathbf{A} = \mathbf{T}\hat{\mathbf{x}}^{-1}$, where $\hat{\mathbf{x}}^{-1}$ is the inverse of the diagonal total output vector $\mathbf{x}$. We integrate a new matrix – $\mathbf{Q}$ (physical accounts) – with the economic input system. This matrix is essential for featuring data on environmental, social and economic indicators into an economic dataset. Each row of the $\mathbf{Q}$ matrix holds data on a specific indicator. The direct intensities matrix $\mathbf{q}$ (impacts per dollar of output $\mathbf{x}$) is calculated as: $\mathbf{q} = \mathbf{Q}\hat{\mathbf{x}}^{-1}$ . The power of input-output analysis lies in the ability to capture all upstream supply chains using a total requirements matrix $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$. The matrix $\mathbf{L}$ can be used to calculate the total intensities $\mathbf{m} = \mathbf{q}\mathbf{L}$. The total intensities hold information on both the direct and indirect impacts (e.g., in kg $CO_2$e) embodied in 1$ of final demand/final consumption of a commodity. The impacts embodied in the food products bought by the EU can be calculated by taking the final demand of crops, livestock, aquaculture, meat and fish products, cereal-based products, food crop products, cocoa, chocolate, sugar, oil and fats, dairy products, alcoholic and other beverages and tobacco products by each of the 27 EU member states. This specific final demand vectors for each EU country $\mathbf{y}_{\mathrm{EU\_c\_food}}$ can be post-multiplied by the total intensities to calculate consumption-based footprints as $\mathbf{f}_1 = \mathbf{m} \otimes \mathbf{y}_{\mathrm{EU\_c\_food}}$ , where $\otimes$ denotes element-wise multiplication or impacts according to last point of sale and final consumption; and $\mathbf{f}_2 = \mathbf{q} \otimes \mathbf{L}\mathbf{y}_{\mathrm{EU\_c\_food}}$ as impacts from producing region/sector to final consumption. We calculate both domestic impacts (i.e., impacts that happen within EU, or between EU countries) or spillover impacts (i.e., impacts that take place outside of EU's borders).

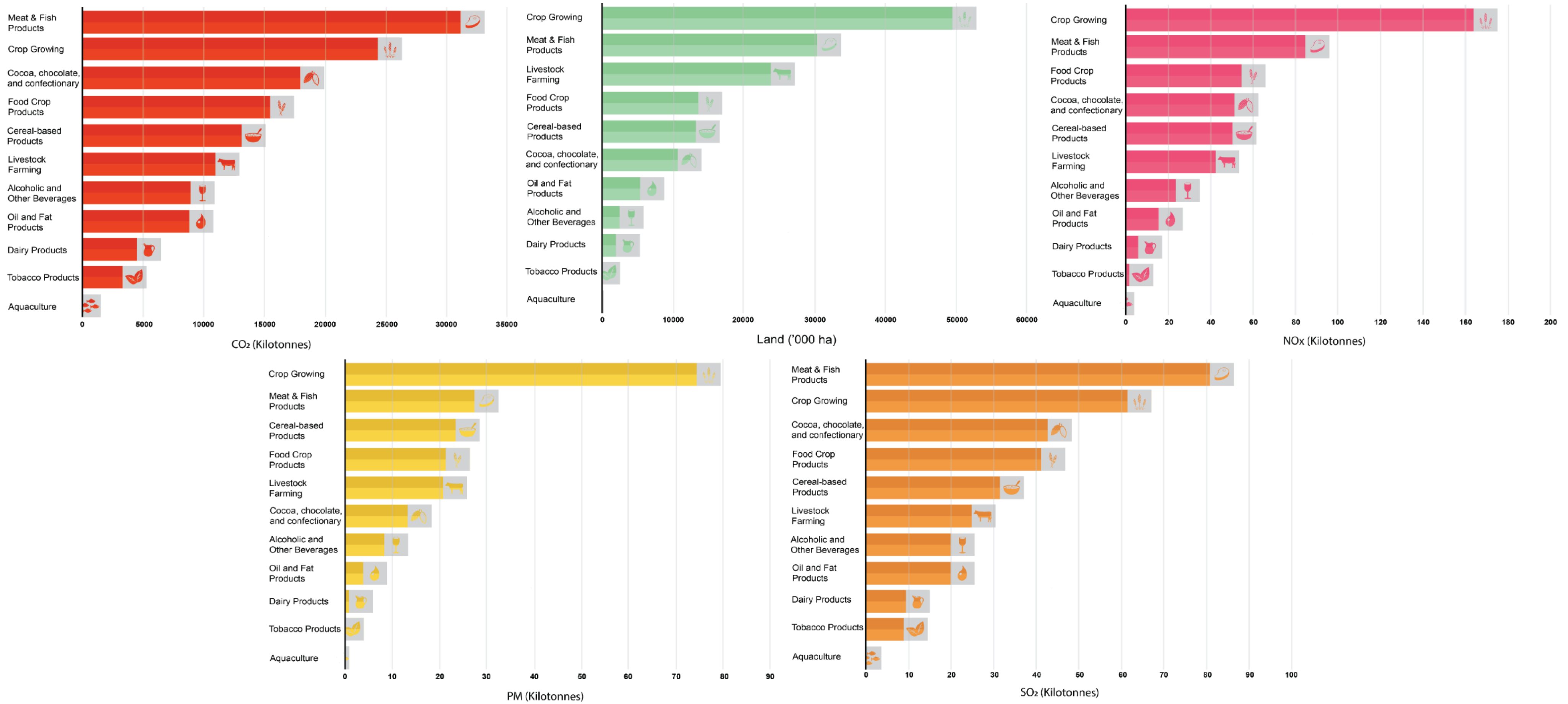



**Figure S1 Environmental impacts embodied in the final demand of key agricultural and food manufacturing commodities**. The values shown in the bar graphs capture all direct and indirect supply chain impacts for the final demand of food, e, g., energy, fuel, and transportation-related carbon dioxide emissions embodied in 'Meat and Fish product' manufacturing are captured in the bar for this category.

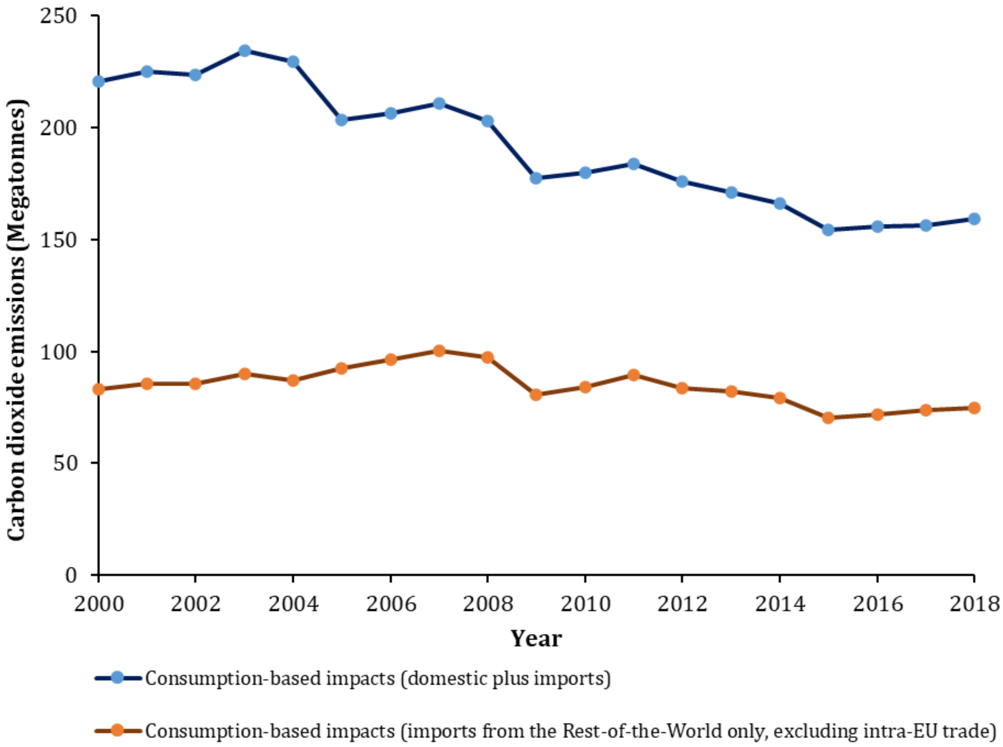



**Figure S2 Trends in consumption-based impacts, both domestic and imports.** Impacts taking place outside of the EU (from imports) are called 'Spillovers' in this study.

**Table S1 Comparison of per-capita spillover impacts for the European Union with two economies (USA and Russia) across all seven indicators.**

| Region/Country | **Carbon dioxide** (Kg per capita) | **Sulphur dioxide** (Kg per capita) | **Nitrous oxide** (Kg per capita) | **Particulate Matter** (Kg per capita) | **Land** (ha per capita) | **Employment** (people per capita) | **Income** (USD per capita) |
|---|---|---|---|---|---|---|---|
| **European Union** | 168 | 0.5 | 0.6 | 0.3 | 0.2 | 0.04 | 156 |
| **United States of America** | 63 | 0.2 | 0.3 | 0.1 | 0.1 | 0.02 | 107 |
| **Russia** | 31 | 0.1 | 0.1 | 0.04 | 0.06 | 0.01 | 47 |