

Chapter 8

Impacts Embodied in Global Trade Flows

Thomas Wiedmann

Abstract The steep and unprecedented growth of globalisation and trade over the last few decades has led to accelerated economic activity with mixed outcomes. Continued economic growth and alleviation of poverty in many countries has been accompanied with an overall increase and shifting of environmental pressures between countries. Industrial ecology research has contributed decisively to the knowledge around impacts in trade. This chapter summarises the latest empirical findings on global change instigated by trade, discusses new methodological developments and reflects on the sustainability of globalised production and consumption. Significant proportions of up to 64 % of total environmental, social and economic impacts can be linked to international trade. Impacts embodied in trade have grown much more rapidly than their total global counterparts. Policies aimed at increasing the sustainability of production and consumption need to go beyond domestic regulation and seek international cooperation to target production practices for exports worldwide.

Keywords Trade-embodied impacts • Consumption-based accounting • Environmental footprint • Global resource use • Multi-region input-output analysis • Sustainability of trade

1 Introduction

The steep and unprecedented growth of globalisation and trade over the last few decades has led to accelerated economic activity with mixed outcomes. Continued economic growth and alleviation of poverty in many countries has been accompanied with an overall increase and shifting of environmental pressures between countries. Industrial ecology research has contributed decisively to the knowledge around

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impacts in trade. This chapter summarises the latest empirical findings on global change instigated by trade, discusses new methodological developments and reflects on the sustainability of globalised production and consumption. Significant proportions of up to 64 % of total environmental, social and economic impacts can be linked to international trade. Impacts embodied in trade have grown much more rapidly than their total global counterparts. Policies aimed at increasing the sustainability of production and consumption need to go beyond domestic regulation and seek international cooperation to target production practices for exports worldwide.

International trade is not a new phenomenon. People have exchanged goods and services since prehistoric and ancient times. One prominent example of early trade links between countries and continents is the Silk Roads, a network of trading routes established between Asia and Europe during the Han Dynasty in China (206 BC – 220 AD) (Liu 2010). The trade in Chinese silk and many other goods extended over 6,000 km and was very lucrative. It boosted the economic development of China and its Middle Asian and European trading partners and became so important that it was protected militarily by fortified watch towers. The Great Wall was extended to ensure the protection of the trade route. The Silk Roads' importance during ancient times and up to its golden age during the early middle age was confirmed in 2014, when parts of the network were declared a UNESCO World Heritage Site.¹

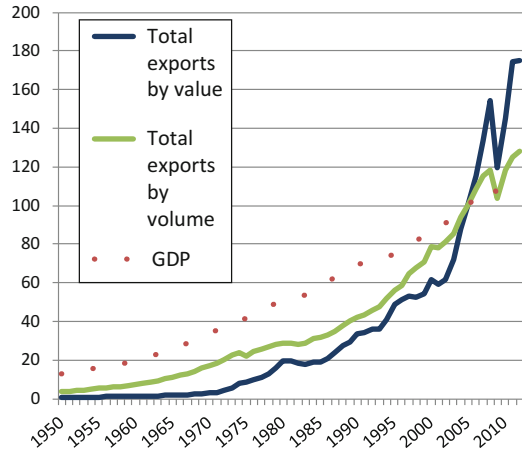
How does this compare to trade in modern times? It is certainly true to say that international trade accelerates economic development – nowadays as it did thousands of years ago. What is different – due to economic globalisation and technological advances, especially in the last 20 years – is the unprecedented scale, speed and complexity of trade movements and transactions.

Over the last few decades, international trade has grown much more rapidly compared to other indicators of development such as, for example, GDP (gross domestic product), population or CO₂ emissions (Kanemoto and Murray 2013 and Fig. 8.1). The value of exports of goods and services is almost 300 times larger today than it was in 1950 (35 times larger by volume; WTO 2013). On average, exports make up 30 % of a country's GDP (World Bank 2015). The value added along global production chains (outside the country of completion) has steadily increased since 1995, only briefly interrupted in 2008 due to the global financial crisis (Los et al. 2015; Timmer et al. 2014). This trend is seen as a clear sign that production has shifted from the regional to the global scale. The expansion of international trade has changed production and consumption patterns almost everywhere, with wide-ranging implications for economies, societies and the environment.

Undoubtedly, globalisation and trade have helped to alleviate poverty and social hardship in many countries. According to the World Resources Institute, over the last 20 years 'Real incomes in low- and middle-income countries have doubled and poverty rates have halved. Two billion people have gained access to improved drinking water. Maternal mortality has dropped by nearly half, and the share of those who

¹ Retrieved February 23, 2015 from <http://whc.unesco.org/en/list/1442>

Fig. 8.1 World merchandise exports (by value and volume) and gross domestic product 1950–2012 (index 2005=100) (Data from WTO 2013)



are malnourished has fallen by a third' (WRI 2014). At the same time, pressures on the natural environment have increased tremendously: 'Every minute of every day we have been losing the equivalent of 50 soccer fields of forest. Over one billion people already face water scarcity, and this may triple by 2025. Climate change is costing \$700 billion per year, with the greatest impact on the poor' (WRI 2014).

The sheer amount of goods shipped around the world is also unprecedented. Ten billion tonnes (10 gigatons, Gt) of materials and products were shipped between countries in 2005 (Dittrich and Bringezu 2010). And this figure includes only the direct physical trade, i.e. actual shipment of materials and goods. As will be shown later in this chapter, raw materials are also extracted and processed in order to enable exports, even though they never leave the country. Adding these indirect material flows or 'raw material equivalents' to the actual physical trade resulted in a total amount of 29 Gt of materials associated with trade flows between countries in 2008 (Wiedmann et al. 2015).

In addition to growing in scale, trade has become more complex and fragmented. The production process of many products occurs in small stages in different countries, interlinked through complex global supply chain networks. Supply chains have become longer, more fragmented and more complex. World merchandise exports of intermediate and final products were almost identical in 1993 (7–8 % of world GDP), but exports of intermediate exports have grown faster since and were 15 % of GDP in 2012, whilst exports of final goods only reached 11 % of GDP.

Longer and more fragmented supply chains also mean that places of production and consumption are more separated and that it becomes more difficult to establish the link between environmental impacts exerted by the production process and the final destination of the product. In other words, the 'cradle-to-gate' life cycle becomes longer, more convoluted and more difficult to assess. Increasingly sophisticated global models have had to be developed to evaluate impacts embodied in global supply chains (Tukker and Dietzenbacher 2013; Wiedmann 2009; Wiedmann et al. 2007, 2011).

Most of the growth in trade value, volume and complexity occurred in the last couple of decades only. According to Richard Baldwin, possibly the most influential change over the last 20 years was the international movement of firm-specific know-how (Baldwin 2013). Changes in both technology and legislation have made it easier for multinational companies to exchange knowledge and coordinate internal processes, enabling them to quickly respond to changing demands and ramp up production capacities in varying locations. Some large multinational companies, such as Apple, Exxon Mobil, Royal Dutch Shell or IBM, have market values that are comparable or exceed the GDP of countries such as Belgium, Switzerland, Sweden, Norway or Saudi Arabia. Therefore, with respect to international production and consumption, national borders might not be as influential as they seem.

2 Impacts of Trade: New Insights from Recent Research

2.1 *Taking a Consumption-Based Perspective: What Are Impacts Embodied in Trade?*

Two words in this question require further explanation: ‘impacts’ and ‘embodied’. The term ‘impact’ is used here in a very wide sense, comprising both pressure and impact indicators as defined by the causal DPSIR framework (Driving Forces-Pressures-State-Impacts-Responses) that describes interactions between society and the environment.² Environmental pressures include the use of resources, such as land, water or materials as well as the emissions of greenhouse gases (GHG) or pollutants. In the stricter definition provided by Life Cycle Assessment (LCA) standards (ISO 2006; Hellweg et al. 2014), environmental impacts represent the (actual or potential) damage exerted by pressures, e.g. global warming, toxicity or biodiversity loss. Especially in the context of international trade, the expression environmental ‘burden’ or ‘load’ has been used as well as ‘burden shifting’ (e.g. Giljum and Eisenmenger 2008; Schütz et al. 2004; Zhang et al. 2013) or ‘displacement of pressures’ (e.g. Steen-Olsen et al. 2012) to describe the change of location where environmental pressures or impacts occur when resources from other countries are used indirectly through trade. For social and economic indicators, the distinction between pressures and impacts is less well defined. For the sake of simplicity, the term ‘impact’ has been used for all indicators in this chapter (see also Table 8.1).

The word ‘embodied’ describes indirect impacts that can be ‘attributed to’, are ‘associated with’ or are ‘embedded in’ activities that are not directly linked to the impacts. In the context of trade, consuming a product in one country can lead to impacts in many other countries, depending on where the production and supply chain processes occur that are required to produce the final consumer product. All

²Retrieved February 23, 2015 from http://root-devel.ew.eea.europa.eu/ia2dec/knowledge_base/Frameworks/doc101182

these supply chain impacts are said to be ‘embodied’ in the product, even if there is no direct physical connection. This may be exemplified best in the context of water use, where the term ‘virtual’ has been used widely (e.g. Chen and Chen 2013; Dalin et al. 2012; Orłowsky et al. 2014). The virtual water is not actually physically embodied in a traded product – yet the term ‘embodied’ is widely used in the literature to describe indirect impacts. Another expression introduced by Lenzen et al. 2012 is the word ‘implicated’ which was used by the authors to indicate a connection between consumption in one country and threat to species in other countries, even though it would be difficult to prove a direct causal relationship between the two (a point also made with respect to CO₂ emissions embodied in trade, see Jakob and Marschinski 2013). The term ‘implicated’ is again used in Alsamawi et al. 2014b to indicate the inequality associated with the trade of commodities between nations.

As an overarching model of evaluating the embodied impacts of consumption, the concept of environmental footprints has been used widely (Hoekstra and Wiedmann 2014). Applied at the country level, a nation’s total footprint is calculated as follows:

$$\begin{aligned}
 & \textit{Territorial impacts} \\
 & + \textit{impacts embodied in imports} \\
 & - \textit{impacts embodied in exports} \\
 & = \textit{national footprint}
 \end{aligned}$$

The footprint takes a consumption perspective, in most cases equivalent to a ‘cradle-to-shelf’ perspective in LCA. Evaluating footprints has therefore also been referred to as consumption-based accounting (CBA), in particular in the context of accounting for national GHG emissions and resource use (Barrett et al. 2013; Kander et al. 2015; Peters 2008). Countries can use CBA to measure both their impact as well as their dependence on foreign economies and environments. It is well known that impacts have increasingly been shifted abroad (Table 8.1). The consumption view provided by national footprints offers consumer information and policy options for the mitigation of emissions and resource use that are complementary to measures based on territorial accounting (Andrew et al. 2013; Barrett et al. 2013). Both perspectives,³ the production (territorial) and the consumption perspective, provide important insights into the sources and drivers of impacts, and both have their pros and cons. The production perspective is easier to implement, refers to environmental pressures at the source and is widely accepted as an accounting method for national GHG emissions (UNFCCC). However, it does not account for burden shifting or carbon leakage, both of which can occur if domestic production is moved abroad. CBA, on the other hand, adds back embodied impacts in imports to the national balance sheet and correctly accounts for impacts of total national

³A third perspective, named income-based (or downstream) responsibility, was introduced by Marques et al. (2012). This allows for calculating carbon emissions occurring abroad associated with the trade from which a region or country derives its income (also called ‘enabled emissions’) (Marques et al. 2013).

consumption. CBA is more difficult to measure and implement though, and impacts occurring in foreign jurisdictions are hard if not impossible to influence or control (Jakob et al. 2014). Furthermore, CBA provides no incentive for countries to produce clean exports (since impacts embodied in exports are subtracted). It has been suggested recently to address this drawback by using the world-average carbon intensity for exporting industries, rather than the domestic average, when calculating export-related emissions (Kander et al. 2015). Doing so rewards countries that produce export commodities that are cleaner than their counterparts on the world market.

2.2 Recent Research on Environmental, Social and Economic Impacts Embodied in International Trade

2.2.1 Scope and Scale of Embodied Impacts

Numerous studies have been conducted in the last few years to shed light on the question how trade influences the use and distribution of natural, social and economic capital. Table 8.1 summarises some high-level results, in particular the fraction of total global impact that can be attributed to international trade as well as the major bilateral embodied trade flows. Note that these values depend on the number of countries or regions used in the various calculation models. As a general rule, the finer the spatial resolution of the model, the higher the international trade flows, and the lower the intra-regional trade movements. Where possible, individual countries were identified as main traders in Table 8.1.

At least a fifth and up to 64 % of global environmental impacts can be linked to trade (for all references refer to Table 8.1). Greenhouse gas emissions are the best-studied indicator. About one quarter of all global CO₂ emissions are linked to the production of goods and services that are exported and used to satisfy demand in countries other than the country where the emissions occur. One study suggests that the fraction of CO₂ embodied in trade could be as high as a third of global emissions. And if the trade of fossil fuels is taken into account, then the amount of ‘dislocated’ CO₂ emissions from the point of extraction to the point of final consumption is 37 % or more than 10 Gt of CO₂. According to Meng et al. (2015), the median export share of a country’s territorial emissions was 29 % in 2007, and emissions embodied in imports made up almost half of the carbon footprints of countries (median 49 %). The largest bilateral flows of embodied CO₂ emissions with well over 1 Gt of CO₂ are from China to the USA. This finding is not surprising given the large volumes of exports from China and imports to the USA and the fact that China’s production system is very carbon intensive (Minx et al. 2011). The EU is also a large importer of GHG emissions from Asia (0.8 Gt CO₂e). When accounting for international CO₂ emissions embodied in investments (instead of total final demand), China also emerges as the main exporter of investment-embodied emissions and Western Europe and North America as the main importers.

Table 8.1 Global studies quantifying environmental, social and economic impacts embodied in international trade

Impact	Fraction of total global impact embodied in trade (absolute amount, year)	Largest exporter (i), largest importer (ii), largest bilateral trade flow (iii), gross flows, not net flows ^a	Method (name of database/model)	References
CO ₂ embodied in traded products	(a) 23 % (6.2 Gt CO ₂ , 2004)	(a) (i) China (1.43 Gt CO ₂) (ii) USA (1.22 Gt CO ₂) (iii) From China to USA (395 Mt CO ₂)	(a) MRIO analysis (GTAP)	(a) Davis and Caldeira (2010)
	(b) 23 % (6.4 Gt CO ₂ , 2004)	(b) (i) China (1.24 Gt CO ₂ , 2004) (ii) USA (1.22 Gt CO ₂) (c) n.p. ^b	(b) MRIO analysis (GTAP)	(b) Davis et al. (2011)
	(c) 22 % (1.7 Gt C=6.1 Gt CO ₂ , 2004)	(c) n.p. ^b	(c) Synthesis of MRIO-based studies	(c) Peters et al. (2012)
	(d) 25 % (7.5 Gt CO ₂ , 2006)	(d) (iii) From Canada to USA (195 Mt CO ₂)	(d) EEBT ^c analysis with life cycle inventory factors for carbon intensity of products	(d) Sato (2014)
	(e) n.p. (6.9 GtCO ₂ , 2007)	(e) n.p.	(e) MRIO analysis (GTAP)	(e) Andrew et al. (2013)
	(f) 33 % (8.3 Gt CO ₂ , 2007)	(f) n.p.	(f) MRIO analysis (WIOD)	(f) Xu and Dietzenbacher (2014)
	(g) 26 % (7.8 Gt CO ₂ in 2008)	(g) (iii) From China to USA (207 Mt CO ₂ , average 1998–2008)	(g) MRIO analysis (GTAP) using MRIO (global supply chains) and EEBT (domestic supply chains) balances	(g) Peters et al. (2011)
CO ₂ emissions embodied in investments	n.p.	(i) Greater China (2.3 Gt CO ₂ , 2004) (ii) Western Europe (3.6 Gt CO ₂ , 2004)	Global Interregional Social Accounting Matrix (GTAP)	Bergmann (2013)

(continued)

Table 8.1 (continued)

Impact	Fraction of total global impact embodied in trade (absolute amount, year)	Largest exporter (i), largest importer (ii), largest bilateral trade flow (iii), gross flows, not net flows ^a	Method (name of database/model)	References
CO ₂ emissions from traded fossil fuels	(a) 37 % (10.2 Gt CO ₂ , 2004)	(a) (i) Russia (1.47 Gt CO ₂ , 2004)	(a) MRIO analysis (GTAP)	(a) Davis et al. (2011)
	(b) n.p. (10.8 Gt CO ₂ in 2007)	(ii) USA (2.08 Gt CO ₂)	b) MRIO analysis (GTAP)	b) Andrew et al. (2013)
	(a) 23 % (8.7 Gt CO ₂ e, 2007)	(a) (iii) From Asia to EU (0.79 Gt CO ₂ e)	(a) MRIO analysis (EXIOBASE)	(a) Tukker et al. (2014)
GHG emissions (CO ₂ , CH ₄ , N ₂ O)	(b) 27 % (10.4 Gt CO ₂ e, 2008)	(b) (i) China (2.9 Gt CO ₂ e)	(b) MRIO analysis (WIOD)	(b) Arto et al. (2012)
	(a) 26 % (2,320 Gm ³ , 1996–2005)	(ii) USA (1.8 Gt CO ₂ e)	(a) Water Footprint Network method (Hoekstra et al. 2011)	(a) (Hoekstra and Mekonnen (2012);
	(b) 24 % (1900 Gm ³ , 2000)	(a) (i) USA (314 Gm ³ /y)	(b) MRIO analysis (Eora)	(b) Lenzen et al. (2013)
Water		(ii) USA (234 Gm ³ /y)		
		(iii) From USA to Mexico		
		(ii) USA (300 Gm ³)		
Scarce water	(c) 30 % (2004)	(c) (i) China (204 Gm ³)	(c) MRIO (GTAP)	(c) Chen and Chen (2013)
	(d) 22 % (2651 Gm ³ , 2008)	(ii) USA (178 Gm ³)	(d) MRIO analysis (WIOD)	(d) Arto et al. (2012)
	(b) 32 % (480 Gm ³ , 2000)	(d) (i) China (472 Gm ³)	MRIO analysis (Eora)	Lenzen et al. (2013)
		(ii) USA (427 Gm ³)		
		(i) India (30 Gm ³)		
		(ii) USA (45 Gm ³)		
		(iii) From Pakistan to USA (7.9 Gm ³)		

Land	(a) 24 % (1800 Mgha, 2004) (biologically productive land area)	(a)(i) China (218 Mgha)	(a) MRIO analysis (GTAP)	(a) Weinzettel et al. (2013)
		(ii) USA (326 Mgha)		
		(iii) From China to USA (59 mgha)		
(b) n.p.	(b) (i) Russia (258 Mha)	(b) MRIO analysis (GTAP)	(b) Yu et al. (2013)	
	(ii) USA (198 Mha)			
	(iii) From Russia to China (64 Mha)			
(c) 23 % (1660 Mha, 2008)	(c) (i) China (160 Mha)	(c) MRIO analysis (WIOD)	(c) Arto et al. (2012)	
	(ii) USA (260 Mha)			
	(i) USA (37 Mha, 2009)			
Cropland	20 % (271 Mha, 2008)	(ii) China (34 Mha, 2009) (MRIO analysis suggests that China is a major exporter Kastner et al., (2014b))	Analysis of bilateral trade data (FAOSTAT)	Kastner et al. (2014a)
		(iii) North America to East Asia (18 Mha)		
		(i) Indonesia (238 species threats)		
Threatened species	30 % (7500 species threats, 2009)	(ii) USA (1262)	MRIO analysis (Eora)	Lenzen et al. (2012)
		(iii) Papua New Guinea to Japan (91)		
		(i) Russia (23 PJ)		
Energy	35 % (n.p., 2007)	(ii) USA (25 PJ)	MRIO analysis (EXIOBASE)	Simas et al. (2015)

(continued)

Table 8.1 (continued)

Impact	Fraction of total global impact embodied in trade (absolute amount, year)	Largest exporter (i), largest importer (ii), largest bilateral trade flow (iii), gross flows, not net flows ^a	Method (name of database/model)	References				
Raw materials	(a) 26 % (15 Gt, 2005)	(a) n.p. for countries	(a) IOT and bilateral trade analysis (GRAM/OECD)	(a) Bruckner et al. (2012)				
		(i) OECD LD (5.5 Gt)						
		(ii) OECD HD (9.9 Gt)						
		(b) 34 % (22 Gt, 2007)			(b) MRIO analysis (GTAP, materialflows.net)	(b) Gijjum et al. (2014)		
		(i) China (3.9 Gt)						
		(ii) USA (3.5 Gt)						
		(c) 24 % (16 Gt, 2008)					(c) MRIO analysis (WIOD)	(c) Arto et al. (2012)
		(i) China (2.6 Gt)						
		(ii) USA (2.8 Gt)						
		(d) 41 % (29 Gt, 2008)						
(i) India (0.5 Gt biomass)								
China (5.2 Gt construction materials)								
Russia (1.2 Gt fossil fuels)								
Chile (0.7 Gt metal ores)								
(ii) USA (0.8 Gt biomass)								
USA (2.1 Gt construction materials)								
USA (1.3 Gt fossil fuels)								
USA (0.7 Gt metal ores)								
Metal ores	62 % for iron ore (1,380 Mt, 2008)	(i) Brazil (315 Mt iron ore), Australia (44 Mt bauxite)	MRIO analysis (Eora)	Wiedmann et al. (2014)				
		(ii) China (350 Mt iron ore), USA (24 Mt bauxite)						
	64 % for bauxite (136 Mt, 2008)							

Ozone precursors emissions (NMVOC, CH ₄ , CO, NO _x)	28 % (109 Mt NMVOCe, 2008)	(i) China (17.4 Mt NMVOCe) (ii) USA (18.6 Mt NMVOCe)	MRIO analysis (WIOD)	Arto et al. (2012)
Acid emissions (NH ₃ , NO _x , SO _x)	26 % (2.1 Mt H ⁺ e, 2008)	(i) China (0.65 Mt H ⁺ e) (ii) USA (0.35 Mt H ⁺ e)	MRIO analysis (WIOD)	Arto et al. (2012)
(a) Labour	(a) 18 % (560 million persons-year equivalents, 2007)	(a) (i) China (130 mpeq) (ii) USA (115 mpeq) (iii) China to USA (27 mFTE, 2010, Alsamawi et al. (2014a))	(a) MRIO analysis (EXIOBASE)	(a) Simas et al. (2015)
(b) 'Bad' labour	(b) 16 % for total labour, 15 % for low-skilled labour, 17 % for forced labour, 18 % for occupational health damage, 19 % for child labour, 19 % for vulnerable employment, 20 % for hazardous child labour and 38 % for labour by women (all numbers for trade between seven world regions)	(b) (i) The APAC region is the largest exporter of all forms of (bad) labour, except for child labour and hazardous child labour for which Africa is the largest exporter (ii) n.p. (iii) APAC to Europe for all forms of (bad) labour, except for child labour and hazardous child labour for which Africa to Europe is the largest flow	(b) MRIO analysis (EXIOBASE)	(b) Simas et al. (2014)
Wages	n.p.	(iii) USA to Japan (112 US\$bn, 2010)	MRIO analysis (Eora)	Alsamawi et al. (2014a)

^aSame year as fraction unless otherwise stated

^bn.p. not provided

^cEEBT emissions embodied in bilateral trade

Virtual water embodied in trade makes up between 22 and 30 % of total global water use, with the USA taking on a dual role of both largest exporter and importer of virtual water (though some studies suggest that China is the main exporter). When adjusting water use numbers with a factor for its scarcity in regions and countries of extraction, almost one third (32 %) of this 'scarce water' is associated with trade. India is the largest exporter of scarce water, the USA its largest importer.

Comparable numbers for the share of total impact embodied in trade are reported for other environmental indicators: 20–24 % for land use, 30 % for threatened species and 35 % for energy. Even higher is the share for raw materials: 41 % of all raw materials (biomass, fossil fuels, construction materials, minerals and metal ores) are extracted worldwide only in order to enable the export of goods and services from the country of extraction. And for metal ores the majority of extraction occurs due to export activities: 62 % of the global iron ore extraction and 64 % of the global bauxite mined are associated with trade. On average, only about one third of all raw materials actually leave the country of origin on a cargo ship, truck or plane. The rest are process wastes and auxiliary material flows that, whilst remaining near extraction sites, can still be attributed to the material footprint of other countries that import goods and services for their final consumption.

For most environmental impacts the direction of burden shifting (see Sect. 2.1) is from developed countries to developing countries, but not for all. An indirect threat to species through trade is experienced in countries such as Papua New Guinea, Madagascar or Indonesia, whereas air pollution and GHG emissions embodied in exports occur mostly in China. Russia exports embodied energy and emissions from traded fossil fuels as well as land. For the virtual use of land through trade, there are mixed results, depending on the type of land and on the characteristics of the model used for the analysis. In addition to Russia as the largest exporter of embodied land, China has been identified as exporting the most biologically productive land area and the USA as exporting the most cropland. Resource-rich countries that physically export large quantities of raw materials are also amongst the top exporters of embodied materials, e.g. India for biomass, Russia for fossil fuels, Chile for metal ores in general and more specifically Brazil for iron ore and Australia for bauxite. China virtually exports 39 % of all construction materials extracted worldwide (5.2 Gt of 13.3 Gt). Again, most of this material is not physically shipped abroad but used domestically in China to build up infrastructure for a highly export-oriented economy.

A strong driver of globalisation has been the move of production to places where wages and therefore total production costs are relatively low (Timmer et al. 2014). A large workforce in developing low-wage countries is employed to manufacture goods for exports, mostly to the developed world. Often working conditions are poor, and workers have low skills or are exposed to health and safety hazards. Sometimes children and other vulnerable persons are forced to work. Women often experience more detrimental conditions than men.

Industrial ecology research entered a new field when several studies were published in 2014 that investigated the 'labour footprint' of nations and the role of trade in employment conditions of exporting countries. On average, about 16–18 % of all

labour in the world is embodied in trade (between seven world regions – the numbers would be higher when considering trade between all countries). Some forms of damaging labour conditions seem to be supported by trade, e.g. 20 % of all hazardous child labour is for exports. And 38 % of all work done by women became embodied in international trade. Asia is the largest exporting region of all forms of (bad) labour, except for child labour and hazardous child labour for which Africa is the largest exporter (Simas et al. 2014).

Wages on the other hand are highest in the developed world, and therefore trade flows of embodied wages take different paths to those for labour. The highest flows of wages embodied in exports are between developed countries, mostly from the USA to Japan (and backwards), Canada and Europe, but also to China.

The flow of money in trade has been studied extensively for a long time, but recently researchers have used newly available multi-region input-output (MRIO) models to study specific economic aspects of trade, such as fragmentation or value added (VA) in trade. Trade statistics are normally based on gross export values, thus double counting the VA along global supply/value chains (Kelly and La Cava 2013). Interest has therefore grown in VA as a ‘trade commodity’ that can become embodied in international trade flows, and methodological frameworks have been developed accordingly (e.g. Koopman et al. 2014). One study found that the foreign VA content of exports from Luxembourg was 61 % in 2011 (Foster-McGregor and Stehrer 2013). Interestingly, there seems to be a trend towards value being added by capital and high-skilled labour and away from less-skilled labour (Timmer et al. 2014). The capital share in the VA of emerging economies is rising, whilst the share of low-skilled labour in their VA is declining.

Meng et al. (2015) synchronously evaluate VA and CO₂ emissions in global trade. Their detailed analysis confirms the increasing fragmentation of international trade. They find that more than half (ca. 60 %) of China’s emissions attributable to foreign final demand are embodied in the trade of intermediate goods (ca. 40 % of export emissions are embodied in the trade of final goods). Whether a country’s emissions become embodied in the trade of final or intermediate goods depends on its position in the global value chain. Meng et al. (2015) demonstrate how CO₂ emissions from Poland’s metal industry are associated with final demand in the USA: 90 % of these emissions are embodied in intermediate good trade (roughly half of which are traded directly between Poland and the USA, and the other half is traded by way of third countries).

2.2.2 Trends of Impacts Embodied in Trade

The results in Table 8.1 show clearly that trade is associated with a significant dislocation of environmental, social and economic factors, thus further separating impacts of production (both negative and positive) in one place from consumption elsewhere. Forty per cent of the national carbon footprint of the UK is exerted abroad (Hertwich and Peters 2009) and 75 % of its national water footprint (Hoekstra and Mekonnen 2012). The numbers presented in Table 8.1 are the latest available,

but there has been a strongly increasing trend for the last few decades. For example:

- Land for the export production of crops grew rapidly by +2.1 % per year between 1986 and 2009 (Kastner et al. 2014a). At the same time, land supplying crops for direct domestic use remained almost unchanged.
- Flows of materials embodied in international trade are reported to have increased by 62 % between 1997 and 2007 (Giljum et al. 2014) and by 123 % between 1990 and 2008 (Wiedmann et al. 2015).
- Global trade in embodied iron ore has grown faster than its extraction, by a factor of 2.7 between 1990 and 2008 (Wiedmann et al. 2014). Trade of embodied bauxite has grown by a factor of 2.4.
- From 1995 to 2007 total global CO₂ emissions from production have increased by 32 %, whereas global emissions embodied in trade have increased by 80 % in the same period (from 4.6 Gt or 24 % of global production emissions to 8.3 Gt or 33 %) (Xu and Dietzenbacher 2014).
- In the most comprehensive study, Arto et al. 2012 present the trend of impacts embodied in trade from 1995 to 2008 for the following indicators: land +3.0 Mkm² (+22 %); raw materials +7.3 Gt (+80 %); blue, green and grey water +1.2 PL (+88 %); acid emissions +734 kt H⁺e (+54 %); GHG emissions +4.7 Gt CO₂e (+83 %); and ozone precursors emissions +55.3 Mt NMVOCe (+103 %).

These examples show impressively how rapidly impacts associated with trade have grown in little more than 20 years, given that total global impacts have grown much slower (land +2 %, raw materials +43 %, water +37 %, acid emissions +12 %, GHG emissions +29 %, ozone precursors emissions +11 %; Arto et al. 2012).

3 Notes on Methodological Developments

This section briefly addresses some of the current issues surrounding the methods used to quantify impacts associated with trade. The list of topics discussed is not exhaustive but merely presents some of the highlights discussed in the literature and the industrial ecology community.

3.1 *Merging of Disciplines*

The analysis of social and economic indicators in the same way as for environmental issues – namely, from the viewpoint of trade embodiments and by using MRIO analysis – is a new and encouraging trend. It goes hand in hand with a similar development in life cycle sustainability assessment (LCSA) where social LCA increasingly complements the more traditional environmental impact and life cycle costing assessments (Kloepffer 2008; Parent et al. 2013).

Embracing and merging of data, metrics and methods from different disciplines is needed to address the fundamental questions of how a transition to sustainability can be achieved. Industrial ecology research greatly benefits from such an extension of its portfolio. After all, humans are part of the ‘ecology’ of industrial systems. Issues such as income inequality are of concern to both social and ecological sustainability (Alsamawi et al. 2014b). It is therefore important that socio-economic issues such as employment, wages, income inequality, occupational health, bad labour conditions, slavery, war casualties, etc. are monitored alongside environmental indicators.

It is to be hoped that the joint analysis of data from different fields supports a similar cooperation across different disciplines. The complexity of the sustainability challenge requires inter- and transdisciplinary solutions.

3.2 Assessing Actual Impacts and Their Unsustainability

As mentioned previously, most of the indicators described in this chapter represent pressures rather than impacts in the strict sense defined by LCA. Most footprint indicators (and consumption-based accounting studies) are designed to portray indirect pressures (Hoekstra and Wiedmann 2014), but there are recent attempts to introduce (environmental) impact assessment in footprint analysis.

This is perhaps most prominently the case for water footprinting where it has been argued that the scarcity of water needs to be incorporated into the metric (Chenoweth et al. 2014; ISO 2014; Kounina et al. 2013; Ridoutt and Pfister 2010). Some recent studies related to trade weight water use with data on water scarcity (e.g. Lenzen et al. 2013; Orłowsky et al. 2014).

A similar case can be made for the material footprint which sums up the mass of different raw materials into one number, thus reflecting an unweighted physical measure of pressure and *potential* impact (Wiedmann et al. 2015). Weighting according to *actual* environmental impacts has not been tried yet and is difficult, because different materials have different impacts, one material may have several impacts and characterisation data and models for localised impacts are not yet well developed. However, preliminary attempts of weighting resource footprints based on resource depletion have been presented (Fang and Heijungs 2014a).

Yet, there remains value in reporting footprints based on pressures alone. The pure mass or volume of resource use is practical information that relates to physical reality, i.e. how *much* actually is flowing. It allows, for example, to address questions of allocation of limited supplies or security of supply and sustainability of overall production and consumption. The ultimate goal of footprint accounting in general (and the assessment of impacts embodied in trade specifically) should be an evaluation of whether or not particular activities are sustainable (Fang and Heijungs 2014b). Environmental footprints measure human appropriation of natural resources and need to be interpreted in the context of maximum sustainable levels at the local and the global scale (Hoekstra and Wiedmann 2014). Exactly how high the sustainable thresholds of earth systems are is the subject of intense research (Steffen et al. 2015).

3.3 *Addressing Uncertainty in MRIO Modelling*

Currently the only tool to unravel the intricacies of international supply chains is MRIO modelling. The remarkable development in MRIO databases (Tukker and Dietzenbacher 2013; Wiedmann et al. 2011) has been accompanied by an equally impressive number of publications studying the impacts of globalisation and trade. Some studies have begun comparing the results obtained from different models, finding reasonable agreement as well as significant discrepancies for certain indicators (e.g. Peters et al. 2012 for CO₂ emissions and Wiedmann et al. 2015 and Schoer et al. 2013 for raw materials).

An important observation was made by Peters et al. (2012) in a pioneering comparative study: differences in consumption-based, embodied CO₂ emissions from different models were mostly due to the use of different territorial emission data and different definitions for allocating emissions to international trade. When adjusting for these issues, results were robust and in reasonable agreement. Larger discrepancies occur when different approaches are used for the calculations. Kastner et al. (2014b) find contradictory results for China's trade in embodied cropland when using physical instead of monetary input-output data. And Schoer et al. (2013) explore the differences of employing life cycle inventory data versus MRIO modelling for raw material equivalents embodied in EU27 imports.

A special issue of *Economic Systems Research* 2014 (26/3) was devoted to the question of uncertainty in MRIO analysis (Inomata and Owen 2014). Insights gained included the finding that the trade matrix structure (Leontief Inverse) is one major determinant of differences (Owen et al. 2014), likely due to assumptions made during its construction.

Further work remains to be done to improve the accuracy of MRIO models and to increase confidence in their results. This should include an increase in resolution, the use of specific process data in mixed units and hybrid LCA models and regular inter-comparison studies.

4 **Is Trade Good or Bad? Some Final Thoughts**

Is trade good or bad for sustainability? To answer this question conclusively would require comparing the status quo with the counterfactual of a world without trade. Alas, no one knows what this world would look like. It is easy enough to 'switch off' trade in models and to assume that the final demand is met by domestic production alone. But would final demand be the same? Would countries without trade consume the same amount of the same products? Most likely not. Many countries would certainly not be able to produce the products they import. What is clear, from the facts presented in the introduction, is that trade has been a strong driver of economic growth around the world. Had trade not happened, the GDP of all countries would very likely be much lower than it is today. Trade has also undoubtedly

enabled and reinforced an increased exploitation of resources. Was it not for trade, many well-endowed countries would have extracted less materials for their own consumption.

Some studies have tried to quantify the effects of trade on GHG emissions. Using the domestic production assumption, López et al. (2013a) found that 1.1 Gt CO₂ were avoided through trade between seven world regions in 2009, representing a reduction of 18 % of embodied emissions embodied in trade or 4.4 % of global production emissions. But according to Arto and Dietzenbacher (2014), the increase in trade at the global level and associated embodied emissions between 1995 and 2008 had little effect on total global GHG emissions. This was because ‘Although domestically produced goods have been substituted by imports, the production abroad was on average as emission intensive as the production at home’ (Arto and Dietzenbacher 2014, p. 5393).

For individual countries, the balance can be positive or negative, depending on the relative carbon intensity of their domestic production compared to the main trading partners. Trade between Spain and China, for example, is said to have increased global emissions by 30 Mt CO₂ in 2005 (López et al. 2013b). Arto et al. (2014), on the other hand, assert that overall Spain has been avoiding emissions through trade between 1995 and 2007.⁴

Undoubtedly, trade has had many economic and social benefits. Yet the economic growth spurred by trade has led to a corresponding rapid growth in physical activity with more raw material extractions, more throughput and more consumption in material terms. Any gains in efficiency achieved through technological advances were offset by this strong growth in demand. And even if domestic activities are strictly regulated – as, e.g. is the case for air pollution in western countries – global impacts are likely to rise further if policies do not address the issue of impacts embodied in trade. Kanemoto et al. (2014) have shown that emissions of air pollutants (SO₂ and NO_x) have been rising rapidly in developing countries, where regulation is missing or patchy. Parts of these emissions are embodied in exports to developing countries. In general, exports from developing and low-income nations are more ecologically intensive for GHG emissions, water, scarcity-weighted water, air pollution, threatened species, biomass, total material flow and ecological footprint than those from developed nations (Moran et al. 2013). This has been confirmed for SO₂ by Grether and Mathys (2013) who argue that trade imbalances tend to aggravate, rather than alleviate existing asymmetries in pollution intensities.

Policies aimed at increasing the sustainability of production and consumption need to go beyond domestic regulation and also target production technologies employed abroad. International cooperation on reducing trade-embodied and total impacts worldwide is the only way to tackle unsustainability at the national scale.

⁴Arto et al. (2014) estimated the net emissions avoided (NEA) by Spain through trade between 1995 and 2007 and found that a domestic technology assumption (DTA) based on physical values results in a three times higher estimate of NEA than a DTA based on monetary values. See also Tukker et al. (2013) for a discussion on how the DTA affects the estimation of CO₂ emissions embodied in imports to Europe.

Sato (2014) found that the lion's share of global carbon emissions embodied in trade is concentrated in a relatively small number of product categories of traded goods (amongst the top ten in 2006 were motor spirit (gasoline/petrol), steel, aluminium, motor vehicles, ships/boats and Portland cement). This suggests that focusing trade and mitigation policies on these products may be an effective strategy to tackle at least the pressing issue of global warming.

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