

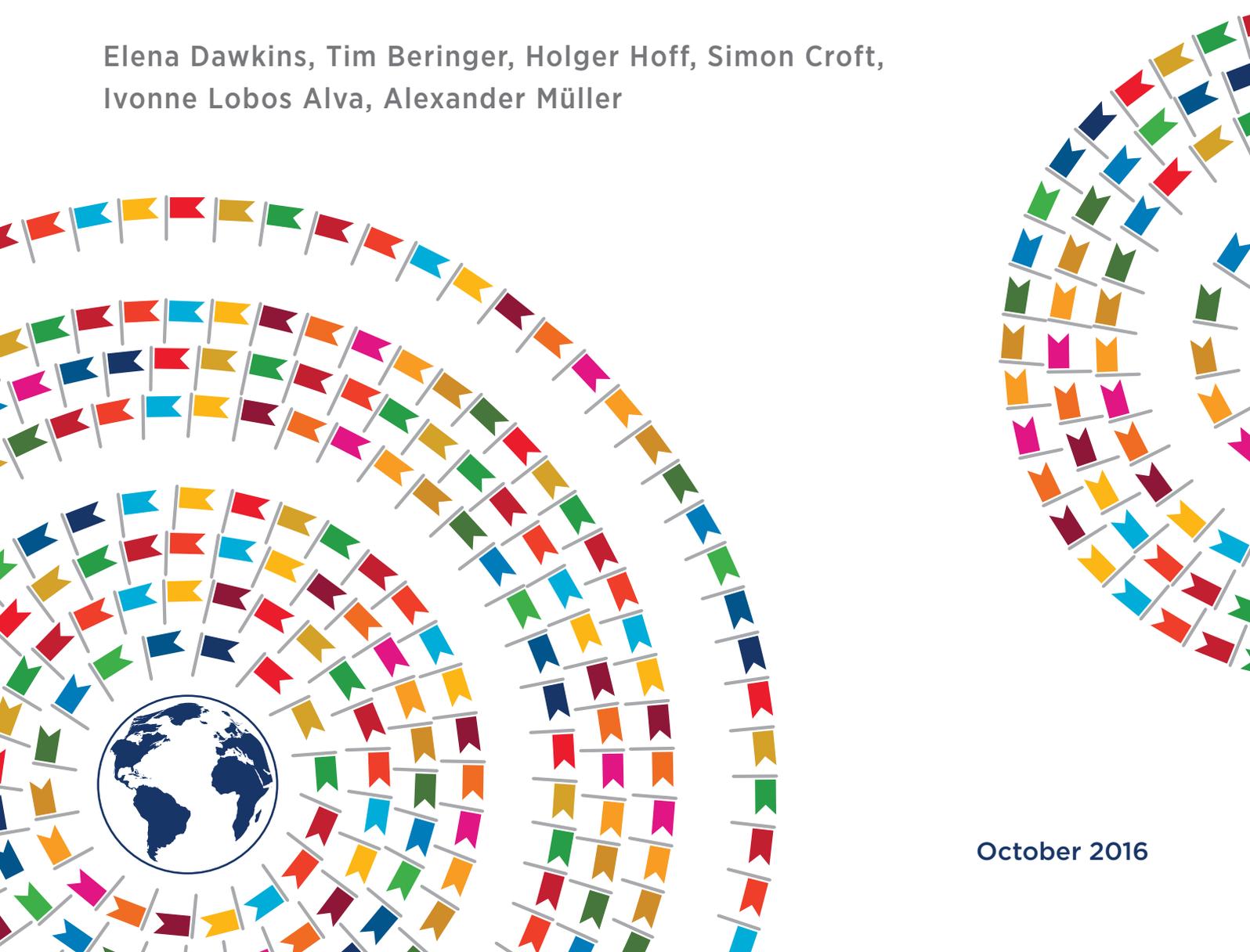


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Tracking Germany's Biomass Consumption: Scientific Underpinning for the Implementation of the 2030 Agenda

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Key findings

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- Germany increasingly depends on imported agricultural and other biomass-based commodities and has become a large net importer.
- Their production causes environmental and socio-economic impacts in source countries, i.e. Germany's external "footprint".
- Conventional trade statistics tell only parts of the story, but do not account for indirect or virtual imports of commodities that are used elsewhere in the production process or along the supply chain (such as soybean for meat production) but which do not physically enter Germany; or those embedded in other imported products, such as palm oil in cosmetics; they also exclude re-exports in processed form from Germany to other countries. Advanced analytical methods such as multi-regional input – output (MRIO) models or material flow analysis (MFA) are therefore required to understand complex trade relations in the globalized world and the associated environmental footprints of consumption patterns.
- Using SEI's MRIO Input-Output Trade Analysis (IOTA) model to analyse supply chains and their environmental impacts from the consumption end, we find that Germany's total (including indirect and embedded) requirement for soybean is almost double its net direct imports. Germany's consumption-based external land requirement for soybeans alone equals 20% of Germany's total domestic cropland area.
- Using SEI's MFA Spatially Explicit Information on Producer to Consumer Systems (PCS) model from the production end of the supply chains enables the precise origins of Germany's imports to be traced and pinpointed at much higher resolution than previously possible. By combining this information with high-resolution environmental (e.g. land and water use) data, context-specific environmental impacts (footprints) of production can be derived for German imports.
- When combining, for example, high-resolution export production and water scarcity data, we find that some of the Brazilian soy imported by Germany originates from water-scarce areas, which may further exacerbate water scarcity in these regions.
- The combination of these innovative tools for supply chain analysis with (e.g. land or water) resource productivity data can also be used to identify opportunities for increasing overall resource productivity of commodity production through smart sourcing.
- Innovative analytical tools such as MRIO and MFA can support the integrated implementation of the Sustainable Development Goals (SDGs) and contribute to effective follow-up and review mechanisms.

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1. Introduction

The 2030 Agenda redefines national responsibility and policy making for global sustainable development based on the principles of integration and universality. The 2030 Agenda calls for the integrated implementation of the Sustainable Development Goals (SDGs), which will require coherence across different policy areas connecting environment and development related goals, and ensuring that progress in one SDG does not hinder progress in others. Besides this “horizontal” integration, another important dimension of SDG implementation is the need for “vertical” integration across different levels and scales, from local to national, regional, and global. The 2030 Agenda is universal in scope and commits all countries to engage in comprehensive efforts for environmental, social, and economic sustainability, taking into account their different capacities and circumstances. Even though implementation will primarily occur at national level, countries have a responsibility to contribute to the global achievement of the SDGs.

Germany's National Sustainable Development Strategy (NSDS) (Die Bundesregierung, 2016), which is currently undergoing a revision process, provides the framework for national SDG implementation. The 2016 draft of the Strategy clearly acknowledges Germany's international responsibility with respect to the external impacts of German consumption patterns, stating that countries such as Germany have a strong responsibility for the economic, environmental, and social effects of international trade. It also argues that Germany, like other industrialized countries, bears specific responsibility for the worldwide implementation of SDG12 and the promotion of sustainable consumption and production (SCP), recognizing that SCP can meet the legitimate needs of current and future generations. During negotia-

tion of the 2030 Agenda, it was also widely held that developed countries should take the lead on implementing the SDG on Sustainable Consumption and Production (see target 12.1). Germany's economy is highly integrated with global trade and supply chains, and therefore has significant environmental and socio-economic impacts in other regions, including natural resource use and production conditions in trade-partner countries.

The NSDS explicitly acknowledges sustainable use of natural resources as a cross-cutting theme that will contribute to various SDGs, such as sustainable agriculture (SDG2), water management (SDG6), sustainable energy for all (SDG7), sustainable cities (SDG11), sustainable consumption and production (SDG12), climate action (SDG13), and the sustainable use of terrestrial ecosystems, land, and soils (SDG15).

The global use of natural resources has increased eightfold since 1900, with material and energy use being geographically highly imbalanced (UNEP, 2011). Per capita consumption in industrialized countries exceeds that in developing countries by a factor of between 5 and 10 (Krausmann, Erb, Gingrich, Lauk, & Haberl, 2008). This is also true for Germany and Europe. In order to meet their total demands for goods and services, Germany and the entire European Union increasingly depend on external resources and on longer and more complex supply chains. Germany has become the third largest importer, and with that also a large net importer, of agricultural commodities and products (e.g. Lugschitz, Bruckner, and Giljum 2011; von Witzke and Noleppa 2011). According to DESTATIS/UBA (2015), more than 13 million ha of agricultural land in other countries is utilized for German consumption.

The production of these export goods and services for Germany's consumption has significant environmental and socio-economic impacts ("footprints") in often distant exporting countries and all along the supply chains. In other words: trade allows Germany to export negative externalities related to its consumption patterns/consumer behaviour. Over the past decades, many internal environmental footprints have been reduced while external footprints have increased, so that total (so-called "consumption-based") footprints have either remained constant or even increased (e.g. Dao et al., 2015; Hoff, Nykvist, & Carson, 2014; Peters, Minx, Weber, & Edenhofer, 2011; Pierer, Schröck, & Winiwarter, 2015; Wiedmann et al., 2015). This effect is often neglected when stating a decoupling of economic development from environmental pressures. Germany's ecological footprint in 2012 was 5,3 ha per capita, of which only 2,3 ha was within the national territory, the remainder having been "outsourced" to other regions (Global Footprint Network 2016⁴).⁵ Similarly, the largest share of Germany's total consumption-based land and water footprints occur externally (Tukker et al., 2014).

Conventional trade statistics (e.g. statistical databases from the Food and Agriculture Organization of the United Nations (FAOSTAT) or the United Nations Commodity Trade Statistics Database (COMTRADE)) tell only part of the story of the continuously longer and more complex supply chains and the associated environmental and socio-economic impacts at every step of those chains. Conventional trade statistics only consider direct imports and exports of commodities, but cannot capture a country's dependence on commodities (and underlying natural resources) that were utilized somewhere along a supply chain yet did not physically enter Germany themselves, and/or

are embedded in more complex commodities (e.g. soybeans used in producing imported meat or dairy products, or palm oil contained in imported cosmetics). Neither do conventional trade statistics account for re-exports of processed products from Germany to other countries (which in fact reduces Germany's consumption-based footprint). Moreover, most environmental impacts such as land and water footprints cannot simply be derived from the flow of commodities between countries; they also depend on local contexts in the producing and exporting regions, such as resource scarcities and ecosystem vulnerabilities. Lenzen et al. (2013) demonstrate, for example, that Germany imports disproportionately high amounts of virtual water from water-scarce regions. Hence, conventional bilateral trade information at national scale is not sufficient for deriving true environmental footprints, especially in the case of large and diverse countries.

New approaches and tools are required, to inform national SDG implementation in a way that lives up to the principles of universality and integration. This implies including relevant information on Germany's external footprints when implementing the NSDS and related policies (and eventually improving policy coherence). It further implies follow-up and review processes that account for external footprints. Such approaches and tools need to analyse the complex international supply chains, associated direct and indirect commodity flows, and underlying resource inputs and environmental footprints. Consequently, this requires detailed information for each step of the supply chain, as well as precise localization of production areas within exporting countries and associated contextual information.

⁴ www.footprintnetwork.org/en/index.php/GFN/page/trends/germany/

⁵ Note that this global sourcing of inputs for Germany's economy also holds opportunities for improving resource efficiency globally (see SDG 8.4) by exploiting comparative advantages that certain producer regions have over Germany; for implementing SDG 17 (global partnerships) through cooperation on and access to science, technology, and innovation, and by enhancing knowledge sharing (target 17.6).

Here we apply two innovative analytical tools developed and applied at the Stockholm Environment Institute (SEI): the Input-Output Trade Analysis (IOTA) model, and the Spatially Explicit Information on Producer to Consumer Systems (SEI-PCS) model (see the Methods section for a detailed description of both tools). We use the examples of soy and oil palm, cultivated in Brazil and Indonesia respectively, to illustrate the relevance of information generated by these tools for implementing the 2030 Agenda and Germany's National Sustainable Development Strategy. In conventional bilateral trade statistics, soy and palm oil together make up 8% of Germany's total agricultural commodity imports (or 15% including oil palm kernel, palm kernel cake, soybean oil, and soybean cake). Soy and palm oil are (generally) not produced in Germany, and are therefore two prime examples of the increasing globalization of Germany's supply chains and consumer products. The demand

for these commodities has grown rapidly: Since 1990, Germany's soybean imports increased by 33% and palm oil imports nearly quadrupled (FAOSTAT, 2016). Soy is primarily used as feed for livestock, but also in other food products. Its imports may serve to produce, for example, beef, dairy products, leather, or wool for final consumption in Germany. Palm oil is contained in many different products for final consumption. According to the WWF (2012), 50% of all products on a typical supermarket shelf contain palm oil, e.g. food products and cosmetics. Palm oil is also used for biofuel or, more recently, has substituted for the various functions of other oil seeds when these are converted into biofuel feedstocks. Accordingly, soybean and palm oil arrive in Germany in numerous forms and processing stages and along various supply routes. They might be imported for final consumption in Germany, or they might eventually be re-exported.

2. Methods

In this paper we apply two different methods to analyse the supply chains of soy and palm oil for German use and consumption, and the displaced (external) environmental impacts associated with this consumption: a) the environmentally extended multi-regional input-output (MRIO) model IOTA; and b) the enhanced material flow analysis (MFA) model SEI-PCS. The two approaches and the respective SEI tools are briefly described below. For more detailed descriptions please refer to West et al. (2013) for IOTA, and Godar et al. (2016) for SEI-PCS.

a) Multi-Regional Input-Output (MRIO) analysis is based on financial linkages between countries and economic sectors. For footprint analyses, these are combined with physical data, to capture the full and complete global supply chains and processing steps of raw and processed commodities between the *producer country* and the *final consumer* in Germany. These commodity flows are then integrated with data on resource requirements and environmental effects in order to estimate total impacts, including all production and processing stages associated with all goods and services consumed.

SEI's environmentally extended multi-regional input-output (MRIO) model, IOTA, starts from the consumption end of supply chains, integrating all commodities that are required for meeting Germany's total demands for goods and services across different sectors of the economy (Fig. 1). For the purpose of this paper, we used this model to quantify the total amount of soy and oil palm fruits required to satisfy Germany's total demands, capturing all soy (soybean, soybean oil, soybean cake) and oil palm (palm oil, palm kernel oil, palm kernel cake) products directly imported as raw commodities; or indirectly imported via goods that have used soy or oil palm products in their supply chains; or that contain soy or oil palm products (such as meat fed on soy, or cosmetics containing palm oil). IOTA represents the different commodities as aggregated product groups defined by the Global Trade Analysis Project (GTAP) database (Narayanan, Aguiar, & McDougall, 2012). Furthermore, IOTA also accounts for direct and indirect exports of soy and oil palm products to determine net imports that correspond to the actual level of final consumption in Germany. All results from the IOTA model in this report represent the year 2007.

IOTA is used here to estimate the land and water resources required in the respective producer countries for producing all the soy and palm oil that are ultimately consumed in Germany. By integrating financial data from MRIOs with bilateral trade and environmental data in physical units (e.g. tonnes of commodity traded, and hectares of land used in production of these commodities), IOTA enables estimation of the total amounts of individual commodities that are consumed in Germany. IOTA also estimates the land area and the amount of water required in the producer country.

b) Material flow analysis (MFA) traces the movement of raw commodities, starting from fine-scale local (e.g. municipal level in Brazil) production data and per-shipment custom records and logistics data — from the production location, via international traders, to importing countries, and to the country where the commodities are first utilized. This trade mapping, coupled with a detailed, spatially explicit understanding of the production locations and associated resource inputs and environmental impacts of each commodity, provides insight into the context-specific

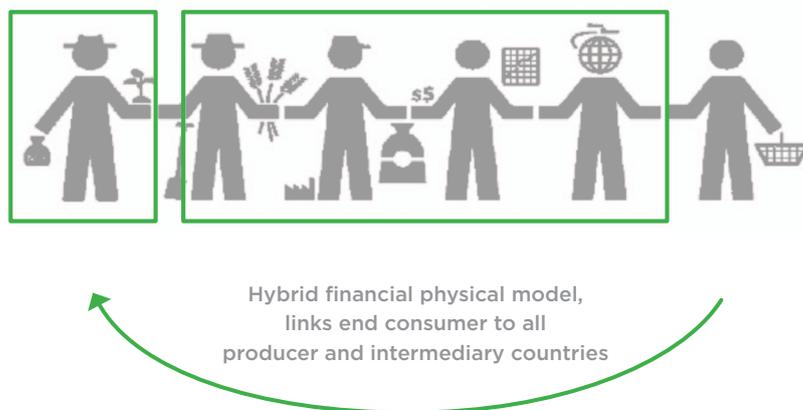


Figure 1: Graphical representation of the IOTA model. Boxes represent country and industrial sector level.

Source: Figure adapted from <https://next-genafricanfarmers.com/2013/06/16/value-chain-in-agriculture/>

footprints associated with commodities that arrive in Germany.

The SEI-PCS model (Fig. 2) starts from the production end of supply chains, tracing flows of raw commodities from sub-national regions in producer countries, via different traders, to countries of first consumption. Here, trader refers to the company exporting the goods, i.e. the company that owns the cargo of palm oil and hires a carrier at a given port for the cargo to be transported overseas. The importer is the company that receives the cargo in the country of destination. Here, we use the SEI-PCS model to trace the flows of raw soy and palm oil, from the producing and exporting countries, via the various shipping and trading stages, to countries of first import (such as the Netherlands, through the port of Rotterdam), until they reach Germany as a country of first con-

sumption, where the raw commodity is then used as an input to the industrial and agricultural sectors. Two unique capabilities of the SEI-PCS tool are that: (1) it is able to identify specific geographical regions of production (e.g. municipalities in Brazil) and thus estimate fine-grained environmental impacts and resource use associated with production; and (2) it retains the identity of traders and shippers responsible for a given supply chain, and their connection to production regions and associated impacts. All results from SEI-PCS represent the years 2013 and 2014.

This paper presents the results from each of these approaches and tools for assessing the total resource requirements (and footprints) associated with German consumption patterns, and the specific locations where these resource uses and footprints manifest.

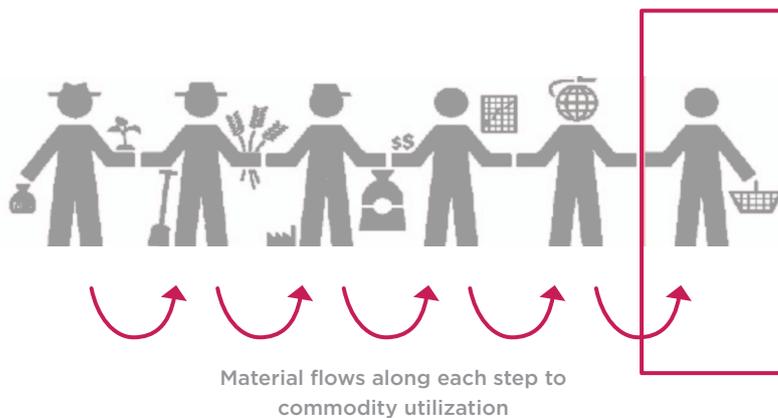


Figure 2: Graphical representation of the SEI-PCS model. The box indicates that supply chains are truncated at the level of the first consuming sector (e.g. agriculture or industry) in the target country, not tracing commodities to the final consumer.

Source: Figure adapted from <https://next-genafrikanfarmers.com/2013/06/16/value-chain-in-agriculture/>

3. Results

3.1 Germany's demand for soy and related external effects

According to conventional trade data from FAO-STAT, Germany imports around 6.8 million tonnes of soybeans, soybean oil, and soybean oilcake per year, and exports around 1.8 million tonnes (average values for the years 2010–2013). Approximately 97% of Germany's imports derive from only seven countries: The Netherlands (31%), USA (25%), Paraguay (13%), Canada (11%), Brazil (10%), and Uruguay (7%). Accordingly, the Netherlands accounts for about one third of Germany's imports despite not cultivating soy domestically but rather acting as a major hub for international trade flows through its ports. This case further shows that conventional trade statistics are not sufficient to trace all of Germany's imports back to the original producer location for assessing the associated environmental footprints.

According to the IOTA model, which accounts for all direct, indirect, and embedded flows, 6.5 million tonnes of soybean were consumed in Germany in 2007, either as soybean themselves or as inputs along the supply chain for products such as meat. FAO-STAT reports only about 3.4 million tonnes of direct net imports of raw soybean by Germany in recent years (FAOSTAT, 2016). Here, MRIO demonstrates that Germany relies on large additional amounts of indirect or embedded soy imports in processed products. IOTA provides a complete overview of all countries producing soy that supports Germany's final consumption of goods and services. Figure 3 shows the top 10 countries from which Germany sources soybean.

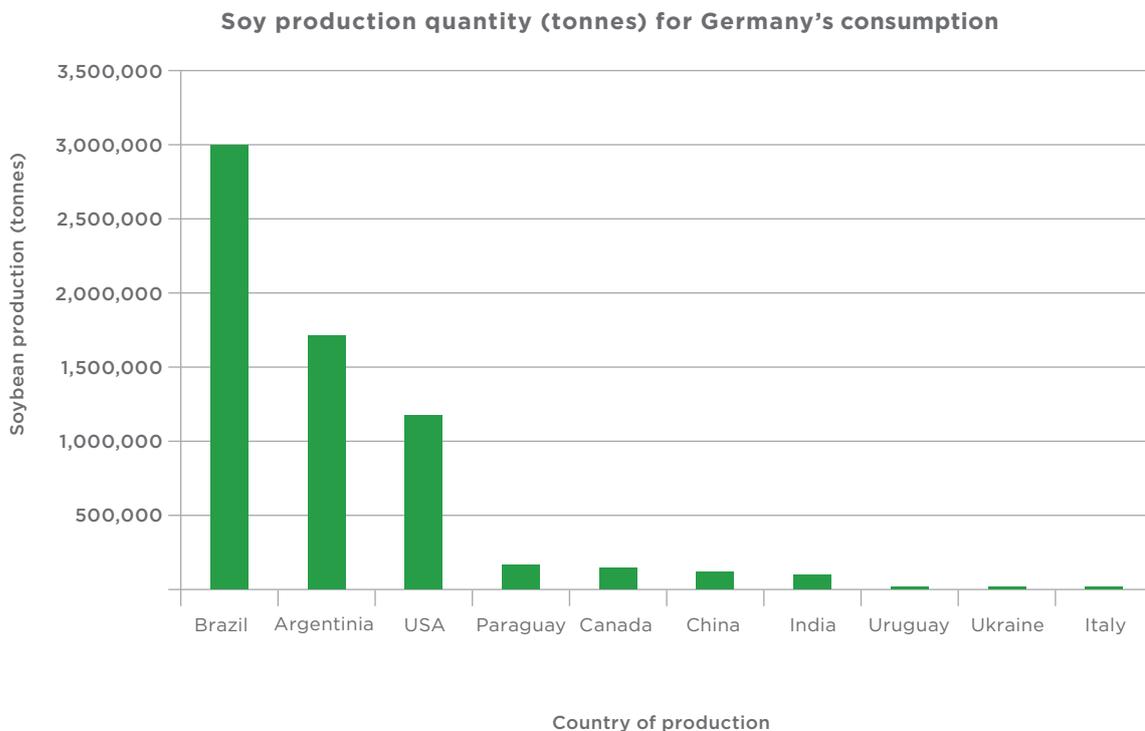


Figure 3: Top 10 producers of soy used along the supply chains for Germany's final consumption of goods and services based on results from the IOTA model for the year 2007.

According to IOTA, the global land area required to meet Germany's demand for soy amounts to 2.4 million hectares, equivalent to approximately 20% of Germany's domestic cropland or 15% of all agricultural land in Germany (Statistisches Bundesamt & Umweltbundesamt, 2015). Table 1 shows the land and water requirements associated with the total soy production required to meet Germany's final consump-

tive demands, for the three most important producer countries. Note that blue water refers to irrigation water, and green water is direct rainfall used for soy production. Grey water indicates freshwater pollution associated with soy production, defined as the amount of freshwater required to dilute pollutants to natural background concentrations or ambient water quality standards.

Country of production/ impact	Production quantity (tonnes)	Percentage of total domestic production for German demand	Land use (ha)	Green water use (m³)	Blue water use (m³)	Grey water use (m³)
Brazil	3,022,327	5.2%	1,074,284	6,593,120,696	2,514,319	45,348,839
Argentina	1,726,951	3.6%	581,239	3,615,512,033	9,174,425	19,705,486
United States of America	1,173,866	1.6%	418,249	1,831,637,361	108,423,795	11,263,552

Table 1: Total soy production for final consumption in Germany, and associated land and water requirements in the three largest producer countries calculated by the environmentally extended IOTA MRIO tool for the year 2007.

IOTA also provides information on the soy requirements of the different consumption categories in Germany (Fig. 4). Most soy is associated with the final

consumption of meat, dairy, and other food products. Together, these products account for about 75% of total German soybean requirements.

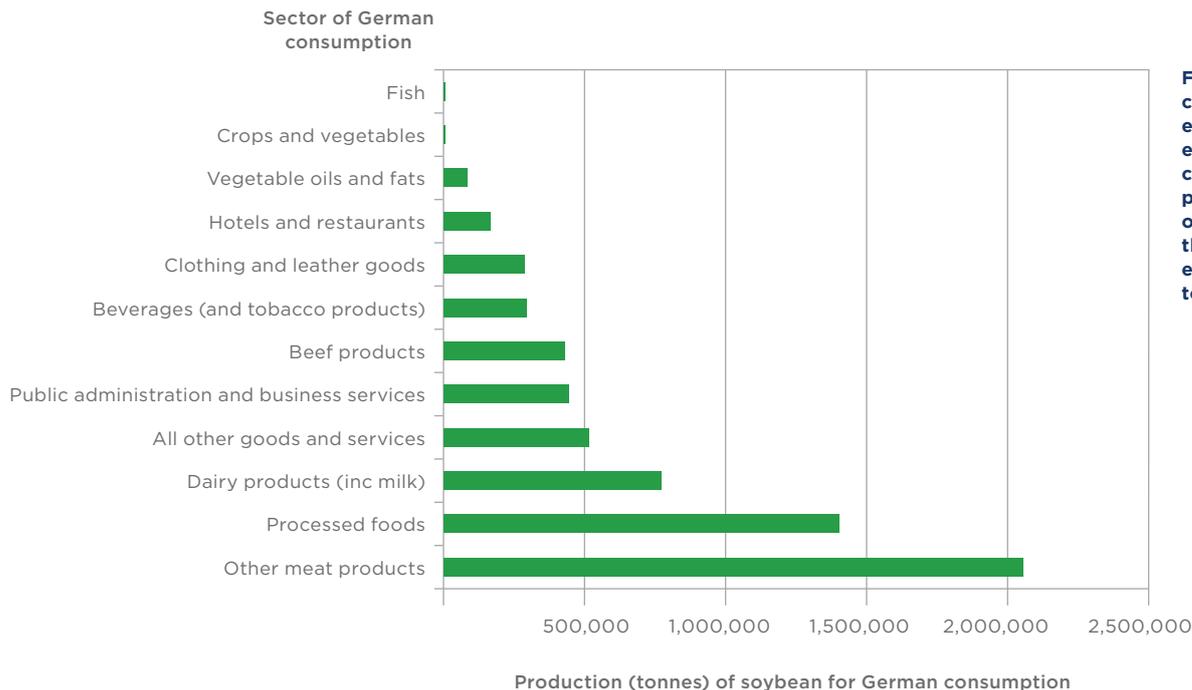


Figure 4: Germany's consumption of soy embedded in different categories of final consumption (tonnes of production and hectares of land) as calculated by the environmentally extended IOTA MRIO tool for the year 2007.

Results from IOTA indicate that Brazil is an important producer of soy for various soy-related or soy-dependent products that are consumed in Germany. The PCS analysis can be used to examine one part of this relationship (i.e. the soy that comes to Germany in its raw forms as raw soybean, soy cake, and soy oil) in greater detail than bilateral trade statistics, ranging from individual municipalities in Brazil — via exporters, shippers, and importers — to Germany. This PCS analysis shows that Germany's agricultural and industrial sectors are sourcing soy and soy derivatives from more than 1000 municipalities in Brazil, but that 40% originates from just 30 municipalities (Fig. 5). Altogether, about 50% of all direct flows of soybean from Brazil to Germany come from the Cerrado region, followed by Mata Atlantic (33%) and Amazonia

(15%). The Cerrado is a savanna region, richer in biodiversity than any other savanna region in the world and storing vast amounts of carbon in the soil. Over the past couple of decades, large parts of this region have been transformed into large-scale monocultures for (export) agricultural production (Brannstrom et al., 2008; Spera, Galford, Coe, Macedo, & Mustard, 2016) that pose a major threat to biodiversity and carbon stocks (Lapola et al., 2013; Mello et al., 2014).

The SEI-PCS tool also identifies interim countries through which soy is shipped on its way to Germany — in this case, about half of the direct flow of soy came directly from Brazil whereas the other half first went via interim countries, particularly The Netherlands ports of Rotterdam and Amsterdam.

Furthermore, the PCS analysis (Fig. 5) shows that four traders and their subsidiaries account for more than 70% of soy imports to Germany (in descending order of volumes traded): Bunge (nearly 200,000 tonnes), ADM (almost 165,000 tonnes), Cafetra (145,000 tonnes), and Cargill (76,000 tonnes). At the Brazil-

ian end of the supply chain, companies exporting soy from Brazil to Germany include those involved in the farming and processing of soybeans, such as Caomo and Caramuru Alimentos. Both Bunge and Cargill are also found to be key exporters, with company operations that span the entire supply chain.

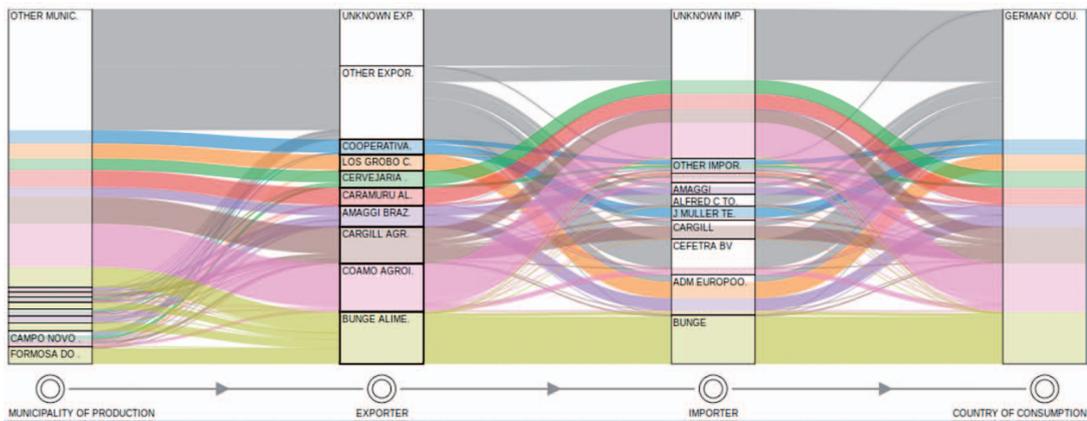


Figure 5: Supply chains of Brazilian soy before entering Germany (arrow width indicates flow volume in tonnes) based on results from the SEI-PCS model for the years 2013/2014.

Using the SEI-PCS MFA tool to localize the export production regions at municipal level in producing countries such as Brazil enables the calculation of true footprints in the sense of context-specific local impacts. Using data on water scarcity (Flach, Ran, Godar, Karlberg, & Suavet, 2016), we find that most

of the water demand related to soy production for imports into Germany occurs in areas with no or low water scarcity, but 6% occurs in areas with medium water scarcity, and 5% in locations with high water scarcity (Fig. 6).

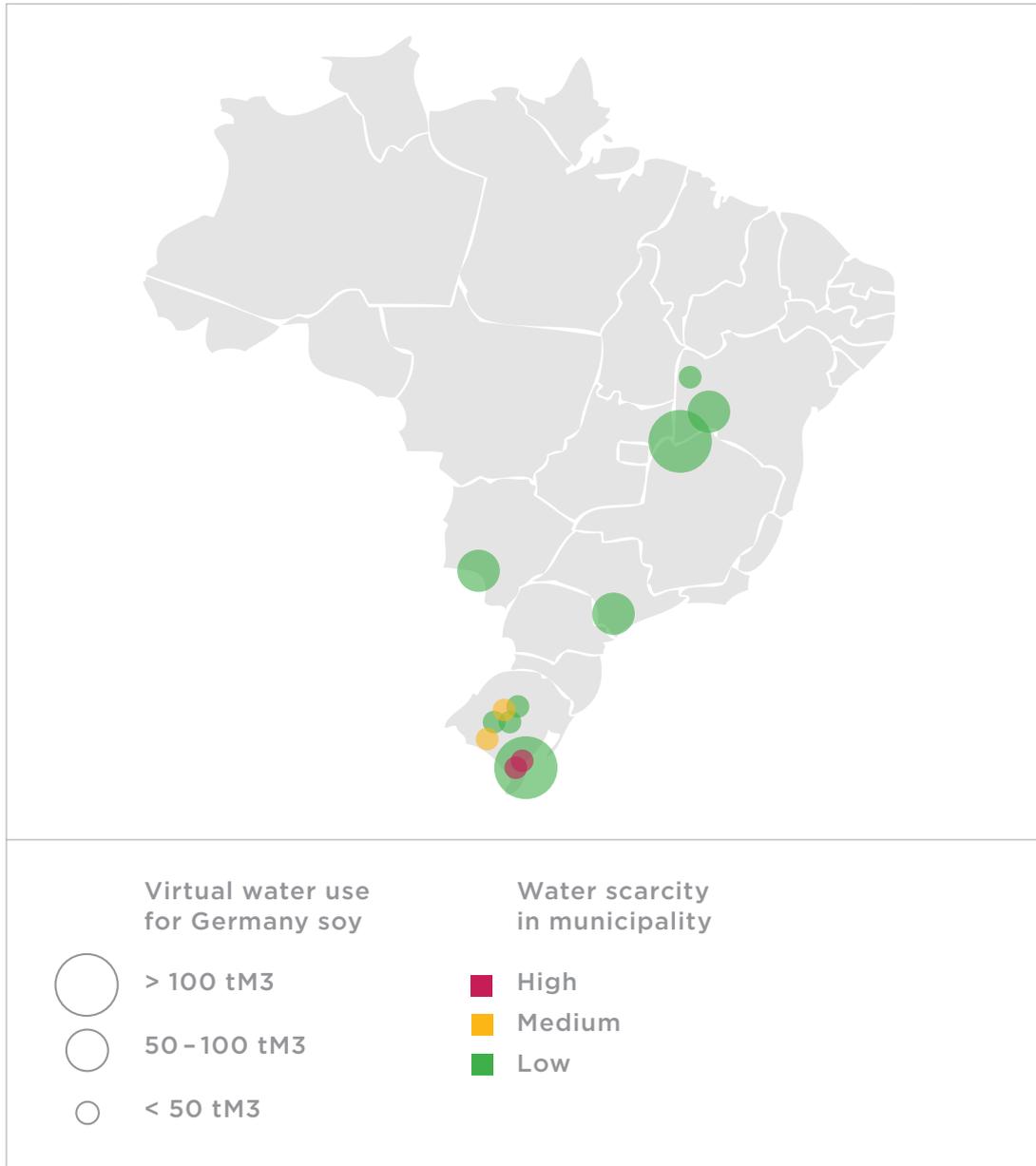


Figure 6: Virtual water exports embedded in soy exported from Brazil to Germany, and water scarcity per municipality: circle size represents the volume of virtual water export, and colour indicates water scarcity in the source municipality (red = high water scarcity, yellow = moderate water scarcity, green = no water scarcity).

Combining results from the MFA-PCS analyses with information on recent deforestation identifies traders that source their soy from municipalities with particularly high deforestation rates. Some exporters (e.g. Bunge and Los Grobo) are sourcing proportionally

greater shares of soy from areas with high deforestation. It is important to note that this deforestation is not necessarily a consequence of soy production, but rather that deforestation and soy production both occur within the same regions.

3.2 Germany's demand for oil palm products and related external effects

Germany imports about 1.7 million tonnes of palm oil and palm kernel oil per year, with annual exports of around 300,000 tonnes (FAOSTAT, 2016). Imports of palm kernel cake, predominantly used as animal feed, amount to 420,000 tonnes. Furthermore, Germany imports around 345,000 tonnes of palm kernel oil each year. Exports of the latter two commodities are small (11,000 tonnes palm kernel oil, 20,000 tonnes palm kernel cake). More than 90% of all imports come from five countries: The Netherlands (37%), Indonesia (29%), Malaysia (15%), Papua New

Guinea (7%), and Thailand (5%). Again, the Netherlands leads the list because it is the EU's largest maritime freight transport country (Eurostat, 2016), making it the third largest importer of palm oil worldwide after India and China (FAOSTAT 2016).

Results from IOTA show that the total demand for oil palm fruit embedded in all supply chains, products, and services consumed in Germany amounted to 3.2 million tonnes in 2007. IOTA MRIO shows that Malaysia and Indonesia are the two most important producers of oil palm fruits for German consumption (Fig. 7).

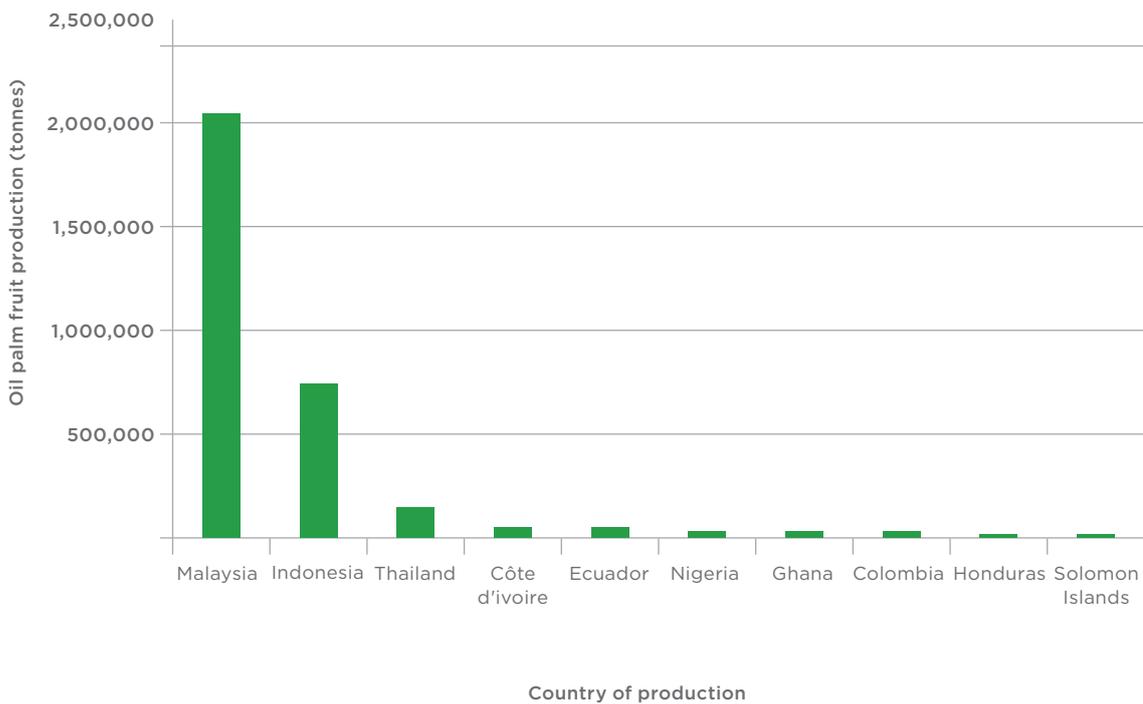


Figure 7: Top 10 producers of oil palm fruits for Germany's final consumption of goods and services, based on calculations by the environmentally extended IOTA MRIO tool for the year 2007.

Country of production/ impact	Production quantity (tonnes)	Percentage of total domestic production for German demand	Land use (ha)	Green water use (m ³)	Grey water use (m ³)
Malaysia	2,043,451	3%	96,644	1,682,797,161	69,163,609
Indonesia	738,690	1%	43,185	667,807,014	46,736,350
Thailand	156,771	2%	10,454	106,968,571	9,101,942

Table 2: Total oil palm fruit production for final consumption in Germany, and associated land and water requirements in the three largest producer countries calculated by the environmentally extended IOTA-MRIO tool for the year 2007.

Associated land requirements for oil palm cultivation are about 184,000 ha worldwide. Table 2 provides details of the production, land demand, and water requirements for the three countries that provide the majority of oil palm fruits for German consumption.

According to the results from IOTA, palm oil, palm kernel oil, and kernel cake made from oil palm fruits are consumed in Germany via a large range of products that consist of / contain / or whose production is reliant on these products, including slightly more than 1.2 million tonnes in processed foods and personal household items (including cosmetics) combined.

In the case of Indonesia, the PCS model shows that raw palm oil imported to Germany for processing originates from more than 130 districts, but that more than 50% comes from just 10 districts, mostly located on Sumatra, through the ports of Dumai and Belewan. More than 50% of the palm oil is imported through two companies — Golden Agri-Resources, Ltd., and AAA Oils and Fats, Ltd. Figure 8 shows the movement of Indonesian palm oil from the respective districts, via ports, traders, and country of import, to Germany where it is used by industry.

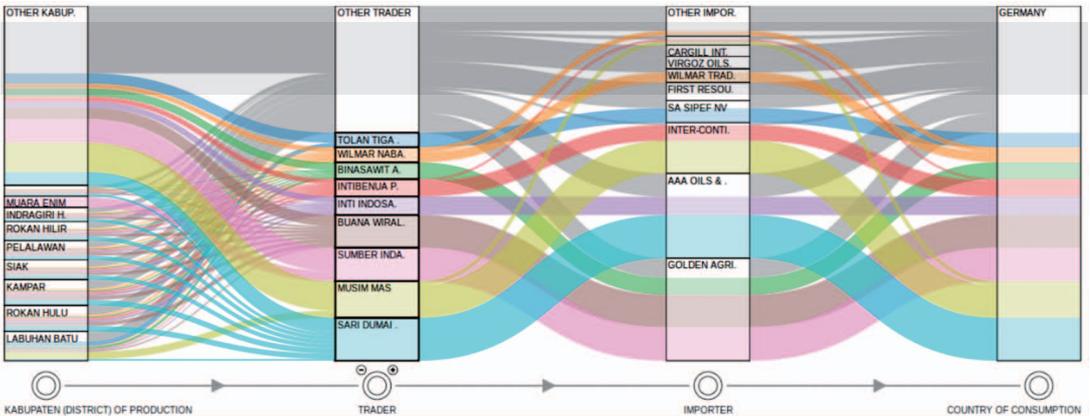


Figure 8: Supply chains of Indonesian palm oil before entering Germany (arrow width indicates flow volume in tonnes) based on results from the SEI-PCS model for the years 2013/2014.

4. Discussion and interpretation of the results

The results of this analysis highlight the importance for developed countries such as Germany to show leadership and to address sustainable consumption and production in implementing the 2030 Agenda. We focus on two commodity supply chains to highlight Germany's external environmental footprints. Such tangible examples can help to define integrated thematic approaches to implementing the 2030 Agenda, and for adopting an integrated approach to the implementation and review of the SDGs. Interlinkages between SDGs related to the production, trade, and consumption of commodities abound, and a thorough analysis of the interlinkages between the SDGs needs to address synergies and trade-offs, including those across regions. Such an integrated approach to the 2030 Agenda and the SDGs can ensure that advances in one goal do not hinder progress in others. Germany has spearheaded the development of the Nexus concept (Hoff, 2011) which provides a useful approach to address these questions.

The cases of soy and oil palm presented here demonstrate Germany's increasing dependence on imported agricultural commodities and biomass-based products; the country has become a large net importer. Given the environmental and socio-economic impacts in source countries, associated with the production of these commodities (i.e. Germany's external footprints), the responsibility to review and address these footprints becomes even more evident.

In this regard, the integrated and universal implementation of the 2030 Agenda and the Sustainable Development Goals (SDGs) will require examining the impacts of a country's policies and actions on other countries. It will further imply reconciling long- and short-term environmental and development-related targets, focusing on critical interlinkages, trade-offs,

and synergies (taking a "nexus approach"). The results of this analysis highlight the need for Germany to track and quantify comprehensively its supply chains for all major commodities and products in order to inform policy- and decision-making and to ensure successful implementation of the SDGs.

Germany is taking some positive steps in this regard. The first report by the German Government to the High-Level Political Forum, responsible for the coordination of SDG follow-up and review, confirms the country's commitment to address the implementation of this agenda in its national policies as well as internationally. To this end, implementation priorities have been defined at three levels: first, with regard to implementation and impacts in Germany; second, with regard to (e.g. trade-related) impacts in other countries and on global public goods by Germany; and third, with regard to supporting other countries through international cooperation with Germany. The report highlights sustainable supply chains, sustainable consumption and production, and resource efficiency as some of the priorities for implementing the 2030 Agenda.

Nonetheless, for better-informed decision- and policy-making in these priority areas, new approaches are required. Such approaches need to analyse the increasingly complex trade patterns and longer supply chains in our globalized world, and provide evidence of the associated external footprints. Conventional trade statistics tell only parts of the story; they do not account for indirect or virtual imports, i.e. commodities that are embedded in other traded products, or those that were used along the supply chain without physically entering Germany; neither do they include information on re-exports in processed form.

The approaches and tools utilized in this analysis can provide information necessary for properly tracking Germany's total biomass use and consumption and its origin. For instance, using SEI's IOTA model to analyse supply chains from the consumption end, we find that Germany's indirect imports of soy, embedded in or used for other processed import products, are significantly larger than its direct raw soy imports. We further determined that Germany's external land footprint for its soy consumption equals 20% of the total cropland area within Germany. SDG follow-up and review processes need to employ such innovative approaches that allow unearthing the information necessary for assessing the intricate international trade linkages between Germany's consumption and the producing countries.

The tools used here also begin to quantify the environmental impacts of biomass production (soy and oil palm) on the production sites. Using SEI's PCS model to analyse supply chains from the production end, we pinpoint soy and palm oil production areas for exports to Germany, e.g. in Brazil and Indonesia, at much higher resolution than previously possible. By combining that high-resolution information on export production with water scarcity data at the same resolution, we find that some of the soy imported by Germany originates from water-scarce areas of Brazil, most likely exacerbating local water scarcity. Such analyses are crucial for assessing the externalities associated with Germany's wellbeing and wealth. An analysis of complementary governance aspects at the production and consumption ends of the supply chains was beyond the scope of this paper, but would also be necessary to ensure the integrated implementation and review of the SDGs. For instance, the high-resolution data on export production, as generated with PCS MFA, could be linked to information on the state of land tenure at the producing sites. This would be very important for determining potential overlap between production sites and areas with high propensity for land conflicts.

Overall, the results of this analysis have significant implications for decision- and policy-making (discussed in greater detail in section 6), thereby providing opportunities for integrated, universal, inclusive, and participatory implementation of the 2030 Agenda.

The results of our global commodity flow analysis, as presented in this paper, begin to quantify the external environmental pressures (footprints) in the export production areas, as resulting from Germany's consumption and trade patterns. The large land and water demands and other environmental pressures, associated with Germany's consumption patterns but materializing outside of Germany, indicate that national (or European) environmental policies and regulations alone are not sufficient for a sustainability transition. Instead, other strategies, policies, and programmes should also be assessed for the external environmental pressures that they might directly or indirectly impose in other world regions, as transmitted through trade. These other (German or European) policy areas that need to be aligned with the results of such supply chain analyses and with the NSDS and SDGs (and with the EU's Sustainable Consumption and Production Action Plan) include, for example:

- The new German Resource Efficiency Programme (ProgRes II), which names “global responsibility as a key focus of our national resource policy” as one guiding principle (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2016);
- The EU's 7th Environmental Action Programme⁶, which has the vision of “living well, within the planet's ecological limits”, but which does not yet seriously address external environmental pressures and impacts caused by European lifestyles, consumption, and trade patterns;
- The EU's Raw Materials Initiative⁷, which requests “fair and sustainable supply of raw materials from global markets” to create win-win situations for both developing countries and the EU.

⁶ <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1386&from=EN>

⁷ <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008DC0699&from=EN>

Given the complexity of international supply chains, it is difficult to directly attribute external environmental pressures to any one of these German or European strategies, policies, and programmes. As demonstrated in the previous chapters, MRIO- and MFA-based analyses start to untangle these complex supply chains and begin to trace the effects of German consumption and import patterns back to the countries and localities in which the environmental pressures occur. With that, these tools can support the mainstreaming of sustainable consumption and production principles into any given policy; ultimately, they can also support policy coherence among the different policy areas described above. They also help to distinguish true decoupling of economic development and environmental pressures from actions that simply externalize those environmental pressures to other regions. These tools therefore enable monitoring and review of any new policies and measures in the context of sustainability transitions, sustainable consumption, and production, the NSDS, and the SDGs. Moreover, this information is also useful for policies and legislation that focus on consumer products, labelling, or overall demand.

Eventually, the new knowledge on trade-related external environmental pressures, generated with the help of MRIO and MFA tools, may also help to monitor the transgression of Planetary Boundaries more effectively, distinguishing a country's internal vs. external and total contributions to boundary transgression. The quantification of total (consumption-based) environmental pressures also provides an entry point for sufficiency approaches, and opportunities for staying within the global safe operating space (Rockström et al., 2009). Furthermore, this improved knowledge on trade (and underlying production and consumption) patterns can help minimize environmental pressures and resource use, through exploiting comparative advantages that other producer regions may have over Germany or Europe.

Any next step in using the results and information presented in this paper for policy making requires a “co-design and co-production of relevant knowledge” by scientists, policy makers, and other stakeholders as proposed by Future Earth (Mauser et al., 2013). Thereby, remaining knowledge gaps and new policy issues can be identified and addressed.

5. Governance implications for implementation, follow-up, and review of the 2030 Agenda and related policies

The implementation of the SDGs has begun, bringing opportunities to discuss and adopt approaches that fulfil the expectations of this comprehensive normative framework, which is intended to be universally applicable, indivisible in its interconnected nature, and balance the three dimensions of sustainable development. Germany and other countries have committed to contribute not only to its national implementation but also to global achievement of the goals. It is crucial to engage in discussions concerning the governance actions and mechanisms that might contribute to addressing the global responsibility dimension of implementation.

One particular issue to be addressed is the gap between the levels of ambition enshrined in the SDGs compared with business as usual development pathways. As suggested by our previous research (IASS, 2015), the global dimension of national responsibility could be approached from the perspective of the principle of Common but Differentiated Responsibilities, accounting for the different stages of development. In other words, countries like Germany could emphasize resource efficiency and reduction of total biomass consumption while simultaneously supporting the development space within producer countries (*idem*). In view of that, and with the aim of ensuring sound economic development while staying within our Planetary Boundaries, trade (and underlying production) could continue to consider the comparative advantages that other producer regions may have over Germany or Europe, but would also require strong prioritization of the need to increase

the overall productivity of commodity production through smart sourcing, and of minimizing environmental pressures and resource use both domestically and externally. Such an approach would be in line with SDG target 8.4, which aims to “improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead”; and with the NSDS objective to globally increase resource efficiency and to ensure that consumption and production patterns remain within Planetary Boundaries.

The wide array of policies to which this information is relevant further underlines the need to address interlinkages between 2030 Agenda goals and targets from the perspective of thematic areas, including reviews of related strategies, policies, and programmes that focus on consumer products, labelling, or overall demand. It will be equally important to link this type of analysis with officials overseeing said policies. The results of our supply chain analysis, as presented in this paper, begin to quantify the external environmental footprints in the producer areas, resulting from Germany’s consumption and trade patterns. For instance, the findings on Germany’s soy and palm oil demand and their respective footprints significantly expand the previously available information from conventional trade statistics.

The applicability of these results goes, however, well beyond these policies: the large amounts of land and water used, coupled with other environmental pressures that manifest outside Germany, indicate that national (and even European) environmental policies and regulations alone cannot ensure a transition to sustainable production and consumption patterns. In addition to these, other strategies, policies, and programmes need to be assessed to ensure they properly address and support the minimization of external environmental footprints. Examples of such policies highlighted in this study include the EU's Sustainable Consumption and Production Action Plan, the German Resource Efficiency Programme, the EU's Raw Materials Initiative, and the EU's 7th Environmental Action Programme. Further studies should be carried out to review these policies in depth.

Given the complexity of international supply chains and their often indirect effects, it is difficult to directly attribute external footprints to any particular strategy, policy, or programme. At the same time, this analysis shows that it is now possible to begin to untangle these complex supply chains and to trace the effects of German consumption and import patterns back to the countries in which the environmental pressures manifest. Considering this information in terms of a wide set of policies will ultimately support coherence between policy areas related directly or indirectly to Germany's consumption, production, and trade patterns. This goes in line with SDG target 17.14, which aims to "enhance policy coherence for sustainable development". It is further important to improve our understanding of direct and indirect side effects as policies related to trade and investment, such as the EU's Common Agricultural Policy, will influence prices and production and thereby trade patterns. The German and European Bio-Economy Strategies are a further example, as their implementation will inevitably require the sourcing of biomass from other world regions. Finally, Europe's Circular Economy Action Plan includes the cascading use of biomass, which, if implemented, will strongly impact international supply chains. This complex landscape of policies and measures related to sustainable consumption and production of biomass will require properly coordinated and coherent actions to ensure that they support the successful achievement of the 2030 Agenda. Follow-up and review processes will play an important role in this regard.

Follow-up and review mechanisms for the SDGs need to be set up to correspond to the need for universality and integration as laid out by the 2030 Agenda. Progress will be reviewed according to the framework of global indicators for each SDG target. However, the results of this analysis have also highlighted how conventional statistics only partially describe the various aspects involved in supply chains, for instance by only identifying approximately half of Germany's consumption-based soy footprints. Tools such as MRIO and MFA can support integrated SDG implementation as well as follow-up and review, by providing more detailed and comprehensive information. Furthermore, current debates, including within the UN process, require the consideration of qualitative information and other forms of knowledge, including traditional knowledge. The challenge will be to build on different forms of knowledge and to combine them in a non-discriminatory way while being aware and sensitive to power imbalances and cultures of participation. This would imply a monitoring of global indicators, which is accompanied by accountability initiatives including a wide range of stakeholders. Such an approach will require a "co-design and co-production of relevant knowledge" by scientists, policy makers, and other stakeholders (Mauser et al. 2013); and will need to "be accompanied by participatory governance instruments, and effective monitoring and accountability mechanisms that ensure national ownership" (Müller, Lobos Alva, & Weigelt, 2015). In this way, unsustainable trends, remaining knowledge gaps, and new policy issues can be identified and addressed.

Following our considerations so far, the question arises of how to best use the information presented here in implementing the 2030 Agenda. A first step will imply the review and assessment of policies related to the sustainable consumption and production of biomass from the perspective of the SDGs. Reviewing only the environment-related policies in Germany and internationally will not be sufficient to achieve integrated implementation. A review will also be necessary of governance aspects, including land tenure, the effects of supply chains and biomass production on local livelihoods, gender equality, and decent jobs. In this regard, the German Government could commission and carry out assessments of similarly concrete thematic areas to help accomplish an integrated approach to the SDGs. The 2030 Agenda strongly

emphasizes that natural resources such as soils, land, water, and healthy ecosystems are indispensable for sustainable development. Such studies could address the sustainable management and governance of natural resources, and changing patterns of consumption and production, highlighting synergies and trade-offs. Another area to address is the need to intensify and strengthen efforts to reduce demand and consumption. The German Government has some examples in this regard. For instance, the initiative “Zu Gut für die Tonne” (Too Good for the Bin), which aims to reduce food waste; or the Roundtable on Sustainable Palm Oil. Many more efforts of this kind will be needed to ensure sustainable demand and consumption, both at consumer but also at industry level. Such efforts should be accompanied by raising awareness of the sustainability challenges associated with com-

modity supply chains, and by engagement with the public and a wide range of stakeholders on the topic of sustainable production and consumption. In order to achieve coherence in production- and consumption-side efforts, Germany could, for instance, prioritize issues of sustainable production in bilateral agreements with producer countries. Coherence needs to be strengthened, especially between bi- and multilateral trade agreements and the achievement of environmental goals and all other SDGs. Finally, the German Government should engage in multi-stakeholder dialogues for the implementation, follow-up, and review of the SDGs, to ensure that the perspectives of all relevant actors are included, and that quantitative and qualitative information as well as other forms of knowledge are fully integrated within these dialogues and subsequent decision- and policy-making. ■

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