SUSTAINABLE DEVELOPMENT
SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

International spillovers and the Sustainable Development Goals (SDGs)

Measuring how a country's progress towards the SDGs is affected by actions in other countries

SDSN Policy Brief

Guido Schmidt-Traub, Holger Hoff, Maren Bernlöhr[1]
15 July 2019

Abstract
In an interdependent and interconnected world, countries' ability to achieve the Sustainable Development Goals (SDGs) is affected by positive or negative spillovers from other countries. International SDG spillovers are pervasive. They can relate to the environment, socio-economic factors, finance and governance, and security. Yet, monitoring of progress towards the SDGs and national strategies largely ignore such spillovers. This working paper describes international SDG spillovers and reviews techniques for their measurement. It proposes six practical steps to close knowledge and data gaps on trade-related international spillover effects.

[1] Guido Schmidt-Traub is Executive Director of the Sustainable Development Solutions Network (SDSN); Holger Hoff is Senior Scientist at Stockholm Environment Institute (SEI) and Potsdam Institute for Climate Impact Research (PIK); Maren Bernlöhr is Policy Advisor for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on secondment to SDSN. The views expressed in this policy paper may not represent the views of the SDSN, SEI, PIK or GIZ.

Acknowledgments

This policy paper has benefited from extensive advice from many experts. In particular, we would like to thank the following colleagues for their valuable contributions and comments.

Jessica Espey
Sustainable Development Solutions Network (SDSN) / Thematic Research Network on Data and Statistics (TReNDS)

Jorge Gómez-Paredes
SDSN Andes / Earth & Ocean Science Division, Nicholas School of the Environment, Duke University / School of Earth Sciences, Energy & Environment, Yachay Tech University

Guillaume Lafortune
Sustainable Development Solutions Network (SDSN)

Arunima Malik
University of Sydney ISA, School of Physics, Faculty of Science, Discipline of Accounting, Business School

Zach Wendling
Yale Center for Environmental Law & Policy

Kirsten S. Wiebe
SINTEF

In addition, we would like to thank the GIZ project "Strengthening the Sustainable Development Solutions Network", initiated on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) for their support.

Table of Contents

1. Introduction

Implementing the 2030 Agenda and achieving its Sustainable Development Goals (SDGs) (United Nations, 2015) will require deep transformations in every country (TWI2050, 2018; Sachs et al., 2019). In an increasingly interdependent world, countries' actions can have positive or negative effects on other countries' ability to achieve the SDGs. Such international "spillovers" are pervasive and have been proliferating as the expansion of trade has been exceeding the growth in gross world product (Fischer-Kowalski et al., 2015). Examples of international spillovers include greenhouse gas emissions that result in polar melt and rising seas, which threaten to submerge many countries and coastal communities around the world. Demand for commodities (such as palm oil) in one country that fuel deforestation in other countries (Valin et al., 2015; Lustgarten, 2018). Tolerance for poor labor standards in international supply chains that harm the poor, particularly women, in many developing countries (ILO, 2014). Examples of financial spillovers include those related to investments or tax havens and banking secrecy which can inhibit other countries' ability to raise the public revenues needed to finance the SDGs (IMF, 2014; Oxfam, 2016), and as the International Monetary Fund (IMF) has recently shown (Gaspar, 2018), poor countries require increased international development assistance if they are to meet the goals – a positive international spillover.

Positive and negative spillovers must be understood, measured, and carefully managed since countries cannot achieve the SDGs if spillovers from other countries counteract their efforts. The 2017 SDG Index Report issued by the SDSN and Bertelsmann Stiftung (Sachs et al., 2017) provided a first systematic assessment of international spillover effects in the context of the SDGs, which has been developed further in the 2019 edition (Sachs et al., 2019). It shows that negative effects tend to flow from rich to poor countries, including through transnational companies that control international supply chains and are mostly located in high-income countries. As part of global efforts to achieve the SDGs, these countries therefore bear a special responsibility to identify and tackle international spillover effects.

A key challenge lies in the measurement of international spillover effects which is not commonly undertaken by national statistical offices. International institutions tend not to have access to all the data required and the current global statistical architecture is not designed, equipped or mandated to tackle such issues. As a result, spillovers are not well reflected in national and international statistics. As a result, the 232 official SDG indicators (UN Statistics Division, 2017) do not include metrics for spillovers with a few exceptions as official development assistance. Fortunately, the scientific literature on international spillovers and their measurement has expanded significantly in recent years, owing in particular to efforts by the OECD, UNCTAD, and several research teams to harmonize input-output tables and trade statistics, as discussed further below.

The SDGs broadly recognize the importance of international spillover effects with SDG 12 on Responsible Consumption and Production requiring developed countries to take the lead in tackling this issue. Some countries have begun to reflect spillovers in SDG implementation, such as Sweden's Generational Goal which aims to "hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders"(Weitz et al., 2018). The German Sustainability Strategy defines SDG implementation by referring to actions taken "in, by and with Germany" (Bundesregierung, 2018), in recognition of external impacts of its national activities and decision making.

This SDSN Policy Brief aims to make three contributions to the global debate on international spillover effects. First, it describes a typology of international spillovers and their relationship to the SDGs, drawing on Sachs et al. (2017, 2019). Second, it summarizes techniques available for the measurement of trade-related international spillovers and their indicators. And finally, it outlines priorities for closing knowledge and data gaps on trade-related international spillover effects. A technical annex provides more details on the methods measuring spillover indicators.

2. Typology of international SDG spillovers

Economists have studied positive and negative spillover effects or "externalities" since Arthur Pigou's pioneering work in the first half of the 20th century. International spillover effects are said to occur when one country's actions generate benefits or impose costs on another country that are not reflected in market prices, and therefore are not "internalized" by the actions of consumers and producers (Sachs et al., 2017). The benefits or costs may be referred to as positive or negative externalities. Much economic work focuses on how these can be "internalized," for example through corrective taxation, such as proposed cross-border taxes for commodities that come with significant environmental or socio-economic footprints or the widely proposed "carbon tax" to internalize the externality of CO_2-induced global warming.

Most spillovers are mediated through international trade in goods and services. For example, trade in steel or fruits can be said to incorporate the greenhouse gas emissions and water use associated with these products. Financial services can give rise to adverse spillovers, including money-laundering and tax avoidance. Some spillover effects occur through physical flows across borders, such as sulphur dioxide ("acid rain") that crosses many national borders, or the water pollution transmitted through surface water or groundwater flows. Other spillover effects occur through the unsustainable use of "global commons," such as the high seas, the biosphere, and the atmosphere[2]. Richer countries tend to exploit global commons disproportionately, as illustrated by the cases of fishing on the high seas (Sala et al., 2018) and greenhouse gas emissions (Le Quéré et al., 2018).

International spillover effects are said to occur when one country's actions generate benefits or impose costs on another country that are not reflected in market prices, and therefore are not "internalized" by the actions of consumers and producers (Sachs et al., 2017). The benefits or costs may be referred to as positive or negative externalities.

This working paper focuses mainly on trade-related spillover effects, including those associated with international supply chains. Several trade-related environmental and socio-economic spillovers are addressed by the SDGs, including deforestation, greenhouse gas emissions, labor rights, and child labor. They can be grouped into four categories:

1. Environmental spillovers relate to the use of natural resources and pollution. They tend to be negative externalities whereby demand from importing countries increases pollution and natural resources in exporting countries. Spillovers relating to natural resource use occur for example with trade in threatened species and trade in commodities that uses, overuses, or degrades environmental resources. Prominent examples are deforestation and biodiversity loss, which are driven by trade in timber, palm oil, coffee, rubber, soy, and other commodities (Lenzen et al., 2012; Chaudhary and Kastner, 2016; Nishijima et al., 2016; Weinzettel and Wood, 2018; Wiedmann et al., 2015). Another example for the overuse of resources concerns water embodied in international trade, often referred to as "virtual water" (Hoekstra and Hung, 2002), such as the wide-spread mining of groundwater resources for export markets (Dalin et al., 2017).

---

[2] Another positive spillover are "global public goods". In contrast to common goods, the use of such public goods is non-rivalrous. Examples include knowledge and innovation. Markets tend to underprovide global public goods because the total social benefits are not reflected in the market incentives to provide them.

Environmental pollution can have transboundary effects in two ways. First and most importantly, environmental pollution is embodied in international trade. For example, a country may import industrial products that generate high emissions of greenhouse gases and other pollutants instead of producing them locally. This will improve the importing country's domestic environmental performance at the expense of that in the exporting countries (Kander et al., 2015). Similar trade effects are well documented for reactive nitrogen (Oita et al., 2016), sulphur and nitrous oxides (Zhang et al., 2017), particulate emissions (Zhang et al., 2017), pollution from electronic waste (Schmidt, 2006; Lepawsky, 2015), and many other pollutants.

International spillovers can be grouped into several categories: *Environmental spillovers, socio-economic spillovers, spillovers related to finance and governance as well as security spillovers*

Second, environmental spillovers occur through direct cross-border flows of pollutants in air and water. For example, sulphur dioxide emissions from one country can cause acid rain in neighboring countries, even across oceans, as illustrated by the health effect of air pollution generated in China on the Western United States and Canada (Zhang et al., 2017). Transboundary flows in water pollution, in particular through surface waters is widespread but poorly measured and documented.

2. Socio-economic spillovers include the application of international labor standards, particularly across international supply chains (ILO, 2014). Such spillovers can be positive, for example when international corporations introduce higher labor standards in a country, but they are often negative involving the exploitation of workers in developing countries. In some cases, international supply chains tolerate and encourage child labor and forced labor, including modern forms of slavery (Walk Free Foundation, 2016; UNICEF, 2018; Gómez-Paredes et al., 2016). Similarly, international trade may cause spillovers relating to occupational hazards (Alsamawi et al., 2017) in the producer country and along the supply chain.

3. Spillovers related to finance and governance include international development finance as one of the most important positive spillovers. In particular official development assistance is critical for poor countries to achieve the SDGs (Gaspar, 2018; Sachs et al., 2018). Policies for and practice of international investments can support or hinder the achievement of the SDGs (UNCTAD, 2014). Rules and regimes for managing international trade have major implications for economic development in rich and poor countries alike (CGD, 2018) that raise particularly complex issues of definition and measurement. Major negative spillovers are generated by unfair tax competition, banking secrecy, and money laundering. International competition on corporate taxation can lead to a "race to the bottom" and has in many instances, undermined countries' ability to raise public resources (IMF, 2014; Dharmapala, 2014) needed for public investments in the SDGs (Gaspar, 2018) – a process the OECD refers to as base erosion (OECD, 2014). Of particular concern are hidden beneficial ownership of companies and related practices that allow companies and individuals to shift profits and assets out of countries in ways that are difficult to track (Tax Justice Network, 2018; Oxfam, 2016). Some of these efforts are technically legal, but a lot of profit shifting constitutes money laundering that is abetted by tax havens, some of which are under the jurisdiction of OECD countries.

4. Security spillovers include negative externalities, such as the trade in arms, particularly small arms (Adeniyi, 2017) and organized international crime. While difficult to track, the Small Arms Survey: Trade Update 2017 estimates that the international small arms trade was worth at least USD 6 billion in 2014 (Holtom and Pavesi, 2017). Estimates produced by the Stockholm Peace Research Institute (SIPRI) shows that transfers of major conventional weapons have increased in significant parts of the world over the past decade especially in the Middle East and North Africa (SIPRI, 2018). Among the positive spillovers are investments in conflict prevention and peacekeeping, including through the United Nations.

3. Methods for measuring trade-related international spillovers

Data on cross-border spillover effects tends to be sparse and incomplete. The increasing length and complexity of supply chains complicates efforts to assess trade-related spillovers. Moreover, national and international databases are often inconsistent, and national statistical offices tend not to be mandated to measure or report on international spillovers. The work of international organizations in this area is furthermore hampered by political sensitivities among member states on the measurement of spillover effects and on the difficulties of clearly assigning responsibility for negative externalities to individual countries along the complex supply chain.

A lot of work on international spillovers focuses on individual supply chains, such as apparel, or specific products, such as palm oil from South-East Asia. Such case studies have strengthened our understanding of international spillover effects (see box below), but they do not provide the comprehensive data needed for assessing spillover effects on national SDG implementation.

Methods for assessing international trade-related spillovers fall into three broad categories, which are described below and in greater detail in the appendix:

1. Multi-Regional Input-Output (MRIO): MRIO analyses combine internationally harmonized input-output tables and trade statistics for sectors or groups of products and services. MRIOs quantify trade-related spillovers related to environmental, socio-economic, security, and governance/finance spillovers. This top-down method offers comprehensive global coverage of the full supply chain. In turn, it operates at high levels of aggregation. It generally measures average impacts and cannot distinguish between context-specific technologies, efficiencies, and intensities of resource use and pollution. As a result, MRIO methods are best suited for assessing aggregate spillover effects at the sector level or for product groups. Results can be presented for each country. A major advantage is the relative ease with which analyses can be conducted and represented for different countries once the MRIO tables have been set up. Country coverage is limited however, by the scope of available MRIO databases.

Different methods for assessing international trade-related spillovers can be grouped into Multi-Regional Input-Output (MRIO), Life Cycle Assessment (LCA) or Material-Flow Analyses (MFA) models

2. Life Cycle Assessment (LCA): LCA uses a bottom-up approach to assess the environmental impact of individual products and their production processes across geographic and temporal scales. LCA is also increasingly being applied to socio-economic impacts. The principal advantage of this method lies in the high product resolution and the ability to consider different production technologies. However, the analytical scope of the LCA method is limited by the system boundary or cut-off, the so-called “truncation problem”(Reap et al., 2008), which needs to be defined for any product. As a result, LCA cannot be as comprehensive as MRIO. They also require vast volumes of data, which may be unavailable, particularly where information is commercially sensitive. Owing to these constraints, LCA is less suitable than MRIO to quantify SDG spillover effects at the national level.

Case study: Assessing deforestation spillover effects from soy supply chains from South America to Europe and China

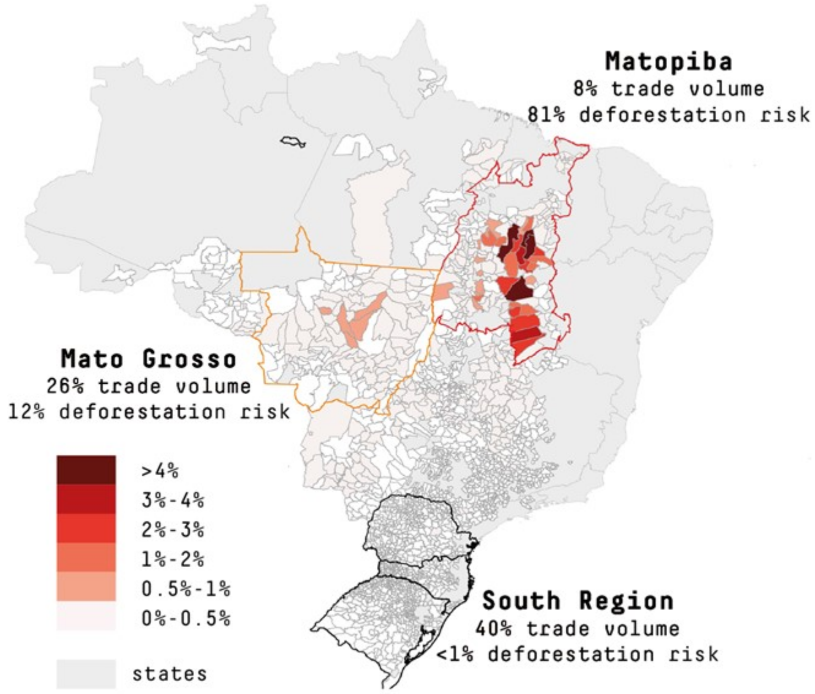

Figure 1: Soy deforestation risk of Chinese imports of soy from Brazil, 2013-2017, by municipality

Europe and China are the biggest importers of soy from South America, primarily for animal feed for poultry and pork, and for biofuels. The production of the soy embedded in these exports is associated with deforestation. Trase, a digital tool for exploring supply chains, makes it possible to better understand the links between import markets and subnational production regions and therefore to see where commodity production is linked to deforestation risks. This means that consumer governments can assess and track deforestation risk in their imports.

Focusing on the European Union (EU) and China's soy imports from Brazil, where forest and native vegetation in the Amazon and Cerrado are being cleared for soy expansion, Trase analysis shows that from 2013 – 2017 Europe's soy imports were linked to almost twice as much soy-related deforestation per ton than soy imports to China. This is because EU countries primarily source from the Cerrado, where vegetation is being cleared for soy, while China predominantly sources from the Southern region, where deforestation rates are much lower (see Figure 1). This shows the importance of sub-national data in understanding spillover effects as deforestation risks depend on sourcing patterns. This detail creates an opportunity for consumer countries to reduce their exposure to soy deforestation by prioritizing efforts to improve the sustainability of soy production in these specific high-risk municipalities.

This case study is part of a survey on the governance of the soybean supply chain with a particular focus on the impact of trade imports from Europe and China on important soybean producing countries. The objective is to understand how the governance of international supply chains can be reformed to curb spillover effects and to comply with the Sustainable Development Goals (SDGs). The survey was commissioned by the GIZ Sector Project "Agricultural Trade, Agribusiness, Agricultural Finance" on behalf of the German Federal Ministry of Economic Cooperation and Development (BMZ) to Climate Focus, the Global Canopy, and the Sustainable Development Solutions Network (SDSN).

3. Material-Flow Analyses (MFA): MFA offer an additional approach for assessing spillovers, by tracking specific material flows along supply chains and across countries. This tracking can be done at high spatial resolution, but primarily for raw or less processed commodities. To some extent, this limitation can be overcome by including conversion factors (e.g. from feed to livestock products). As for the MRIO and LCA methods, there have been more applications of the MFA methodology to environmental impacts than to socio-economic impacts so far. Like LCA, MFA also suffers from the truncation problem, so it cannot be as globally comprehensive as MRIO, and it is hard to estimate country-level impacts.

Different research groups have applied these three methods to different impacts (Figure 2). The focus so far has been primarily on environmental and less on socio-economic impacts. So far, many spillovers relating to finance, governance, and security, cannot be estimated using these methods.

Figure 2: Examples of spillovers quantified using the Eora MRIO database (source: worldmrio.com)

As described further in the annex, hybrid approaches seek to combine advantages of the different methods in an effort to overcome individual constraints. Examples of groups working at the forefront of these questions include Vienna University, that uses hybrid economic-physical MRIO-MFA analyses; ZEF at Bonn University develops MRIO-LCA hybrids; Norwegian University of Science and Technology in Trondheim develops hybrid MRIO analyses to quantify spillovers relating to greenhouse gas emissions and biodiversity loss; Sydney University has pioneered hybrid MRIO-LCA analyses for land, water, biodiversity, and greenhouse gas spillovers. A special case is the described TRASE platform developed by the Stockholm Environment Institute which traces and visualizes at high spatial resolution the impacts of international trade e.g. on carbon, land and forests, initially applied on soy, palm oil and livestock products. The Industrial Ecology Virtual Laboratory (IELAB) and other groups harness big data from social media and other sources for the analyses of supply chains and footprints.

Common across all methods are major data challenges. Data relating to systems of national accounts (SNA) remains weak, particularly in middle- and low-income countries. This is one of the reasons why developing countries are less represented in research on international spillover effects (Tian et al., 2018). Better SNA data is critical to fill key knowledge gaps related to SDG spillover effects, including context information on production and consumption. Another challenge is that research groups which develop new, or improve existing, methods for spillover analyses often lack the resources or incentives to continue their work by updating data sets and producing continued time series over many years, which are critical for policy analysis and advocacy around international spillovers.

4. Recommendations

International spillovers are critical for SDG implementation, but data availability is limited, and these issues are rarely discussed in policy circles. Six priorities for action can help address these gaps:

1. Improve communication and policy use of data on spillover effects

The 2017 SDG Index and Dashboards (Sachs et al., 2017) showed that substantial data is available on international spillovers, but they were mostly confined to scientific publications behind paywalls and written in styles that are inaccessible to many policy makers. International rankings and the inclusion of international spillover data in products like the SDG Index can help raise awareness of available data. In collaboration with Yale Center for Environmental Law & Policy, the SDSN is developing a new Environmental Impact Index (EII)[3], which aims to give greater prominence to the role of international spillovers in driving environmental outcomes. It will also underscore the need for countries to monitor and target their territorial and transboundary environmental impacts through appropriate policies. To this end country profiles in the 2019 SDG Index highlight countries' performance on international spillovers (Sachs et al., 2019).

Moreover, international spillover effects should be considered in international fora, such as the High-Level Political Forum (HLPF) on the 2030 Agenda for Sustainable Development, as well as national SDG reports, including the Voluntary National Reviews (VNRs). High-income countries, in particular, need to describe how they plan to reduce the negative international spillovers they generate.

Recommendations call upon academia, policy makers and businesses to join forces and tackle negative spillover effects.

Since businesses drive most resource use and pollution, they should also systematically include spillover information related to their supply chains in annual sustainability and SDG reporting. The rapid growth of Life Cycle assessments makes such reporting by company and supply chain possible. Spillover data and information also needs to be considered more systematically in standards and ratings for corporate social responsibility, as developed by the Global Reporting Initiative, the Science-Based Targets Networks, the World Benchmarking Alliance, and others.

2. Improve governance of international supply chains based on available spillover data and information

It is known from available spillover analyses that many international supply chains, particularly those relating to food systems, are unsustainable. The ability of individual companies to correct these failings can be limited, so industry- and supply-chain-wide approaches are needed. Several such industry initiatives exist, including for cocoa, coffee, palm oil, soybeans, and zero-deforestation supply chains. Yet, their impact has been limited as illustrated by a recent Greenpeace (2019) report on zero-deforestation supply chains. Such voluntary industry initiatives need to be framed by national and international standards and governance mechanisms. Where potential demand substantially exceeds sustainable supply, as is likely already the case for palm oil fruit, comprehensive approaches are needed to manage demand as well as supply. More research and

[3] Yale Center for Environmental Law & Policy's work on the EII is supported by the Ida and Robert Gordon Family Foundation as well as Marshall Ruben and Carolyn Greenspan, and SDSN's contribution is supported by the GIZ program in support of SDSN, initiated on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

experimentation are needed to understand how the governance of trade and international supply chains can be reformed to curb spillover effects and align the supply chains with the SDGs and the objectives of the Paris Agreement.

3. Apply existing MRIO, MFA and LCA methods to more SDG spillovers, including time series

To date, only a subset of the MRIO, MFA and LCA data has been mined for metrics on international SDG spillovers. Many scientific assessments are one-off analyses that seek to demonstrate a new methodology, so continuous time series data is not systematically available. With modest incremental resources, research teams could apply existing MRIO, MFA and LCA techniques to a broader set of impacts or spillovers and produce time series data using published methods. In this way, major data gaps could be filled in a relatively short period of time. In some areas, new methods might need to be developed, which will take more time and resources. To ensure up-take by the business and policy communities, the data should be made freely accessible and presented in a format that is easy-to-digest.

4. Promote open-access supply chain data for LCA

The rapid growth in LCA approaches (Annex) and application offers tremendous potential for providing high-resolution data on international supply chains and their spillover effects. A key challenge for researchers is to collect the large volumes of high-resolution data of which some is considered commercially sensitive by the companies that own the data. As recommended by SDSN's TReNDs group, new models of open-data protocols are required to bring more data into the public domain without undermining companies' need to keep some supply-chain data confidential.

5. Improve consistency of international and national data, applying the System of National Accounts (SNA), in particular in developing countries

In spite of growing investments in SNA, their coverage and resolution remain insufficient, particularly in developing countries and with regard to the supply-and-use tables (SUT) underlying global MRIO databases. This undermines consistency between international and national data required to better understand spillover effects. Since SNA serve many critical data needs for policymaking, greater investments are necessary to improve their quality and coverage, particularly in middle- and low-income countries.

6. Advance hybrid methods for assessing international spillover

Hybrid methods and higher-resolution MRIOs – as described in more detail in the annex offer promising methods for improving our understanding of international spillover effects related to the SDGs. Given the limited availability of SUT/SNA data, approaches based on combining globally available trade statistics with simple econometric models linking trade to socio-economic impacts could be developed. Multi-footprint assessments can also help identify potential trade-offs between environmental and socio-economic impacts.

Annex: Detailed description of methods

Multi-Regional Input-Output (MRIO)

MRIO models provide "the big picture" of the global economy (i.e. a complete and consistent global overview of international and inter-sectoral exchanges and patterns). At high spatial and sectoral aggregation level, individual products or companies are not explicitly represented, hence their variability. MRIO tables can be extended beyond the purely economic realm, by adding environmental and socio-economic extensions, as satellite accounts (e.g. for water or land use or labor conditions) with the same level of spatial and sectoral detail (Mekonnen and Hoekstra, 2011; UN, 2014). This allows for different spillovers to be quantified and consistently compared for countries or sectors as a whole.

Such satellite accounts commonly consist of average resource use intensities, emission intensities, or socio-economic impacts associated with production and processing per industry sector. This top-down approach may over- or underestimate the actual context-specific environmental or socio-economic impacts. Moreover, satellite accounts mostly consider so-called midpoint indicators, such as greenhouse gas emissions and water use, instead of endpoint indicators, i.e. impacts on the ground or "footprints". Therefore, top-down MRIO supply chain analyses need to be complemented with bottom-up local context information to inform policies at national or sub-national level (e.g. on resource management or environmental and socio-economic governance).

Four major global MRIO databases are updated regularly and openly accessible: EORA, EXIOBASE, OECD-ICIO and WIOD. They are compared in the special issue of Economic Systems Research (Inomata and Owen, 2014) on MRIO inter-comparison and Malik et al., (2018). The GTAP MRIO is not freely available; the Global MRIO lab is functional in a MATLAB-based interface; and GRAM has been discontinued. All databases are available as time series from 1995 to at least 2011 in NACE 1 classification (the classification of economic activities in the European Union). The OECD-ICIO and WIOD databases are being upgraded to a higher-resolution industry classification NACE 2, which corresponds to the system of national accounts used in most countries.

EORA covers the largest number of countries, relying heavily on estimation methods for missing data. EXIOBASE and WIOD focus on European countries and Europe's main trading partners. The OECD-ICIO covers more than 60 countries and increases country coverage, as new data becomes available. Both, WIOD and OECD-ICIO, have been developed for the analysis of economic flows between countries and industries, while the motivation for EXIOBASE and EORA was the estimation of environmental footprints. This is reflected in the level of industry detail, where EXIOBASE emphasizes the detailed representation of extractive industries with corresponding satellite accounts for associated emissions, land-, and water-use. Differences in model outcomes result mostly from differences in input data rather than differences between the models. Efforts are underway to harmonize accounts for employment, energy, and emission across the databases. For details on the assessment see Murray and Lenzen (2013).

Life Cycle Assessment (LCA)

This method quantifies environmental impacts of products, processes, and services from cradle-to-grave, i.e. from raw material extraction through processing, manufacture, distribution, use, up to disposal (ISO 14040:2006 and ISO 14044:2006). It can be used to estimate high-resolution environmental footprints, such as the carbon footprint, across supply chains. LCA is commonly used to evaluate footprints from organizations, sectors, or countries (Hellweg and Mila i Canals, 2014; Martínez-Blanco et al., 2015b, 2015a).

Methodological advances have made LCA comprehensive in its impact assessments across key categories, such as climate change, acidification, ozone depletion, or eutrophication. These can, in turn, be aggregated into endpoint indicators, such as human or environmental health (Hellweg and Mila i Canals, 2014). LCA methods are highly data intensive and rely on databases for resource consumption and emission calculation across upstream and downstream stages of the product life cycle. LCA outcomes must be expressed and communicated with respect to an input to or an output from the system (e.g. 1 ton soybean at farm gate in Brazil, 1 kg of refined sugar packaged in paper and delivered to a consumer in France, 1 km driven under US average conditions, average food consumption per person in the EU). This allows for comparative assessments of systems to aid less resource-intensive design. Work is ongoing to connect LCA with planetary boundaries (Clift et al., 2017).

Life Cycle Costing is frequently applied in parallel to address eco-efficiency (Swarr et al., 2011). More recent methods also assess social impacts within the LCA framework. Such social LCA address impacts on workers, the local communities, the consumers, the society and other supply chain actors. Impacts can include human rights, working conditions, health and safety, cultural heritage, governance or socio-economic repercussions. The Life Cycle Initiative of the United Nations promotes methodological improvements and harmonization towards comprehensive Life Cycle Sustainability Assessment (LCSA) (UNEP, 2009, 2015). LCSA is therefore particularly well suited to become a decision support tool to serve the SDGs.

Similar to the upstream truncation under MFA, LCA must define a system boundary and cut-off criteria to isolate the product system. Hence, LCA usually provides context- or case-specific results, although scenario and uncertainty analyses are frequently applied to enhance their applicability. Most LCA applications quantify average impacts based on historical or measured data; although 'consequential LCA' are becoming increasingly available to explore the impacts of supply- and demand-driven changes in the product system.

One of the main limitations of LCA is the need for large amounts of data and regionalized impact assessment methods, which limits its applicability to global supply chains (Hellweg and Zah, 2016). Data can be hard to obtain, as companies are often hesitant to disclose information on their supply chains.

While LCA is less applicable for country-level assessments of spillover effects, it can provide more details at the product level, particularly with regard to different input technologies that cannot be assessed using MRIO. LCA can also more easily assess different impact categories simultaneously compared with MRIO. This includes exploring trade-offs among impact categories. A key challenge for understanding SDG spillovers is to broaden the scope of LCA to measure impacts from product consumption bundles by means of more streamlined applications.

Material Flow Accounting (MFA)

MFA traces physical flows of materials associated with commodities along national and international supply chains using industry data and international trade analyses. In principle, it can do so at any spatial or product resolution. MFA can be combined with resources embedded in trade, such as virtual water or land use, which serve as inputs for the commodity but do not flow physically with the commodity. By including conversion factors or conversion efficiencies, the method can also associate processed products with resource use and emissions at the location of primary production. Additional local context information is required to derive true impacts on the ground ("footprints"), as in the case of MRIO. Depending on the boundary definitions for the respective application, MFA requires that supply chain analysis is truncated at some point. It, therefore, cannot offer analyses that are as comprehensive as with MRIO. There is also the risk of double counting and of not representing re-exports correctly.

Hybrid approaches for monetary and biophysical assessments

The development of hybrid methods aims to overcome the limitations of each method by combining the strengths of the different approaches. In particular researcher aim to combine the completeness of MRIOs with detailed bottom-up process data available through MFA and LCA (Malik et al., 2015).

As one illustration, studies of land use change and associated impacts of global supply chains on ecosystems tend to use either monetary MRIO models or biophysical MFA (Chaudhary et al., 2017; Chaudhary and Kastner, 2016; Sandström et al., 2017; Nishijima et al., 2016). Several authors have investigated the differences, advantages, and limitations of monetary versus physical accounting (Bruckner et al., 2015; Kastner et al., 2014; Hubacek and Feng, 2016; Weinzettel and Wood, 2018; Weinzettel et al., 2014). It is commonly found that the methods may lead to contradictory results, due to their assumptions and limitations. Whereas MRIOs provide a comprehensive mapping of the global supply chain network, they lack detail on products and spatial resolution. Furthermore, allocating pressures based on monetary values can be problematic in cases when prices of products vary significantly across uses or exhibit unpriced externalities (Liang and Zhang, 2013). Moreover, biophysical accounting models need to truncate and are therefore unable to trace non-food uses of biomass to final consumers. This constitutes a severe drawback when assessing footprints of crops that are primarily for industrial and energy purposes such as vegetable oil. So hybrid monetary and physical models may offer a promising way forward (Bruckner et al., 2015), as demonstrated by assessments of land use and biodiversity footprints of vegetable oils (Többen et al., 2018).

References

Adeniyi, A. (2017), "The human cost of uncontrolled arms in Africa," Oxfam, Oxford.

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.

Bruckner, M., G. Fischer, S. Tramberend, and S. Giljum (2015), "Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods," *Ecological Economics*, 114, 11–21.

Bundesregierung (2018), "Deutsche Nachhaltigkeitsstrategie. Aktualisierung 2018.," Presse- und Informationsamt der Bundesregierung, Berlin.

CGD (2018), "Commitment to Development Index 2018," Center for Global Development, Washington D.C.

Chaudhary, A., L.R. Carrasco, and T. Kastner (2017), "Linking national wood consumption with global biodiversity and ecosystem service losses," *Science of The Total Environment*, 586, 985–994.

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

Clift, R., S. Sim, H. King, J. Chenoweth, I. Christie, J. Clavreul, C. Mueller, L. Posthuma, A.-M. Boulay, R. Chaplin-Kramer, J. Chatterton, F. Declerck, A. Druckman, C. France, A. Franco, D. Gerten, M. Goedkoop, M. Hauschild, M. Huijbregts, and R.J. Murphy (2017), "The Challenges of Applying Planetary Boundaries as a Basis for Strategic Decision-Making in Companies with Global Supply Chains," *Sustainability*, 2017, 279.

Dalin, C., Y. Wada, T. Kastner, and M.J. Puma (2017), "Groundwater depletion embedded in international food trade," *Nature*, 543(7647), 700–704.

Dharmapala, D. (2014), "What do we know about base erosion and profit shifting? A review of the empirical literature," *Fiscal Studies*, 35(4), 421–448.

Fischer-Kowalski, M., M. Dittrich, N. Eisenmenger, P. Ekins, J. Fulton, T. Kastner, H. Schandl, J. West, and T. Wiedman (2015), "International Trade in Resources: A Biophysical Assessment," in: *Report of the International Resource Panel.*, United Nations Environment Programme, Paris.

Gaspar, V. (2018), *Fiscal Policy and Development. Spending Needs for Meeting Selected SDGs*, New York.

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.," 20(3), 611–622.

Greenpeace (2019), "Countdown to Extinction. What will it take to get companies to act?," Greenpeace, Amsterdam.

Hellweg, S., and L. Mila i Canals (2014), "Emerging approaches, challenges and opportunities in life cycle assessment," *Science*, 344(6188), 1109–1113.

Hellweg, S., and R. Zah (2016), "What is new at the data front?," *The International Journal of Life Cycle Assessment*, 21(9), 1215–1217.

Hoekstra, A.Y., and P.Q. Hung (2002), "Virtual water trade. A quantification of virtual water flows between nations in relation to international crop trade.," 11, 166.

Holtom, P., and I. Pavesi (2017), "Trade Update 2017: Out of the Shadows," Small Arms Survey, Graduate Institute of International and Development Studies, Geneva, Switzerland.

Hubacek, K., and K. Feng (2016), "Comparing apples and oranges: some confusion about using and interpreting physical trade matrices versus multi-regional input–output analysis," *Land Use Policy*, 50, 194–201.

ILO (2014), "Rules of the Game: a brief introduction to International Labour Standards," International Labor Organization, Geneva.

IMF (2014), "International Spillovers in Corporate Taxation," IMF Policy Paper, International Monetary Fund, Washington D.C.

Industrial Ecology Virtual Laboratory - Home, http://www.ielab.info/, accessed July 12, 2019a.

Inomata, S., and A. Owen (2014), "A Comparative Evaluation of Multi-Regional Input-Output Databases," 26(3).
Kander, A., M. Jiborn, D.D. Moran, and T.O. Wiedmann (2015), "National greenhouse-gas accounting for effective climate policy on international trade," *Nature Climate Change*, 5(5), 431–435.
Kastner, T., A. Schaffartzik, N. Eisenmenger, K.-H. Erb, H. Haberl, and F. Krausmann (2014), "Cropland area embodied in international trade: Contradictory results from different approaches," *Ecological Economics*, 104, 140–144.
Le Quéré, C., R.M. Andrew, P. Friedlingstein, S. Sitch, J. Hauck, J. Pongratz, P.A. Pickers, J.I. Korsbakken, G.P. Peters, J.G. Canadell, A. Arneth, V.K. Arora, L. Barbero, A. Bastos, L. Bopp, F. Chevallier, L.P. Chini, P. Ciais, S.C. Doney, T. Gkritzalis, D.S. Goll, I. Harris, V. Haverd, F.M. Hoffman, M. Hoppema, R.A. Houghton, G. Hurtt, T. Ilyina, A.K. Jain, T. Johannessen, C.D. Jones, E. Kato, R.F. Keeling, K.K. Goldewijk, P. Landschützer, N. Lefèvre, S. Lienert, Z. Liu, D. Lombardozzi, N. Metzl, D.R. Munro, J.E.M.S. Nabel, S. Nakaoka, C. Neill, A. Olsen, T. Ono, P. Patra, A. Peregon, W. Peters, P. Peylin, B. Pfeil, D. Pierrot, B. Poulter, G. Rehder, L. Resplandy, E. Robertson, M. Rocher, C. Rödenbeck, U. Schuster, J. Schwinger, R. Séférian, I. Skjelvan, T. Steinhoff, A. Sutton, P.P. Tans, H. Tian, B. Tilbrook, F.N. Tubiello, I.T. van der Laan-Luijkx, G.R. van der Werf, N. Viovy, A.P. Walker, A.J. Wiltshire, R. Wright, S. Zaehle, and B. Zheng (2018), "Global Carbon Budget 2018," *Earth System Science Data*, 10(4), 2141–2194.
Lenzen, M., D. Moran, K. Kanemoto, B. Foran, L. Lobefaro, and A. Geschke (2012), "International trade drives biodiversity threats in developing nations," *Nature*, 486(7401), 109–112.
Lepawsky, J. (2015), "The changing geography of global trade in electronic discards: time to rethink the e-waste problem," *The Geographical Journal*, 181(2), 147–159.
Liang, S., and T. Zhang (2013), "Investigating Reasons for Differences in the Results of Environmental, Physical, and Hybrid Input-Output Models," *Journal of Industrial Ecology*, 17, 432–439.
Lustgarten, A. (2018), "Palm Oil Was Supposed to Help Save the Planet. Instead It Unleashed a Catastrophe," *New York Times*.
Malik, A., M. Lenzen, S. McAlister, and F. McGain (2018), "The carbon footprint of Australian health care," *The Lancet Planetary Health*, 2(1), e27–e35.
Malik, A., M. Lenzen, P.J. Ralph, and B. Tamburic (2015), "Hybrid life-cycle assessment of algal biofuel production," *Bioresource Technology*, 184, 436–443.
Martínez-Blanco, J., A. Inaba, A. Quiros, S. Valdivia, L. Milà-i-Canals, and M. Finkbeiner (2015a), "Organizational LCA: the new member of the LCA family—introducing the UNEP/SETAC Life Cycle Initiative guidance document," *The International Journal of Life Cycle Assessment*, 20(8), 1045–1047.
Martínez-Blanco, J., A. Lehmann, Y.-J. Chang, and M. Finkbeiner (2015b), "Social organizational LCA (SOLCA)—a new approach for implementing social LCA," *The International Journal of Life Cycle Assessment*, 20.
Mekonnen, M.M., and A.Y. Hoekstra (2011), "National water footprint accounts: the green, blue and grey water footprint of production and consumption," Paris.
Murray, J., and M. Lenzen (2013), *The sustainability practitioner's guide to multi-regional input-output analysis*, Common Ground Publishing LLC, Illinois, USA.
Nishijima, S., T. Furukawa, T. Kadoya, F. Ishihama, T. Kastner, H. Matsuda, and N. Kaneko (2016), "Evaluating the impacts of wood production and trade on bird extinction risks," *Ecological indicators*, 71, 368–376.
OECD (2014), "Part 1 of a Report to G20 Development Working Group on the Impact of BEPS in Low-Income Countries," Organisation for Economic Co-operation and Development, Paris.
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 (2016), "Tax Battles. The dangerous global Race to the Bottom on Corporate Tax," Oxfam, Oxford.
Reap, J., F. Roman, S. Duncan, and B. Bras (2008), "A survey of unresolved problems in life cycle assessment," 13(5), 374.

Sachs, J.D., V. Fajans-Turner, T. Smith, C. Kennedy-Cuomo, T. Parejo, and S. Loni (2018), "Closing the SDG Budget Gap," Move Humanity and Sustainable Development Solutions Network, Copenhagen and New York.

Sachs, J.D., G. Schmidt-Traub, C. Kroll, D. Durand-Delacre, and K. Teksoz (2017), "SDG Index and Dashboards Report 2017. Global Responsibilities - International Spillovers in Achieving the Goals," Bertelsmann Stiftung and Sustainable Development Solutions Network, Gütersloh and New York.

Sachs, J.D., G. Schmidt-Traub, C. Kroll, G. Lafortune, and G. Fuller (2019), "Sustainable Development Report 2019. Transformations to achieve the Sustainable Development Goals," Bertelsmann Stiftung and Sustainable Development Solutions Network, Gütersloh and New York.

Sala, E., J. Mayorga, C. Costello, D. Kroodsma, M.L. Palomares, D. Pauly, U.R. Sumaila, and D. Zeller (2018), "The economics of fishing the high seas," *Science advances*, 4(6), eaat2504.

Sandström, V., P.E. Kauppi, L. Scherer, and T. Kastner (2017), "Linking country level food supply to global land and water use and biodiversity impacts: The case of Finland," *Science of The Total Environment*, 575, 33–40.

Schmidt, C.W. (2006), "Unfair Trade e-Waste in Africa," *Environmental Health Perspectives*, 114(4), A232–A235.

SIPRI (2018), SIPRI Arms Transfers Database, https://www.sipri.org/databases/armstransfers, accessed April 4, 2017.

Swarr, T.E., D. Hunkeler, W. Klöpffer, H.-L. Pesonen, A. Ciroth, A.C. Brent, and R. Pagan (2011), "Environmental life-cycle costing: a code of practice," *The International Journal of Life Cycle Assessment*, 16(5), 389–391.

Tax Justice Network (2018), Financial Secrecy Index 2018, https://www.financialsecrecyindex.com/introduction/fsi-2018-results, accessed June 22, 2018.

Tian, X., Y. Geng, J. Sarkis, and S. Zhong (2018), "Trends and features of embodied flows associated with international trade based on bibliometric analysis," *Resources, Conservation and Recycling*, 131, 148–157.

Többen, J., K.S. Wiebe, F. Verones, R. Wood, and D.D. Moran (2018), "A novel maximum entropy approach to hybrid monetary-physical supply-chain modelling and its application to biodiversity impacts of palm oil embodied in consumption," *Environmental Research Letters*, 13(11), 115002.

TReNDS, https://www.sdsntrends.org/?locale=en, accessed July 12, 2019b.

TWI2050 (2018), "Transformations to achieve the Sustainable Development Goals. Report prepared by The World in 2050 Initiative.," International Institute for Applied Systems Analysis, Laxenburg, Austria.

UN (2014), "System of Environmental-Economic Accounting 2012," United Nations, New York.

UN Statistics Division (2017), SDG Indicators and Targets, https://unstats.un.org/sdgs/indicators/indicators-list/, accessed May 20, 2017.

UNCTAD (2014), "World Investment Report 2014. Investing in the SDGs: An Action Plan," United Nations Conference on Trade and Development, Geneva.

UNEP (2009), "Guidelines for social life cycle assessment of products: Social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable developme," United Nations Environment Programme.

UNEP (2015), "Guidance on Organizational Life Cycle Assessment," United Nations Environment Programme.

UNICEF (2018), Child Labour, http://data.unicef.org/child-protection/child-labour.html, accessed December 6, 2016.

United Nations (2015), "Transforming Our World: The 2030 Agenda for Sustainable Development," No. A/RES/70/1, United Nations, New York.

Valin, H., D. Peters, M. van den Berg, S. Frank, P. Havlik, N. Forsell, C. Hamelinck, J. Pirker, A. Mosnier, and J. Balkovič (2015), "The land use change impact of biofuels consumed in the EU: Quantification of area and greenhouse gas impacts," Ecofys, Utrecht.

Walk Free Foundation (2016), "Global Slavery Index 2016," Walk Free Foundation, Broadway Nedlands, Australia.

Weinzettel, J., K. Steen-Olsen, E.G. Hertwich, M. Borucke, and A. Galli (2014), "Ecological footprint of nations: Comparison of process analysis, and standard and hybrid multiregional input–output analysis," *Ecological Economics*, 101, 115–126.

Weinzettel, J., and R. Wood (2018), "Environmental Footprints of Agriculture Embodied in International Trade: Sensitivity of Harvested Area Footprint of Chinese Exports," *Ecological Economics*, 145, 323–330.

Weitz, N., H. Carlsen, M. ans Nilsson, and K. Sk\a anberg (2018), "Towards systemic and contextual priority setting for implementing the 2030 Agenda," *Sustainability Science*, 13(2), 531–548.

Wiedmann, T.O., H. Schandl, M. Lenzen, D. Moran, S. Suh, J. West, and K. Kanemoto (2015), "The material footprint of nations," *Proceedings of the National Academy of Sciences*, 112(20), 6271–6276.

Zhang, Q., X. Jiang, D. Tong, S.J. Davis, H. Zhao, G. Geng, T. Feng, B. Zheng, Z. Lu, D.G. Streets, and others (2017), "Transboundary health impacts of transported global air pollution and international trade," *Nature*, 543(7647), 705–709.