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Global Virtual Water Trade, 1990-2015

Assessing Virtual Water Trade Patterns between High Income, Upper-Middle Income, Lower-Middle Income and Low Income Countries

by

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Due to globalization, increasing amounts of water are traded across borders as virtual water embodied in traded products. The thesis traces global water trade patterns at different levels of income between 1990 and 2015 in order to test whether developed countries outsource their water-intensive production to less developed countries increasing global water use in the process. The research problem is approached by means of an environmentally extended multiregional input-output analysis using the Eora26 database to identify the balance of water embodied in trade of high, upper-middle, lower-middle and low income countries. This methodology is supplemented with a new accounting technique from the field of carbon emission research taking technological differences between countries at different income levels into consideration and assessing the contribution of the trade specialization and the monetary trade balance to the technology-adjusted balance of water embodied in trade. The thesis finds that high income countries outsourced water-intensive production to lower-middle income and low income countries between 1990 and 2015 whereas the virtual water trade balance of upper-middle income countries changed over time. The results support the displacement and pollution haven hypotheses and suggest that structural change processes of economic development lead to these unequal terms of trade.

Keywords: Input-output analysis, multiregional input-output tables, Eora26, water use, water footprint, virtual water, global water trade, balance of water embodied in trade

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List of Abbreviations

BEET	Balance of emissions embodied in trade
BWET	Balance of water embodied in trade
CBA	Consumption-based accounting
EKC	Environmental Kuznets curve
Ex	Exports
Im	Imports
m^3	Cubic metres (=0.000001Mm^3)
Mm^3	Cubic megametres (=1,000,000m^3)
MRIO	Multiregional input-output
PBA	Production-based accounting
TB	Monetary trade balance
TBEET	Technology-adjusted balance of emissions embodied in trade
TBWET	Technology-adjusted balance of water embodied in trade
TSp	Trade Specialization
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEI	Water embodied in imports
WEX	Water embodied in exports
WIOD	World input-output database
WTO	World Trade Organization

1 Introduction

An efficient, sustainable and equitable management of the global freshwater resources addresses all 17 Sustainable Development Goals set by the United Nations (UN Environment Programme, 2017, p.4). Freshwater merely constitutes 2% of the earth's total water resources. Approximately half of this freshwater is frozen in the polar ice caps and glaciers reducing the share of water available for human use to merely 1% rendering freshwater a severely limited resource by nature (UN Environment Programme, 2020). Preserving this scarce resource is essential for human as well as ecological well-being. There is international consensus that universal water access is a precondition for development. International human rights law grants the right to water and the right to sanitation (UN General Assembly, 2010) and Sustainable Development Goal 6 of the United Nations Agenda 2030 defines the preservation of freshwater resources and the universal access to water and sanitation as a crucial part of global development strategies (UN General Assembly, 2015). From an ecological perspective, the preservation of freshwater resources is furthermore required to ensure an intact Earth system (Rockström et al., 2009; Steffen et al., 2015).

Despite this global recognition that efficient, sustainable and equitable water resource management plays a crucial role in fostering global sustainable development, global water resources are increasingly under pressure. Water scarcity is now a global issue affecting every continent (UN Water, 2020) and 2.1 billion people lack access to safe drinking water (UNESCO, 2019, p.18). Similar to other environmental stressors, the poorest communities in the world are particularly severely affected (Mekonnen & Hoekstra, 2016). Global water resources are thus currently managed neither sustainably nor equitably. Population growth, climate change and an increasing demand for water are responsible for the increasing pressure on existing water resources (Vörösmarty et al. 2000). With population growth, global water use has increased by 1% annually since the 1980s and is expected to continue to increase at that speed until 2050 (UNESCO, 2019, p.13). The international community therefore needs to reduce water-intensive practices to a minimum and ensure that existing water resources are distributed equitably.

Traditionally, water resources have been assessed and managed at the national or water basin level (Ma et al., 2006; Aldaya & Llamas, 2008; Verma et al., 2009). However, between 1996 and 2005 one fifth of the world's water was traded across national borders due to its utilization in various production processes as so-called *water embodied in trade* (Hoekstra & Mekonnen, 2012). As globalization processes continue with global merchandise exports increasing by 20% and global commercial services exports increasing by 46% between 2008 and 2018 (WTO, 2019, p.10) the amount of water embodied in trade will likely continue to increase. In response to the globalization of the world economy and the corresponding globalization of water, Hoekstra and Chapagain (2008) and Hoekstra (2011) suggest that water resources require global rather than merely local assessment and management. Multiple studies of international water trade have since followed this global approach (Arto, Andreoni & Rueda-Cantuche, 2016;

Han, Chen & Li, 2018). However, in terms of global water management relatively little has been achieved despite the inclusion of the right to water and sanitation in human rights law and in the 2030 Sustainable Development Agenda. Whereas international treaties at least partially regulate other global environmental hazards such as climate change (UN, 2015) and biodiversity loss (UN, 1992), global water resource management remains a nearly untouched issue in the international arena.

The lack of international collaboration on strategies for the preservation of global water resources becomes increasingly problematic as the production and the consumption of goods and services become increasingly detached due to globalization. Purely national water management strategies aiming to reduce the pressure on local water resources might decrease the *water use* in national production while increasing the *water footprint* in national consumption by importing so-called *virtual water* through goods produced abroad (Hoekstra & Mekonnen, 2012). Previous studies of international virtual water trade by Arto, Andreoni and Rueda-Cantuche (2016) and Han, Chen and Li (2018) show that developed countries in particular use this strategy, thereby relocating the negative externalities of water-intensive production to developing countries. Theories such as the environmental Kuznets curve (Panayotou, 1993) in combination with the displacement and pollution haven hypotheses (Copeland & Taylor, 1994; Cole, 2004) also address this issue claiming that higher levels of income reduce local environmental degradation to the detriment of global sustainability by shifting production abroad.

From the perspective of global water resource management, switching from so-called production-based accounting (PBA) of water use to so-called consumption-based accounting (CBA) of water footprints however merely shifts the responsibility for the preservation of water resources from producers to consumers. The distinction between the two accounting techniques is therefore largely driven by debates around fairness, while they cannot account for whether virtual water trade tends to reduce or to preserve global water resources (Hoekstra and Chapagain, 2008, pp.137-140). Hoekstra and Chapagain (2008, pp.137-140) explain that an efficient trade pattern allows for countries with water-intensive production techniques to import water-intensive products from countries with more efficient technology thereby reducing the pressure on global water resources. If the trade pattern is inefficient however, countries might use trade as a means of shifting negative externalities to other parts of the world.

In the carbon emission literature, the recognition of this inability of traditional PBA and CBA techniques to address whether the observed trade patterns effectively reduce or increase environmental externalities at the global level, has sparked new accounting techniques. Jakob and Marschinski (2013), Kander et al. (2015), Jiborn et al. (2018) and Baumert et al. (2019) suggest adjusting the balance of emissions embodied in trade, i.e. the difference between PBA and CBA, previously used to track emission outsourcing. In this strand of literature, the technological level of national production is accounted for when calculating the balance of emissions embodied in trade thereby incentivising countries to reduce their carbon emissions of both, production and consumption, thus ensuring a *global* reduction of emissions.

The thesis proposes the application of this new accounting technique to the context of global virtual water trade and outsourcing of water-intensive production in order to address the concerns raised by Hoekstra and Chapagain (2008, pp.137-140) and Hoekstra (2011). By adjusting the so-called *balance of water embodied in trade*, i.e. the difference between water use and water footprint, according to the technological level of production, the thesis is able to identify water outsourcing patterns that reduce global water resources. Furthermore, a decomposition of the resulting *technology-adjusted balance of water embodied in trade* into the monetary trade balance and the trade specialization as proposed by Baumert et al. (2019) for the case of carbon emissions, allows the thesis to determine the proximate drivers of outsourcing. In order to determine the balance of water embodied in trade the thesis relies on an environmentally extended multiregional input-output analysis employing the Eora26 database (Lenzen et al., 2012; Lenzen et al., 2013a) and the corresponding water use satellite accounts (Hoekstra & Mekonnen, 2012) covering the years 1990 to 2015 and 189 countries.

In the course of the analysis, the thesis aims to evaluate whether developed countries outsource their water-intensive production sectors to developing countries in a way that increases global water use. By addressing this issue, the thesis furthermore assesses the strain placed on countries at different stages of development in the global virtual water trade system. The thesis contributes to existing research firstly, by expanding the scope of previous assessments of global virtual water trade with regard to their time and geographical dimensions. Secondly, the thesis expands the scope of existing research by applying the concept of the technology-adjusted balance of emissions embodied in trade and its decomposition to the context of global virtual water trade creating the new concept of the technology-adjusted balance of water embodied in trade. Lastly, the thesis systematically assesses the trade patterns between different income groups rather than individual countries unlike previous research. This threefold contribution allows for a new assessment of outsourcing patterns in global virtual water trade. The thesis thus addresses the following research question:

Did developed countries outsource their water-intensive production to developing countries between 1990 and 2015?

This main research question is answered by addressing the two following sub-questions:

a) *What global trade patterns are identifiable between 1990 and 2015 based on the balance of water embodied in international trade and its technology-adjusted version?*
b) *To what extent was the technology-adjusted balance of water embodied in international trade driven by monetary trade balances or trade specialization?*

The stage of development is equated to the level of per capita income for the purpose of this thesis based on the high income, upper-middle income, lower-middle income and low income country classification of the World Bank (2020). Additional limitations of the thesis include its theoretical scope as well as the natural limitations of the methodology and the source material. Firstly, the thesis assesses trade in terms of its efficiency with regard to water-intensity but disregards whether the trade is efficient in terms of regional water scarcity mentioned by Lenzen et al (2013b) and Hoekstra (2011) as an additional measure of virtual water trade efficiency. Secondly, while Eora26 is the most appropriate database for this study as argued in section *3.2*, the thesis is limited by the data quality of Eora26 particularly with regard to the level of uncertainty involved in the interpolated water use data. Lastly, input-output analysis relies on assumptions such as sector homogeneity that introduce a level of uncertainty into the analysis.

The thesis begins with a review of relevant literature and theoretical approaches in chapter *2* beginning with the discussion of the theoretical basis of environmental degradation outsourcing at different levels of development in section *2.1*. The section presents the environmental Kuznets curve, the displacement and pollution haven hypotheses, PBA and CBA techniques as well as the improvements of traditional accounting techniques proposed by Jakob and Marschinski (2013), Kander et al. (2015), Jiborn et al. (2018) and Baumert et al. (2019). Section *2.2* proceeds with a presentation of the conceptual basis for global virtual water trade before reviewing the results of previous global virtual water trade studies (section *2.2.1*). Chapter *3* of the thesis is dedicated to discussing the data employed in the analysis beginning with a presentation of the structure of multiregional input-output tables (section *3.1*) before discussing the source material Eora26 more specifically (section *3.2*). The chapter concludes with a presentation of the water use data employed in the analysis (section *3.3*). Chapter *4* focuses on the methodology, first presenting environmentally extended input-output analyses (section *4.1*) and then discussing the modifications to the analysis through technology-adjustment and decomposition analysis (section *4.2*). Chapter 5 contains the empirical analysis, firstly presenting the results (section *5.1*) and secondly discussing and contextualising these results with regard to the research question and the previous research presented in chapter *2*. The final chapter *6* of the thesis draws conclusions based on the previous analysis.

2 Theoretical Background and Literature Review

This chapter begins with a presentation of the theoretical background for environmental degradation outsourcing (section *2.1*) and proceeds with the relevant concepts related to global virtual water trade in section *2.2*, before reviewing the results of previous studies on global virtual water trade in section *2.2.1*.

2.1 Outsourcing of Environmental Degradation

Trade provides countries with risks as well as opportunities in addressing environmental degradation. On the one hand, the displacement and pollution haven hypotheses interpretation of the environmental Kuznets curve (EKC) suggest that individual countries decrease their local environmental degradation by outsourcing their environmentally harmful production abroad while continuing to consume the same products consequently decreasing sustainability at the global level. This issue raises the question whether to allocate the responsibility for environmental degradation to producers or to consumers. On the other hand, if resources are efficiently allocated trade can theoretically help decrease global environmental degradation.

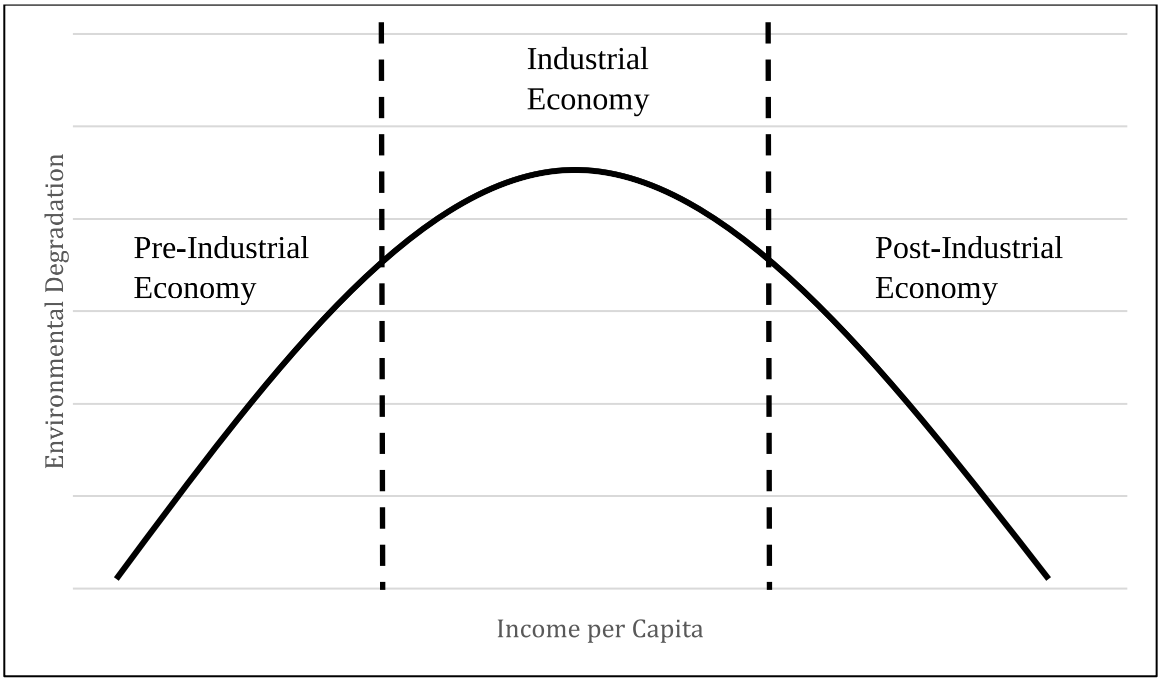

Figure 2.1 Stylized Environmental Kuznets Curve (adapted from Panayotou, 1993)

In 1955, Kuznets suggested that economic development leads to an increase in inequalities before reaching a turning point where inequalities begin to decrease again due to structural change processes. This inverted u-shape became known as the Kuznets curve. In the 1990s, several studies repurposed the original Kuznets curve to the EKC suggesting that higher levels of income per capita will first increase and finally decrease environmental degradation (Panayotou, 1993; Grossmann & Krueger, 1995; Selden & Song, 1994). The EKC thus assumes that countries first increase environmental degradation as they develop from pre-industrial agrarian economies into industrial economies but eventually reach a tipping point past which environmental degradation will decrease again as they transform into post-industrial economies (see *Figure 2.1*). There are two common theoretical explanations for the EKC: one relating to the structural transformation process and the other relating to shifting consumer preferences (Dinda, 2004). Firstly, the inverted u-shape could be the result of the structural transformation process from a clean agrarian economy to a polluting industrial economy to a clean service economy accompanied by continuous technological improvement towards more resource-saving production processes. Secondly, as people become richer they might shift their preferences towards higher environmental quality resulting in the corresponding policy measures.

However, empirical evidence for the EKC relationship remains contested (Ekins, 1997). Empirical studies supporting the theory are commonly based on territorial environmental degradation, i.e. production-based accounting techniques. In contrast, studies relying on environmental footprints, i.e. consumption-based accounting techniques, suggest a more linear relationship between income per capita and environmental degradation (Dong, Wang & Guo, 2016; Rothman, 1998) and provide evidence for environmental degradation outsourcing at higher levels of development, particularly in the field of carbon emissions (Peters et al. 2011; Davis & Caldeira, 2010). This discrepancy in the empirical results suggests that high income countries reduce environmentally harmful production at the national level but continue to consume environmentally harmful products thus causing increasing harm to the environment at the global level (Stern, Common & Barbier, 1996). The EKC therefore merely focuses on the degree of local environmental degradation while disregarding that a globalized economy allows countries to shift their environmentally harmful production abroad.

This EKC critique was formalized in two related hypotheses. Firstly, the displacement hypothesis asserts that environmentally harmful economic sectors shift from higher income to lower income countries as the structural change process in the production of high income countries is not accompanied by changes in consumption (Copeland & Taylor, 1994). Secondly, the pollution haven hypothesis predicts that more stringent environmental regulation causes firms to relocate their production to countries with lower environmental standards in a globalized world economy (Cole, 2004). According to these hypotheses, the downward slope of the EKC thus merely reflects the outsourcing practice of developed countries as consumers continue to demand environmentally harmful products while the production of those products shifts abroad.

The debate surrounding the EKC and the related displacement and pollution haven hypotheses highlights that trade plays a key role in addressing environmental degradation as the world becomes increasingly globalized. Production and consumption activities are becoming increasingly geographically detached from one another. The previously mentioned debate on production- versus consumption-based accounting techniques is therefore also a debate on the allocation of responsibility for environmental degradation.

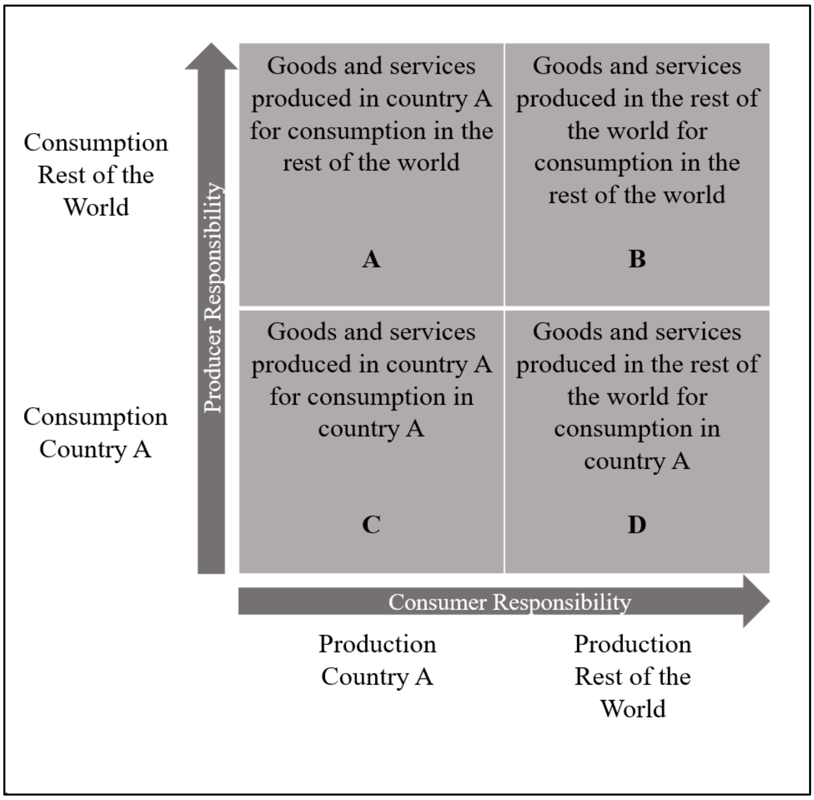

Figure 2.2 Schematic Representation of Production- versus Consumption-Based Accounting (adapted from Munksgaard et al., 2009)

The production-based accounting approach is the most common approach to environmental degradation accounting. International treaties such as the United Nations Framework Convention on Climate Change (UN, 2015) as well as national statistical offices (Giljum et al., 2009) commonly allocate responsibility for environmental degradation with the country of production. Under this accounting scheme, countries are responsible for their production for the domestic market as well as for their production for the world market, i.e. their exports. In the schematic representation of environmental degradation accounting approaches in *Figure 2.2,* country A is thus responsible for the environmental degradation of fields A + C. Under the CBA approach, countries are instead held accountable for their production for domestic consumption as well as for the consumption of goods produced abroad, i.e. their imports. In *Figure 2.2,* country A is thus responsible for the environmental degradation from fields C + D according to CBA. The environmental degradation embodied in the trade of a country or region is then calculated by subtracting the CBA from the PBA. In *Figure 2.2,* the balance of environmental degradation embodied in the trade of country A thus results from fields A – D. The trade balance thus shows whether a country is a net exporter or a net importer of environmental degradation, which is then commonly used to identify outsourcing of environmental degradation, e.g. in Moran et al. (2013).

In these studies, a trade deficit is interpreted as environmental degradation outsourcing. However, the carbon emission literature in particular has directed increasing criticism at this interpretation and recent studies have begun to take a different approach (Jakob & Marschinski, 2013; Kander et al., 2015, Jiborn et al., 2018; Baumert et al., 2019). Jakob and Marschinski (2013) criticize that the traditional PBA and CBA approaches merely constitute two distinct accounting methods that do not provide sufficient information to develop policies for reducing carbon emissions on the global scale. The researchers highlight that trading emissions globally may have negative or positive effects on total global emissions. For instance, global emissions are reduced when particularly carbon-efficient countries specialize in producing carbon-intensive goods. Therefore, the emissions embodied in trade require further decomposition to account for the emission-intensity of production compared to the rest of the world, the monetary trade balance and the trade specialization. Kander et al. (2015) further specify this criticism suggesting that a an effective accounting scheme for carbon emissions needs to fulfil the conditions of "sensitivity", "monotonicity" and "additivity" (p.431). Firstly, the accounting measure needs to rely on factors individual countries can influence (i.e. sensitivity). Secondly, countries should not be able to decrease their own emissions while increasing global emissions (i.e. monotonicity). Thirdly, the sum of country-level emissions should add up to total global emissions (additivity). PBA and CBA measures do not fulfil the first two conditions. The PBA creates the widely recognised problem of outsourcing emissions (Peters & Hertwich, 2008; Davis & Caldeira, 2010) and other types of environmental degradation (Moran et al., 2013). The CBA provides no incentive for countries to increase the emission or resource efficiency of their export production thus discouraging types of trade that reduce emissions or resource use at the global level. Based on their own criticism and that of Jakob and Marschinski (2013), Kander et al. (2015) and Baumert et al. (2019) propose the new concept of the technologically adjusted balance of emissions embodied in trade and its decomposition into the trade specialization and the monetary trade balance. The virtual water trade literature has also recognised the previously mentioned issues (Hoekstra, 2011; Hoekstra & Chapagain, 2008; Liu et al., 2019) rendering the solutions proposed by the carbon emission literature relevant for the context of global virtual water trade.

2.2 Conceptual Basis of Virtual Water Trade

The sustainability sciences identify the preservation of water resources as a key factor in maintaining an intact Earth system. In their influential presentation of nine planetary boundaries defining a safe operating space for humanity within the Earth system's limits, Rockström et al. (2009) and Steffen et al. (2015) present freshwater use as one of those boundaries. In addition to the environmental aspect of safeguarding water resources, the inclusion of Sustainable Development Goal 6 in the United Nations' Agenda 2030 (UN General Assembly, 2015) promoting the sustainable management and availability of water and sanitation for all demonstrates that water resource preservation also plays a key role in development policy. While responsible water use is therefore a key aspect of sustainable development, Vörösmarty et al. (2000) show that economic growth and population growth place increased pressure on water resources through increased demand highlighting the complex interdependent relationship between water use and development. Furthermore, Vörösmarty et al. (2000) find that climate change has the potential of increasing global water scarcity in the future. While initial research into water resources focused primarily on regional water basins or national level research (e.g. Ma et al., 2006; Aldaya & Llamas, 2008; Verma et al., 2009), Hoekstra (2011) and Hoekstra and Chapagain (2008) began to promote a more global perspective on water resources adjusted to the realities of a globalized world economy and globally traded virtual water.

Where water is measured according to production-based accounting principles, the term *water use* is commonly employed. Water use is therefore a national measure assessing the water inputs involved in national production. When water is recorded from a consumption-based accounts perspective the terms *water footprint*, *embedded* or *embodied water* and *virtual water* are employed interchangeably to describe the same phenomenon. Consumption-based accounted water is nationally consumed often after travelling through complex global value chains. Allen (1993) first proposed the concept of virtual water referring to the total amount of freshwater used in the production of all goods and services to satisfy an economy's final demand. While Allen's (1993) study still focused on the regional water resource context of the Middle East and North Africa, the virtual water concept was soon applied to the context of international trade. Virtual water trade became a prominent term for referring to the water embedded in traded goods and services (Hoekstra & Hung, 2002). Hoekstra (2003) and Hoekstra and Hung (2002) first calculated the water footprints of individual products and individual economies. The water footprint is part of a larger family of footprint concepts in sustainability studies, which always refer to the consumption-based accounts of environmental degradation.

Hoekstra et al. (2011) provide an extensive manual for water footprint assessment. Hoekstra et al. (2011 pp.23-40) distinguish three types of water: blue, green and grey water. Blue water refers to fresh surface and groundwater. Green water refers to the rainwater that does not recharge the groundwater but either remains inside crops or evaporates. Lastly, grey water refers to polluted fresh water, i.e. the amount of freshwater required to dilute pollutants. A product's water footprint therefore consists of the fresh water used in its production (i.e. blue water), the rainwater that helped grow the crops involved in the production of the good (i.e. green water) and the water polluted during the production process. The thesis summarizes all three types of water in a single measure to arrive at the total water footprint.

The distinction between blue, green and grey water demonstrates that certain types of water use only exist in the agricultural sector. Being the only sector that directly employs green water in its production processes, the agricultural sector is regarded as particularly water-intensive. Hoekstra et al. (2011, pp.99-103) highlight that the agricultural sector cannot eliminate its water footprint entirely but can merely reduce it, whereas industrial sectors could theoretically fully eliminate their water footprints by fully recycling the water embodied in their production processes.

Since awareness has increased that water resource depletion requires global rather than merely regional assessment and management similar to other environmental concerns such as climate change (Hoekstra, 2011; Hoekstra & Chapagain, 2008), there has been a debate concerning the opportunities and risks arising from the global trade of virtual water. Chapagain and Hoekstra (2008) present the main arguments of that debate. There is an increased risk that countries use trade to outsource their particularly water-intensive production and thus its negative externalities to other countries. Developed countries in particular might employ this strategy to meet the demands of their citizens to reduce local negative externalities while potentially increasing such externalities at the global scale. Furthermore, geographically water-scarce countries might become dependent on importing water-intensive goods thus becoming particularly exposed to global water scarcity threats. At the same time, the import of water-intensive goods provides those same countries with the opportunity of preserving their limited local freshwater supplies. Efficient water trade would shift the most water-intensive production to water-abundant regions and the least water-intensive production to water-scarce regions. Similarly, efficient virtual water trade would relocate the production of particularly water-intensive goods to the regions with the most water-saving production processes. In case of inefficient trade, global virtual water trade can therefore lead to larger pressure on global water resources when employed by developed countries to preserve local water resources through outsourcing practices. Efficient trade could in contrast reduce global water stress by allocating production according to the water-intensity of the local technology or by local water scarcity. This thesis focuses on the water-intensity aspect of global virtual water trade.

2.2.1 Previous Global Virtual Water Trade Research

Water footprint research has primarily focused on the national level or on the product level. The few studies that cover global virtual water trade in its entirety remain limited in either their geographic or in their temporal scope. Previous global virtual water trade studies have furthermore focused on countries or regions rather than systematically analysing the terms of trade between higher and lower income countries. None of the previous studies employ the technology-adjusted trade balance approach used in recent carbon emission research.

Initial research quantifying global virtual water trade focused on the water embodied in traded crops thus assessing the water impact of only part of the agricultural sector and focusing on green and blue water only (Hoekstra & Hung, 2002; Hoekstra & Hung, 2005; Liu, Zehnder & Yang, 2009). Hoekstra and Hung’s (2002, 2005) analyses cannot identify a distinctive pattern of virtual water trade between countries at different development stages. The United States, Canada, Thailand, Argentina and India emerge as net exporters, while Japan, the Netherlands, South Korea, China and Indonesia emerge as net importers of water embodied in crops in their analysis. In contrast to Hoekstra and Hung’s (2002, 2005) findings, Liu, Zehnder and Yang’s (2009) results suggest that imports of water embodied in crops are indeed constrained by income level. Initial analyses of virtual water trade with the specific focus on internationally traded crops thus remained inconclusive with regard to the question of systematic trade patterns between high and low income countries.

Subsequent studies of virtual water trade expanded their scope beyond the agricultural sector to assess the virtual water trade of all economic sectors. In the first comprehensive analysis of global virtual water trade covering almost the entire world economy between 1997 and 2001, Chapagain and Hoekstra (2008) focus on national issues of water import dependency and water scarcity in relation to trade finding less developed countries at a disadvantage. The study however did not assess the trade patterns with regard to outsourcing practices.

More recently, multiple studies have started to explore global virtual water trade patterns between countries with preliminary results concerning the trade balance between developed and developing countries. Moran et al. (2013) were the first to explore whether ecologically unequal exchange occurs between richer and poorer countries in terms of embodied water as well as other ecological measures. Similar to other research on global virtual water trade however, their analysis focuses on regions rather than income level groups. Drawing on the large geographical coverage of the Eora dataset for the year 2000, the authors find that Asia and Africa emerge as net exporters of virtual water to Europe. The former at a lower level than the latter. Furthermore, Arto, Andreoni and Rueda-Cantuche (2016) provide a comprehensive study of water footprints and water trade balances of 41 countries between 1995 and 2008 based on the World Input-Output Database (WIOD; Timmer et al., 2015). The authors find that emerging economies are net exporters of virtual water whereas developed economies are net importers. The water embodied in the production of emerging economies therefore satisfies the demand of developed economies. However, the study remains limited in scope as the WIOD only provides data for developed economies and large emerging economies such as Brazil, Russia, China, India and Indonesia thus excluding a vast amount of developing countries from the analysis. Lastly, Han, Chen and Li (2018) trace global water transfers embodied in international trade across 180 countries based on the geographically more comprehensive Eora database. Their findings are similar to Arto, Andreoni and Rueda-Cantuche (2016) in that large emerging economies such as China and India are identified as net exporters of virtual water while Western regions such as the European Union and the United States are identifies as net importers of water. However, the study merely focuses on the year 2010.

Overall, previous literature exploring global water trade finds that emerging economies satisfy the water demand of developed economies rendering developed economies net importers and developing economies net exporters of water embodied in trade. However, previous analyses have been less comprehensive in their time and geographical dimensions than this thesis and have not systematically analysed the trade patterns between different income groups. Furthermore, previous research did not further explore whether the water trade balances are based on technological differences between exports and imports and the contributions of the monetary trade balance and the trade specialisation to the technology-adjusted balance of water embodied in trade remain unexplored.

3 Data

This chapter begins with a presentation of the structure of environmentally extended multiregional input-output (MRIO) tables (section *3.1*) as the basis for the subsequent discussion of the Eora26 database that constitutes the main source material employed in this study (section *3.2*). Both sections furthermore clarify the assumptions and limitations underlying MRIO tables generally and the Eora26 database more specifically. The chapter closes with a presentation of the satellite accounts, i.e. the water use data, provided in the environmentally extended version of the Eora26 database (section *3.3*).

3.1 Multiregional Input-Output Tables

In order to trace the water embodied in international trade this thesis employs environmentally extended multiregional input-output tables, which firstly display the trade linkages between different sectors and countries and secondly report the environmental degradation caused by each sector in each country. The construction of input-output tables in order to analyse complex value chains was pioneered by Leontief (1936, 1953) and later extended to encompass environmental satellite accounts that help trace the environmental degradation embodied in trade (Leontief, 1970).

Table 3.1 Stylized Multiregional Input-Output Table (adapted from Timmer et al., 2015)

		Intermediate Demand (Z)							Final Demand (F)			Total Output (x)
		Country 1			…	Country *k*			Country 1	…	Country *k*	
		Sector 1	…	Sector *n*		Sector 1	…	Sector *n*				
Country 1	Sector 1											
	...											
	Sector *n*											
...												
Country *k*	Sector 1											
	...											
	Sector *n*											
Value Added (w’)												
Total Input (x’)												
Satellite Accounts (g’)												

Based on a schematic presentation by Timmer et al. (2015), *Table 3.1* shows a stylized version of a multi-region input-output table extended with satellite accounts, which commonly report environmental degradation but may also display other types of externalities. MRIO tables are based on the assumption of sector homogeneity meaning that each sector produces merely one homogenous product. Considering the high heterogeneity of economic sectors in reality, MRIO tables achieve higher accuracy, the more sectors they incorporate. However, the sectoral detail of MRIO tables can be restricted either by data availability at the national level or by limits to comparability at the global level.

The typical MRIO table consists of multiple matrices and vectors as depicted in *Table 3.1*. The intermediate demand matrix Z represents inter-sectoral product flows delivered and consumed in the production process. Matrix Z consists of $kn \times kn$ cells, where k denotes the country and n refers to the sector. Each cell z_{ij} in matrix Z reports the monetary value of the intermediate goods delivered from sector i to sector j. The final demand matrix F reports the monetary value of the demand for each product by non-industry consumers, which is not included in matrix Z. Matrix F consists of $kn \times kc$ cells, where n denotes the number of sectors, k denotes the country and c denotes different final demand categories such as private households or the government. As shown in *Table 3.1*, the final demand matrix F may however simply depict the total final demand per country summarizing all final demand categories. Each cell f_i in matrix F thus reports the monetary value of goods from sector i serving the final demand of country k. Finally, total output vector x reports the sum of intermediate and final demand consisting of $kn \times 1$ cells. Total output vector x can thus be described by the formula $x_i = \sum_j z_{ij} + f_i$. Each cell x_i in vector x depicts the monetary value of the total output of sector i.

As depicted in *Table 3.1*, MRIO tables contain multiple $1 \times kn$ vectors below intermediate demand matrix Z. Value added vector w' depicts the monetary value of the value added each sector j generates. Vector w' and the intermediate demands contained in matrix Z add up to total input vector x' ($x'_j = \sum_i z_{ij} + w'_j$) which constitutes the transposed total output vector x, therefore $x'_j = x_i = \sum_i z_{ij} + w'_j = \sum_j z_{ij} + f_i$. Finally, satellite accounts vector g' reports externalities such as environmental degradation generated in the production of sector j in order to produce total output x_j. In contrast to the previously discussed matrices and vectors expressed in monetary value, the satellite accounts are reported in the appropriate unit for the specific indicator employed.

3.2 Source Material: Eora26

The thesis relies on MRIO tables from the Eora26 global supply chain database (Lenzen et al., 2012; Lenzen et al., 2013a) and the corresponding satellite accounts for water use (Hoekstra & Mekonnen, 2012) covering the time period between 1990 and 2015 for 26 sectors in 189 countries. The dataset thus covers 26 consecutive years and nearly the entire world economy. The Eora26 database has been extensively employed for different types of environmentally extended input-output analysis (Kanemoto, Morna & Hertwitch, 2016; Wiedmann et al., 2015; Moran & Kanemoto, 2016) as well as for water footprint and virtual water trade analyses more specifically (Lenzen et al., 2013b; Han, Chen & Li, 2018).

After careful consideration of the comparative advantages and drawbacks of each of the three available environmentally extended MRIO databases with water use accounts, i.e. EXIOBASE (Stadler et al., 2018), the World Input-Output Database (Timmer et al., 2015) and Eora26 (Lenzen et al., 2012; Lenzen et al., 2013a), Eora26 was selected as the most suitable database for the specific purposes of this thesis.[1] The comparatively large country coverage of Eora26 constituted the decisive factor in the selection process. The research question demands an assessment of trade patterns between countries at different stages of economic development thus requiring sufficiently large samples of countries at all income levels. Eora26 provides near complete data for the world economy including data for many small and low income countries. In contrast, WIOD and EXIOBASE merely provide extensive data on high income countries and only few developing countries mostly focusing on large emerging economies such as China, India, Brazil and Russia. The significantly smaller country sample of the WIOD and EXIOBASE and their focus on high income countries would thus severely limit the validity of the results of this study. In addition to this, Eora26 provides the most recent data available with data coverage until 2015, compared to 2009 in the WIOD and 2011 in EXIOBASE. The Eora26 data furthermore extends to 1990 compared to 1995 in the WIOD and EXIOBASE. The results of this study thus additionally increase their validity by covering a larger time frame than studies relying on other datasets.

However, some comparative drawbacks of Eora26 limit the accuracy of the data. Firstly, the water use satellite accounts in both, Eora26 (KGM & Associates Pty. Ltd., 2019a) and the WIOD (Genty, A., Arto, I. & Neuwahl, F., 2012) merely rely on a single source: Hoekstra and Mekonnen (2012). In contrast, EXIOBASE offers the advantage of relying on data triangulation for its water use satellite accounts by complementing the Hoekstra and Mekonnen (2012) data with data from Pfister et al. (2011), Pfister and Bayer (2014) and Flörke et al. (2013). However, the employment of the Hoekstra and Mekonnen (2012) data in all three datasets demonstrates its wide recognition suggesting sufficient data quality. Secondly, the WIOD and EXIOBASE provide a considerably more detailed distinction between sectors than Eora26 with 35 sectors and 163 sectors respectively compared to merely 26 sectors. As explained in the previous section *3.1*, larger sectoral detail increases the accuracy of MRIO tables. While all three datasets thus have distinctive advantages and disadvantages, Eora26 however remains the most appropriate choice for the purpose of this study as it allows for a more accurate country sample in terms of different economic development stages.

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[1] See Tukker and Dietzenbacher (2013) for a detailed discussion of the technical differences between the three databases that would exceed the scope of this thesis

Eora26 constitutes the harmonized version of the full Eora dataset, which the authors deem the most appropriate version for MRIO input-output analysis (KGM & Associates Pty. Ltd., 2019b). The harmonization renders the dataset less accurate than the full Eora dataset but is recommended for environmentally extended input-output analysis and particularly for higher comparability between countries. *Appendix A* lists all sectors and countries covered by the dataset. Eora26 reports all data in current year thousands of US dollars.

The thesis employs the water use satellite accounts available together with the Eora26 database. The water use data originates from the Water Footprint Network (2020) and was first published by Hoekstra and Mekonnen (2012). The water use per sector is provided in cubic megametres (Mm^3), i.e. millions of cubic metres. The data lists blue water, green water and grey water use separately. For the purpose of this thesis, the three different types of water are added up to the total water use. As the water use time series is incomplete, the authors of the dataset interpolated the available data employing the year 2000 as the base year and holding the water-intensity (Mm^3/\$US) constant for each year while scaling the water use according to the yearly growth per each sector (KGM & Associates Pty. Ltd., 2019a). The reliability of the water use data provided by Eora26 therefore depends on relatively small variations in water-intensity per sector over time.

Apart from calculating the total water use based on the blue, green and grey water use, the dataset is further edited by creating income groups for the purpose of this study. The 189 countries listed in the Eora26 dataset are grouped into high income, upper-middle income, lower-middle income and low income categories for each year based on the historical income classification of the World Bank (2020). The thesis therefore proxies the stage of economic development of each country with its per capita income level. Some countries ceased to exist but continue to be covered by the Eora26 database for the purpose of a complete and consistent time series. These cases are matched with the latest available income classification. The original dataset is further edited by summarizing the final demand categories per country, as the study does not aim to distinguish different final demand categories. Lastly, final demand and intermediate demand are added according to the formula provided in the previous section *3.1* in order to find total output vector x and total input vector x'. After editing the Eora26 dataset as described, the final MRIO table provides 104 income group-sector combinations of 26 sectors in 4 different income groups thus creating a 104×104 matrix Z showing intermediate demand, a 104×4 matrix F showing the final demand and the 1×104 vector g' for water use.

3.3 Presentation of the Water Use Data

The edited version of the Eora26 database (Lenzen et al., 2012; Lenzen et al., 2013a) reporting the water use environmental satellite accounts (Hoekstra & Mekonnen, 2012) per sector and income group allows for a production-based accounting assessment of the water used in the direct production processes of each income group.

Table 3.2 Water Use (Mm³) and Average Contributions to Total Water Use (%) and Total Output (%) per Income Group in the Eora26 Satellite Accounts, 1990-2015 (author's own calculations)

Year	High Income	Upper-Middle Income	Lower-Middle Income	Low Income
1990	1,744,775.45	1,282,400.44	1,746,098.24	3,958,152.18
1991	1,740,755.76	1,441,480.43	1,558,096.21	3,987,074.23
1992	1,740,755.76	1,137,687.70	1,851,676.54	3,996,725.22
1993	1,740,755.76	1,150,863.10	2,092,889.09	3,742,898.67
1994	1,753,946.02	1,113,562.10	2,079,833.72	3,798,984.52
1995	1,770,777.06	1,083,441.81	2,903,429.03	3,748,547.12
1996	1,787,945.90	1,129,099.50	2,061,747.87	3,748,613.35
1997	1,789,852.90	1,273,381.52	3,064,953.79	2,599,218.42
1998	1,773,220.24	1,236,733.69	1,640,376.35	3,999,474.94
1999	1,773,170.86	1,208,850.78	2,677,690.05	2,970,966.33
2000	1,773,417.74	1,299,032.41	2,574,870.92	3,080,085.55
2001	1,789,904.58	1,128,654.75	2,804,791.96	3,088,140.93
2002	1,790,191.35	657,492.21	3,318,072.31	2,959,923.50
2003	1,789,953.96	657,729.61	3,658,766.33	2,620,956.73
2004	1,802,880.83	1,190,559.86	3,126,972.94	2,606,992.98
2005	1,802,920.73	1,234,118.72	3,125,343.62	2,565,023.56
2006	1,820,190.97	1,780,659.44	2,562,271.79	2,564,284.42
2007	1,855,658.36	1,800,886.32	3,701,299.00	1,369,562.95
2008	1,861,288.84	1,913,202.20	4,013,469.86	939,445.72
2009	1,921,695.30	1,970,727.17	4,056,158.25	778,825.91
2010	1,917,675.60	3,307,647.56	2,773,555.19	728,528.27
2011	1,917,675.60	3,333,521.32	2,744,925.81	731,283.89
2012	2,309,900.34	2,978,180.66	2,710,797.36	728,528.27
2013	2,309,900.34	2,978,180.66	2,903,429.03	717,970.36
2014	1,959,153.25	3,352,431.80	2,903,429.03	512,392.54
2015	1,959,153.25	3,352,431.80	2,903,429.03	512,392.54
Contribution to Total Water Use	21.16%	19.75%	31.41%	27.68%
Contribution to Total Output	68.97%	15.54%	13.24%	2.25%

Table 3.2 reports the water use of each income group per year. The different income groups were subject to considerable change over time as individual countries became richer or poorer. For instance, China started out as part of the low income group in 1990, became a lower-middle income country by 1997 and joined the ranks of upper-middle income countries in 2010. The absolute numbers reported in the water use accounts therefore partially reflect these considerable changes. In absolute terms, the high income group was never the largest user of water in its production for domestic and export markets although multiple additional countries joined the high income group over time. The high income group's water use stayed relatively stable around 1,853,750.64Mm³ over time, whereas the water use of the upper-middle income and lower-middle groups fluctuated, which is likely partly related to the frequent changes in the country composition of those groups. The low income group significantly reduced its water use from 3,958,152.18Mm³ in 1990 to merely 512,392.54Mm³ in 2015. This decrease by 87.05% is almost matched by a 76.72% decrease in total output as an increasing amount of countries

proceeded to higher stages of economic development. In contrast to the yearly increase reported by UNESCO (2019, p.13), the Eora26 satellite accounts report relatively stable total water use over time, which could be due to the interpolation of the data described in the previous section *3.2*. Comparing the average contribution to the total water use of the world economy with the average contribution to the total world output per income group, it is particularly striking that only the high income group contributed significantly less to global water use (21.16%) than to global economic output (68.97%). The upper-middle income group's contributions to world water use and world economic output were relatively similar with a slightly higher contribution to global water use (19.75%>15.54%). The lower the income group, the larger the divergence between the contributions to world economic output and world water use in favour of the water use contribution.

Table 3.3 Average Water Use (Mm^3) per Sector in the Eora26 Satellite Accounts, 1990-2015 (author's own calcualtions)

Sector	Water Use (Mm^3)
Agriculture	8,104,606.97
Fishing	73,215.86
Mining and Quarrying	17,937.60
Food & Beverages	44,241.69
Textiles and Wearing Apparel	19,265.76
Wood and Paper	13,640.45
Petroleum, Chemical and Non-Metallic Mineral Products	47,049.62
Metal Products	19,527.24
Electrical and Machinery	48,127.93
Transport Equipment	15,528.35
Other Manufacturing	13,275.54
Recycling	6,015.31
Electricity, Gas and Water	221,173.00
Construction	6,446.83
Maintenance and Repair	1,913.84
Wholesale Trade	2,972.94
Retail Trade	3,865.78
Hotels and Restaurants	5,864.17
Transport	18,932.35
Post and Telecommunications	7,656.76
Financial Intermediation and Business Activities	31,579.38
Public Administration	4,923.19
Education, Health and Other Services	22,388.24
Private Households	2,166.75
Others	4,778.31
Re-export & Re-import	4,592.33

The water use data also shows which sectors used the largest amount of water in their direct production. *Table 3.3* lists the average water use per sector in the observed time period. The satellite account data demonstrates that *agriculture* used by far the largest amount of water (8,104,606.97Mm^3) in line with the literature discussed in section *2.2.1*, followed by the *electricity, gas and water* sector (221,173.00Mm^3) and the *fishing* sector (73,215.86Mm^3).

Services dominated sectors such as *maintenance and repair* (1,913.84Mm^3) and *wholesale trade* (2,972.94Mm^3) but also *private households* (2,166.75Mm^3) on average used the least amount of water between 1990 and 2015.

The water use data of the different income groups suggests that high income countries suffer from comparatively lower environmental degradation caused by high water usage than lower income countries. It is particularly striking that high income countries while contributing more than two thirds of global economic output only contributed to a fifth of the global water use. In contrast, for all lower income groups the contribution to global water use exceeds their contribution to global economic output with the distance between the two increasing with declining income levels. The water use data per sector confirms the findings of previous water research showing that the agricultural sector is particularly water-intensive. This suggests that the balances of water embodied in trade will be heavily determined by the balance of agricultural exports and imports. The next chapter *4* discusses the methodology required to assess whether the observed PBA data results from developed countries outsourcing their water-intensive production to developing countries or from the technological differences between countries at different stages of development.

4 Methods

The first section *4.1* of this chapter explains the method of environmentally extended input-output analysis for analysing global virtual water trade from a consumption-based accounting (CBA) perspective. The second section *4.2* presents the recently introduced extension of the CBA method through technology-adjusted accounting and a decomposition analysis.

4.1 Environmentally Extended Input-Output Analysis

Input-Output analyses were first conducted by Leontief (1936; 1953) to trace complex value chains and later extended to encompass environmental satellite accounts (Leontief, 1970) allowing for CBA assessments of environmental degradation, so-called environmental footprints. The thesis employs the input-output methodology to calculate the water footprint of each income group from the edited version of the Eora26 dataset described in the previous section *3.2* and to compare this footprint to the PBA data presented in section *3.3* to arrive at the balance of water embodied in trade (BWET). Suh (2009) provides an extensive collection of articles explaining input-output analysis and its applications in detail providing methodological guidance for this chapter. The formulas are based on Peters and Hertwich (2009).

Based on intermediate demand matrix Z and total input vector x' the production formula of each good *j* can be calculated to obtain input coefficient matrix A with the dimensions *kn* × *kn*, where *k* indicates the income group and *n* indicates the sector. Matrix A then shows the monetary value of the production input of sector *i* required to produce one unit of the good produced by sector *j*. The coefficients a_{ij} in matrix A are calculated by dividing each intermediate demand z_{ij} by total output x_j:

(1) $a_{ij} = \frac{z_{ij}}{x_j}$

However, matrix A merely shows the direct inputs required for each good. In complex value chains the inputs themselves are however also produced in different sectors and therefore the second and higher order effects need to be calculated to obtain the direct and indirect inputs required for the production of one unit of each good, i.e. the interdependence coefficients, also known as Leontief inverse. The Leontief inverse matrix L is calculated by subtracting input coefficient matrix A from identity matrix I, with the same *kn* × *kn* dimensions as matrix A but containing diagonalized 1 values and 0 values in the remaining cells. The result is then calculated to the power of -1:

(2) $L = (I - A)^{-1}$

Matrix L then shows the indirect and direct value of sector *i* required to produce one unit of sector *j* thus tracing the entire value chain for each product. For an environmentally extended analysis, the satellite accounts need to be included. For the purpose of this study, the satellite accounts contain a water use measure. First the direct water use coefficient vector d' needs to be determined by dividing each satellite account in vector g' by the corresponding value in total input vector x'. The formula then determines how much water use directly results from producing one unit of good *j*:

(3) $d'_j = \frac{g'_j}{x'_j}$

In order to determine how much water use results from the direct as well as the indirect inputs per sector to serve final demand, the direct water use vector d' needs to be diagonalized in matrix $\hat{d}$ where all remaining cells contain the value 0. Then the new matrix $\hat{d}$, the Leontief inverse matrix L and the final demand matrix F need to be multiplied in order to arrive at the embodied water use matrix E which shows the water use resulting from the direct and indirect production effects to serve the final demand.

(4) $E = \hat{d}LF$

The results of matrix E can then be employed to determine the water footprint of each country group and the resulting trade balance of the water embodied in trade. Matrix E indicates the direct and indirect water used in the production of each sector *i* to serve the final demand of each income group *k*. The matrix then allows for the calculation of the water embodied in the exports (WEX) and the water embodied in the imports (WEI) of each income group *k*.[2] Furthermore, the domestic water use can be determined and added to the WEX to arrive at the production-based accounts for the water use of each income group *k* or to the WEI to arrive at the CBA for the water footprint of each income group *k*.

(5) $PBA_k = Domestic_k + WEX_k$
(6) $CBA_k = Domestic_k + WEI_k$

The difference between PBA and CBA or the difference between WEX and WEI then determines the BWET of each income group *k* showing whether the income group runs a trade deficit or a trade surplus of virtual water.

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[2] The terms and abbreviations for water embodied in imports and exports and the balance of water embodied in trade vary across the virtual water trade literature. The thesis adopts similar terminology to that employed in the carbon emissions literature for simplicity, as part of the methodology follows that strain of literature

(7) $BWET_k = PBA_k - CBA_k = WEX_k - WEI_k$

However, the result of the BWET alone does not show whether the high income group does indeed outsource its water-intensive production to the lower income groups. The next section *4.2* further elaborates this issue and proposes a solution based on recent carbon emission accounting literature.

4.2 The Technology-Adjusted Balance of Water Embodied in Trade and its Drivers

Based on the criticism of the BEET discussed in section *2.1*, Kander et al. (2015) and Baumert et al. (2019) propose the new concept of the technology-adjusted balance of emissions embodied in trade (TBEET). In this thesis, their methodology is applied to the context of global water trade thus adjusting the BWET to the technologically adjusted balance of water embodied in trade (TBWET). Baumert et al. (2019) suggest harmonizing the emission-intensity to the average world level for each sector thus replacing vector d' containing differentiated emission-intensities per country with vector d'^{WA} with global average emissions per sector *n* harmonized across countries *k*. Each country is then assumed to produce at equal emission-intensity. Applied to the context of water use, this implies that the global average water use directly embodied in one unit of output per sector i (d'^{WA}_i) can be calculated by dividing the total water use of sector i (C'^{total}_i) by the total output generated by sector i (x'^{total}_i):

(8) $d'^{WA}_i = \frac{C'^{total}_i}{x'^{total}_i}$

The original equation (4) for the calculation of embodied water use matrix E is then modified by replacing $\hat{d}$ with $\widehat{d^{WA}}$ to arrive at the direct and indirect water used by each industry to serve the final demand if all sectors had produced at the world average water-intensity.

(9) $E^{WA} = \widehat{d^{WA}}LF$

The newly generated matrix E can then be employed to calculate the technology-adjusted balance of water embodied in trade (TBWET) of income group k by either subtracting the technology-adjusted water embodied in imports (TWEI) from the technology-adjusted water embodied in exports (TWEX) or by subtracting the technology-adjusted consumption-based accounts (TCBA) from the technology-adjusted production-based accounts (TPBA) arriving at an adjusted version of formula (7):

(10) $TBWET_k = TPBA_k - TCBA_k = TWEX_k - TWEI_k$

In contrast to the BWET, the TBWET accounts for the possibility that water trade balance deficits could originate from particularly water-efficient export production above the world average. The procedure thus corrects for the violation of the principles of sensitivity and monotonicity by the BWET. This TBWET can then be further decomposed without leaving any residual to determine whether a country outsources particularly water-intensive production due to a trade specialization in products with low water-intensity or due to the monetary trade balance. Jiborn et al. (2018) and Baumert et al. (2019) propose a decomposition of the TBEET, into trade specialization and trade balance using a Laspeyres index decomposition method based on Sun (1998) further refined by Jakob and Marschinski (2013). The following formulas help determine the trade specialization (TSp) and monetary trade balance (TB) per country group *k* based on the TBWET following the proposed decomposition method by Jiborn et al. (2018) and Baumert et al. (2019), where Im indicates imports and Ex indicates exports:

(11) $$TSp_k = \left(\frac{TWEX_k}{Ex_k} - \frac{TWEI_k}{Im_k}\right) \times Im_k + \frac{1}{2} \times \left(\frac{TWEX_k}{Ex_k} - \frac{TWEI_k}{Im_k}\right) \times (Ex_k - Im_k)$$

(12) $$TB_k = \frac{TWEI_k}{Im_k} \times (Ex_k - Im_k) + \frac{1}{2} \times \left(\frac{TWEX_k}{Ex_k} - \frac{TWEI_k}{Im_k}\right) \times (Ex_k - Im_k)$$

While traditional measures of resource outsourcing can therefore hinder reducing resource use at the global level, the technology-adjusted measure and the subsequent decomposition of that measure allow for a more detailed assessment of water trade balances leading to global rather than merely local reductions of water use. The next chapter *5* presents the empirical analysis based on this methodology.

5 Empirical Analysis

This chapter discusses the results of the environmentally extended input-output analysis and the technology-adjusted balance of water embodied in trade with its decomposition (section *5.1*) before interpreting the findings in terms of the research question and previous literature (section *5.2*).

5.1 Results

The results of the input-output analysis show that approximately 14.5% of all global water used between 1990 and 2015 was traded across borders. The results also demonstrate which sectors were particularly water-intensive in the observed time period. Furthermore, the results help assess whether there is a recognizable pattern of higher income countries outsourcing their water-intensive production to lower income countries in multiple ways. Firstly, the balance of water embodied in the trade of the high income, upper-middle income, lower-middle income and low income group is reported. Secondly, the technology-adjusted balance of water embodied in trade for these four income groups is reported testing whether the patterns observed hold if the water-intensity of production had been equal across all income groups. Lastly, the results show to what extent the TBWET of each income group is driven by the trade specialization in water-intensive economic sectors and the monetary trade balance. *Appendix B* contains the complete results.

Table 5.1 Average Direct Water Use per Unit of Output (m^3/$US), 1990-2015 (author's own calculations)

Sector	Direct Water Use per Unit of Output (m^3/$US)
Agriculture	25.1730
Fishing	1.9344
Mining and Quarrying	0.1116
Food & Beverages	0.0984
Textiles and Wearing Apparel	0.0943
Wood and Paper	0.0861
Petroleum, Chemical and Non-Metallic Mineral Products	0.0877
Metal Products	0.0650
Electrical and Machinery	0.0897
Transport Equipment	0.0956
Other Manufacturing	0.1473
Recycling	0.3140
Electricity, Gas and Water	1.5653
Construction	0.0126
Maintenance and Repair	0.1321
Wholesale Trade	0.0148
Retail Trade	0.0141
Hotels and Restaurants	0.0394
Transport	0.0522
Post and Telecommunications	0.0524
Financial Intermediation and Business Activities	0.0279
Public Administration	0.0206
Education, Health and Other Services	0.0414
Private Households	0.4444
Others	0.0830
Re-export & Re-import	8.9348

The direct water use coefficients *d'* determined by the input-output analysis shown in table *5.1* reveal which sectors were the most water-intensive in their production in terms of their direct inputs between 1990 and 2015. *Agriculture* was by far the most water-intensive sector in terms of direct inputs with 25.17m^3 per unit of output worth 1$US, followed by the *re-export and re-import* sector with 8.93m^3 per dollar and the *electricity, gas and water* sector with 1.57m^3 per dollar. The agricultural sector was thus the most water-intensive sector of the world economy far ahead of all remaining sectors. The services dominated sectors of *wholesale trade* (0.0148m^3), *retail trade* (0.0141m^3) and c*onstruction* (0.0126m^3) were the least water-intensive sectors all using less than a fifth of a cubic metre of water in direct inputs per unit of output. Compared to the absolute water use across sectors presented previously in section *3.3*, the *agriculture* sector remains particularly water-intensive even in relative terms. The *fishing* sector is however replaced by the *re-export and re-import* sector in the top three most water-intensive sectors when measured in relative terms and the *retail trade* and *construction* sectors are less water-intensive than the *maintenance and repair* sector and *private households* when normalized by their output.

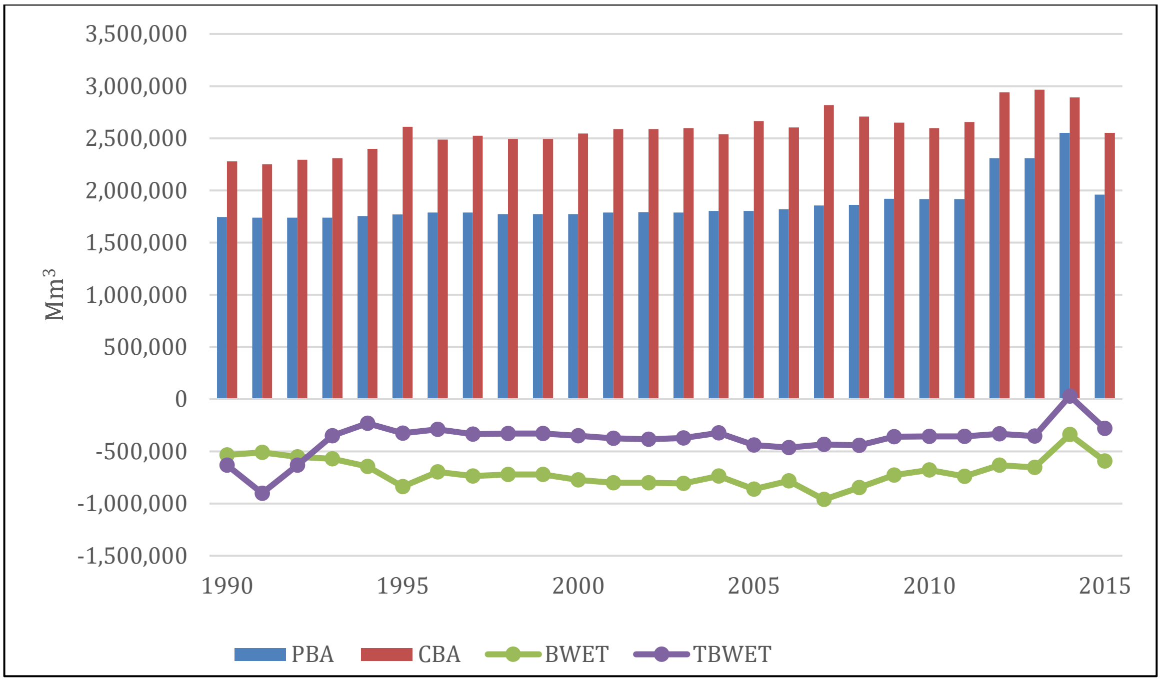

Figure 5.1 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts of High Income Countries in Mm^3, 1990-2015 (author's own calculations)

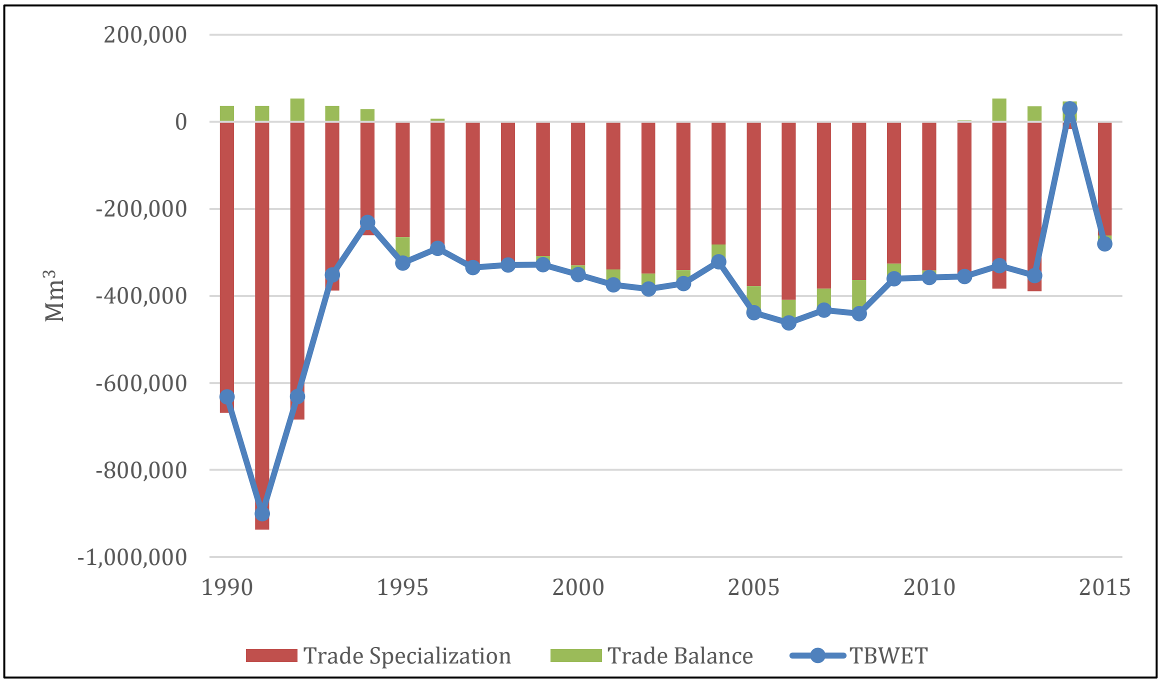

Figure 5.2 Technology-Adjusted Balance of Water Embodied in Trade, Contributions of the Monetary Trade Balance and of the Trade Specialization of High Income Countries in Mm^3, 1990-2015 (author's own calculations)

The BWET for of the high income group was consistently negative between 1990 and 2015 (see *Figure 5.1*) showing that this group of countries consistently imported more virtual water than it exported. The TBWET was consistently higher than the BWET but remained below zero with the exception of 2014 demonstrating that the high income group produced more water-efficiently than the rest of the world. However, this technological difference of their exports was not large enough to fully counteract the negative trade balance. The production- and consumption-based accounts indicated in *Figure 5.1* furthermore show a slight upward trend in overall water production and consumption as the high income country group expanded over time with several East Asian countries joining its ranks. As total output of the high income group increased by 213.22% between 1990 and 2015 the increase in water use and water footprint however remained minimal. A closer examination of the TBWET in *Figure 5.2* reveals that the negative water trade balance was largely driven by a clear trade specialization in less water-intensive economic sectors rather than by the monetary trade balance, which had a comparatively marginal effect on the TBWET across all observed years.

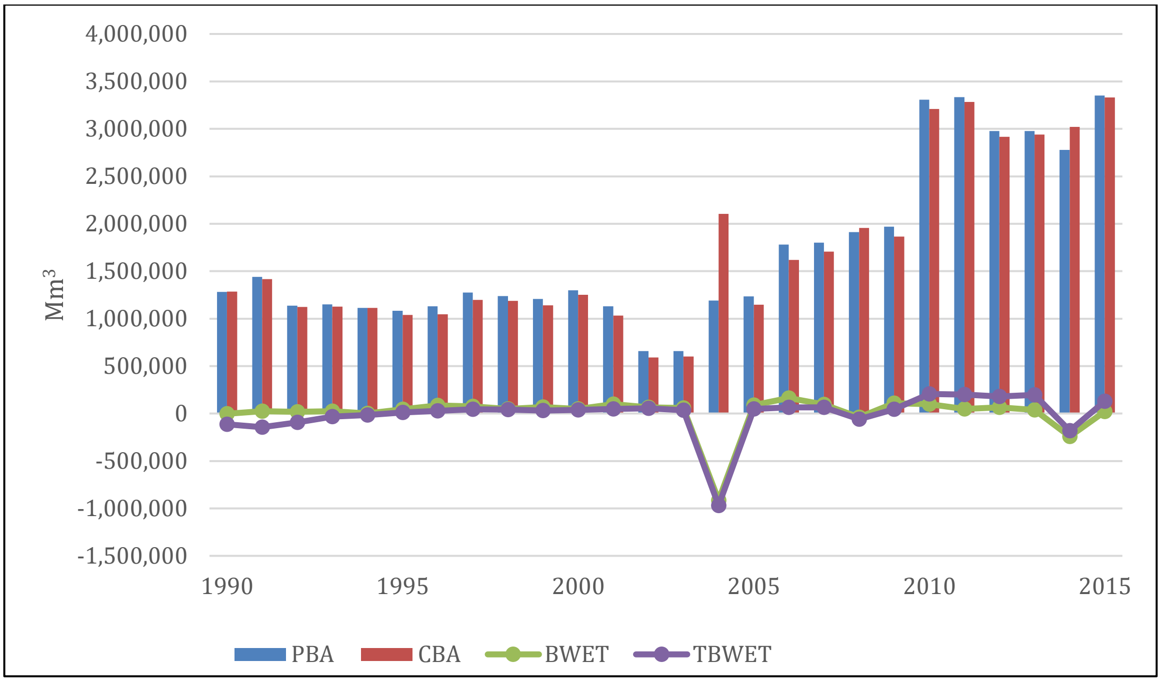

Figure 5.3 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts of Upper-Middle Income Countries in Mm^3, 1990-2015 (author's own calculations)

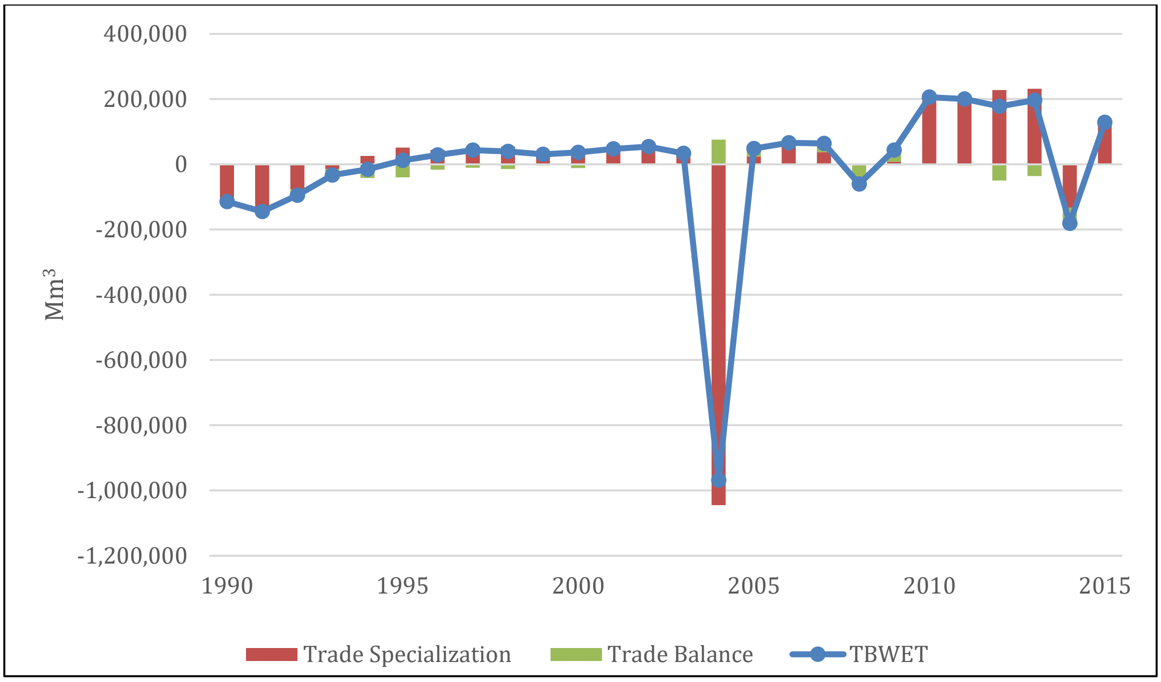

Figure 5.4 Technology-Adjusted Balance of Water Embodied in Trade, Contributions of the Monetary Trade Balance and of the Trade Specialization of Upper-Middle Income Countries in Mm^3, 1990-2015 (author's own calculations)

The upper-middle income group shows a higher tendency towards a positive BWET indicating higher water exports than imports in most years with relatively minimal exceptions in 1990, 2008 and 2014 and the most notable exception in 2004 (see *Figure 5.3*). The TBWET remained below the BWET until 2009 indicating that part of this positive water trade balance derived from the upper-middle income group producing its exports at a higher water-intensity than the world average. Notably, the TBWET shifts the water trade balance of upper-middle income countries from a surplus to a deficit between 1990 and 1994. From 2010 until 2015, the TBWET rose above the BWET indicating that the upper-middle income group began producing its exports at lower than world average water-intensity. Between 1990 and 2010, both water production and consumption as indicated by the PBA and the CBA remained relatively stable over time. The large upsurge in water use and footprint in 2010 is likely caused by China leaving the lower-middle income group and joining the group of upper-middle income countries. The more detailed image of the TBWET given in *Figure 5.4* demonstrates that similarly to the high-income group, the trade balance was largely driven by the trade specialization rather than the trade balance. Upper-middle income countries were largely specialised in exporting products from water-intensive sectors throughout the observed time period with exceptions between 1990 and 1994 and in 2004, 2008 and 2014.

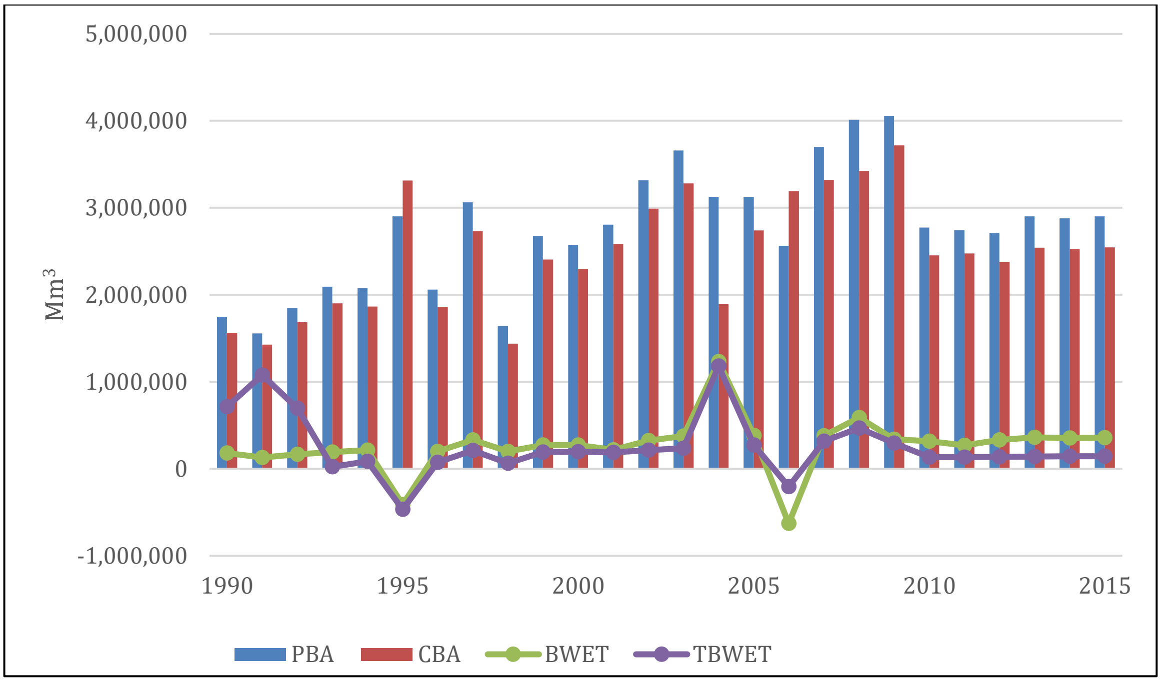

Figure 5.5 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts of Lower-Middle Income Countries in Mm³, 1990-2015 (author's own calculations)

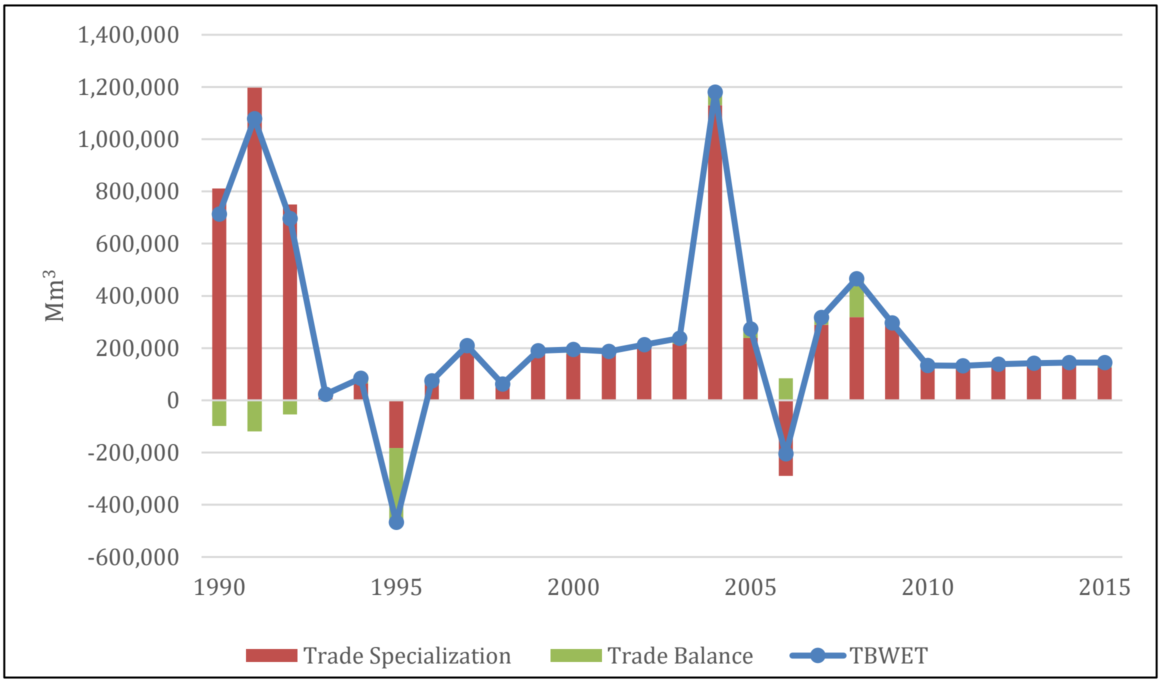

Figure 5.6 Technology-Adjusted Balance of Water Embodied in Trade, Contributions of the Monetary Trade Balance and of the Trade Specialization of Lower-Middle Income Countries in Mm³, 1990-2015 (author's own calculations)

The lower-middle income group displays a trade surplus in virtual water in all years except in 1995 and 2006 (see *Figure 5.5*). The exports of water thus exceeded the imports. Products in lower-middle income countries were produced at a lower water-intensity compared to the world average only between 1990 and 1992 and in 2006 and with a higher water-intensity than the world average in the remaining years. The lower-middle income group shows a slight but inconsistent upward trend in PBA and CBA over time. The instability of the trend can be attributed to the frequent changes in the group composition. The decomposition of the TBWET in *Figure 5.6* demonstrates that the water trade balance in the lower-middle income group was largely driven by its trade specialization, similar to the previous income groups. Merely in 1995 and 2006, the lower-middle income countries specialized in exporting products from less water-intensive sectors. In all other years, they displayed a specialization in exporting products from particularly water-intensive sectors.

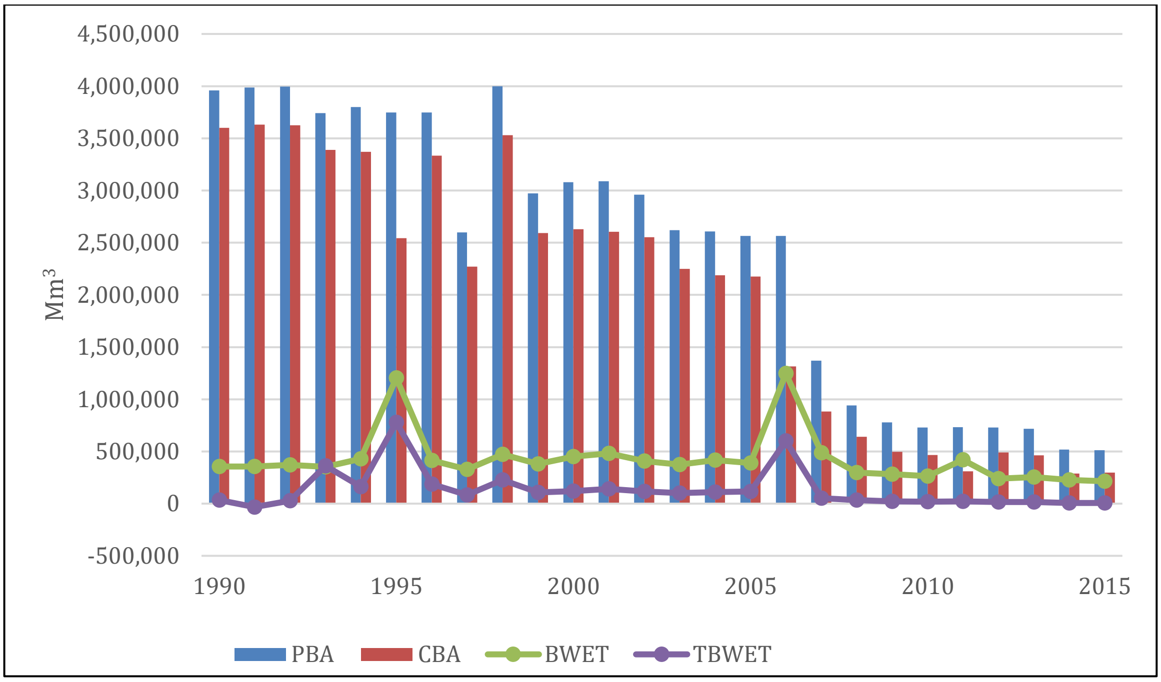

Figure 5.7 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts of Low Income Countries in Mm^3, 1990-2015 (author's own calculations)

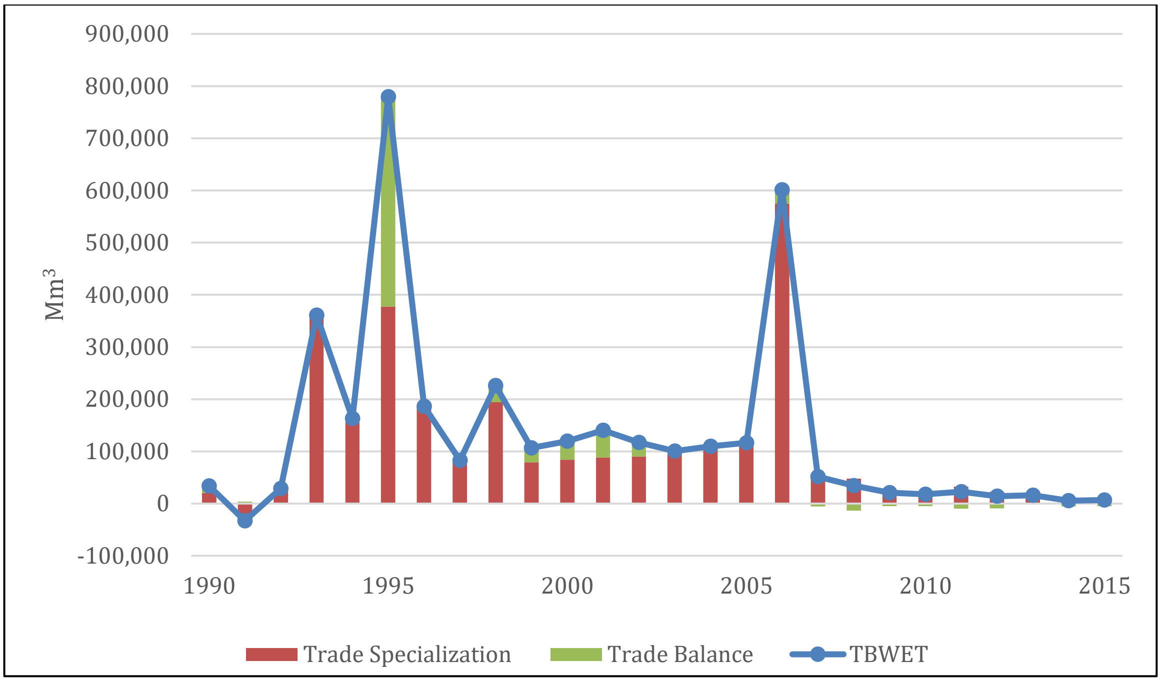

Figure 5.8 Technology-Adjusted Balance of Water Embodied in Trade, Contributions of the Monetary Trade Balance and of the Trade Specialization of Low Income Countries in Mm^3, 1990-2015 (author's own calculations)

The low-income country group had a consistently positive virtual water trade balance with a higher amount of water embodied in production than in consumption (see *Figure 5.7*). The decrease in both water use and water footprint can be attributed to the group of lower income countries becoming smaller over time as many countries moved up into higher income level groups. The consistently lower TBWET than BWET indicates that the low income group's exports were produced at higher water-intensities than the world average in all years but 1993. In 1991, this technology difference turned the trade surplus recorded by the BWET into a deficit according to the TBWET. In line with all previous income groups, the water trade balance is largely driven by the trade specialization rather than the monetary trade balance, only in 1995 the monetary trade balance significantly drove the TBWET upwards (see *Figure 5.8*). The low income country group was consequently specialized in particularly water-intensive export sectors throughout the observed time period.

High-income countries emerge as net importers of virtual water whereas the remaining three income groups appear to have been net exporters of water with few exceptions throughout the observed time period. The upper-middle income group shows the least consistent balance of water embodied in trade of the four income groups in the observed time period. The observed trade patterns largely hold even after adjusting the trade balance for technological differences in terms of water-intensity. The pattern of net exporters and net importers remains relatively stable over time despite changes in the income group compositions. In all four income groups, the trade balance was largely driven by a trade specialization in either particularly water-intensive or comparatively water-saving economic sectors and only marginally by the monetary trade balance.

5.2 Discussion

The results of the empirical analysis in the previous section *5.1* showed a relatively clear pattern throughout the observed time period. The high-income country group emerged as a net importer of virtual water, whereas the lower-middle and low-income groups were net exporters of virtual water between 1990 and 2015. The upper-middle income group displayed a mixed water trade balance over time. The trade general patterns remained relatively stable even after adjusting for technological differences at different income levels suggesting that they were only partly driven by differences in technology. What do these results imply with regard to the research question? Do developed countries indeed outsource their water-intensive production to less developed countries? This section address these questions and contextualises the data with regard to the previously discussed theoretical background and previous findings of similar studies.

The results help answer the main research question posed at the beginning of this thesis: *Did developed countries outsource their water-intensive production to developing countries between 1990 and 2015?* Firstly, the BWET shows that high-income countries consistently imported a larger amount of water than they exported, whereas the lower-middle income and the low income group generally displayed the reverse trade pattern. Secondly, the TBWET confirms that this result does not occur because the production of exports is considerably more water-saving in high income countries compared to the other income groups. While there were notable differences in technology, the trade patterns remained largely similar as observed from the BWET. The TBWET slightly shrank the virtual water trade deficit of the high income group and the virtual water trade surpluses of the lower-middle and low income group. Therefore, high-income countries did indeed outsource their water-intensive production to lower income countries between 1990 and 2015. The decomposition of the TBWET confirms this result, showing that the observed water trade balances in all income groups largely resulted from a specialization in water-saving (high income group) or water-intensive (lower-middle and low income group) economic sectors while the monetary trade balance usually had little effect. Merely the upper-middle income group did not adhere to a consistent virtual water trade surplus or trade deficit. The outsourcing of water-intensive production thus mainly seems to occur between the high income group and the lower-middle and low income group. Despite considerable changes in the composition of the income groups over time, the virtual water trade balances of each group remained relatively stable in the observed time period with the exception of the upper-middle income group. The relatively high robustness of the observed trade patterns over time provides a strong indication that the stage of economic development determines the trade balance of water, particularly at very high and very low levels of income.

The results provide support for the theories discussed in section *2.1*. The observed trade patterns suggests that the downwards curvature of the water use EKC is at least partly driven by outsourcing of particularly water-intensive production by high income countries to less developed countries. The results of this thesis therefore offer support for the pollution haven and the displacement hypotheses. The observation that the agricultural sector was by far the most water-intensive sector as predicted by Hoekstra et al. (2011), whereas the service-dominated sectors were particularly water-saving suggests that the observed trade patterns may be related to structural change processes. Low income economies are commonly largely based on agriculture thus producing the most water-intensive goods according to the results of the analysis. With proceeding economic development agricultural economies transition towards industrial and finally to service economies. High income countries might therefore outsource water-intensive agricultural goods to lower income countries while switching to water-saving services sectors themselves. The upper-middle income group could thus show relatively unstable results as some but not all developing countries face so-called “premature de-industrialization” (Rodrik, 2016).

The results are largely in line with the trade patterns observed in previous studies of global virtual water trade. While none of the previous studies systematically assessed trade balances at different income levels, instead focusing on individual countries, most provided preliminary evidence that developed countries are net importers and developing countries net exporters of virtual water. Moran et al. (2013) found evidence that Asian and African countries export their water to Europe with a larger trade surplus in Africa compared to Asia. The results of thesis suggest that the lower trade surplus in Asia could result from the high-income level of many East Asian countries and from the relatively instable trade balance of upper-middle income countries. The results from Arto, Andreoni and Rueda-Cantuche (2016) presenting large emerging economies as net exporters of water and developed economies as net importers are confirmed by the results of this thesis and extended to include smaller income countries. The similar results of Han, Chen and Li’s (2018) study are likewise supported by the findings of this thesis while demonstrating that their results hold over a larger time span. The thesis furthermore shows that the outsourcing pattern from developed to developing countries remain when adjusted for technological differences. Furthermore, by systematically assessing the balance of water embodied in trade at different income levels, the thesis revealed that the upper-middle income group does not show a stable trade pattern which was not observed by previous literature.

The results thus show that high countries outsource their water-intensive production to lower-middle income and low income countries while specializing in less water-intensive economic sectors. This result provides strong evidence for the pollution haven and displacement hypotheses showing that the outsourcing pattern is likely driven by structural change processes. While the results largely confirm the trade patterns observed in previous research, they extent their scope geographically and in terms of their time dimension as well as through an extended analysis of the trade balance. The instable water trade balance in the upper-middle income group provides a notable addition to the previous literature.

6 Conclusion

The thesis addressed the issue of environmental degradation outsourcing from developed countries to developing countries for the case of global virtual water trade asking whether high income countries outsourced their water-intensive production to lower income countries between 1990 and 2015. The thesis used a multiregional input-output analysis to trace the global virtual water trade patterns of 189 countries classified into high, upper-middle, lower-middle and low income groups between 1990 and 2015. The traditional methodology resulting in the calculation of the balance of water embodied in trade was adjusted to account for different levels of technology and the contributions of the monetary trade balance and the trade specialization based on recent carbon emission literature by Baumert et al. (2019). A modified version of the Eora26 database provided the basis of the analysis.

The thesis began with a discussion of the relevant theory and previous literature (chapter *2*). The discussion of the environmental Kuznets curve and the pollution haven and displacement hypotheses (section *2.1*) demonstrated that the empirically contested u-shape relationship between environmental degradation and the level of income could stem from outsourcing emissions particularly as production- and consumption-based accounts diverge. However, PBA and CBA accounting methods are not sufficient for assessing whether the observed trade patterns are environmentally harmful and thus require a revision as proposed by the carbon emission literature. Section *2.2* provided the conceptual basis for the global virtual water trade study followed by section *2.2.1*, presenting previous studies of global virtual water trade concluding that developed countries emerge as net importers of virtual water while developing countries emerge as net exporters of virtual water.

Chapter *3* began with a presentation of the structure of multiregional input-output (MRIO) tables (section *3.1*) providing the basis for the subsequent presentation of the Eora26 database as the main source of this study highlighting its large country sample and documenting the editing process (section *3.2*). The presentation of the water use satellite accounts data established agriculture as the most water-intensive economic sector and demonstrated that only high income countries contribute a larger fraction to world economic output than to world water use (section *3.3*). Chapter *3* provided the basis for the subsequent methodological discussion in chapter *4*, which presented environmentally extended input-output analysis as a tool for assessing the balance of water embodied in trade (section *4.1*). The next section *4.2* then presented the technology-adjusted balance of water embodied in trade and its decomposition into the trade specialization and monetary trade balance contribution as an improved accounting method based on recent carbon emission literature by Baumert et al. (2019).

Chapter *5* proceeded with the empirical analysis. Based on the results of the BWET, CBA, PBA, TBWET and its trade specialization and monetary trade balance decomposition for the four income groups of high, upper-middle, lower-middle and low income, the high income group emerged as a net importer of water, whereas the lower-middle and low income groups emerged as net exporters (section *5.1*). The upper-middle income group was as a net exporter and net importer of virtual water at different points in time. The agricultural sector remained the most water-intensive sector in terms of direct water use per unit of output. Overall, the results support the conclusions drawn by previous studies (section *5.2*). High income countries specialize in relatively water-saving sectors and outsource water-intensive production in particular to lower-middle and low income countries. Interestingly, upper-middle income countries show relatively diverse virtual water trade patterns.

The entire thesis was guided by a main research question broken down into two sub-questions:

Did developed countries outsource their water-intensive production to developing countries between 1990 and 2015?

a) *What global trade patterns are identifiable between 1990 and 2015 based on the balance of water embodied in international trade and its technology-adjusted version?*
b) *To what extent was the technology-adjusted balance of water embodied in international trade driven by monetary trade balances or trade specialization?*

With regard to sub-question *a)* high income countries had a persistently negative balance of water embodied in trade between 1990 and 2015 whereas lower-middle and low income countries had positive BWET. The upper-middle income group displayed a positive BWET that turned negative during four out of the 26 observation years. The TBWET indicated that the high income group produced at lower water-intensity than the world average during the observed period whereas lower-middle income and low income countries produced above the world average level of water-intensity. However, these differences in technology did not change their virtual water trade balances. In the case of the upper-middle income group however, the TBWET turned three previously positive trade balances into negative virtual water trade balances. With regard to sub-question *b)* the TBWET was largely driven by the trade specialization and only marginally by the monetary trade balance in all income groups. The final answer of the main research question follows from these results. High-income countries outsourced their water-intensive production to lower-middle income and low income countries between 1990 and 2015. Upper-middle income countries also outsourced water-intensive production at times but were net exporters of virtual water during most years.

These results offer support for the displacement and pollution haven hypotheses interpretation of the environmental Kuznets curve as high income countries seem to decrease their local water use by outsourcing part of it to lower-middle income and low income countries. This trade pattern suggests that ecologically unequal trade patterns occur to the detriment of global water resources due to inefficient allocation of water-intensive production while placing a particularly high burden on poor countries. The observed ecologically unequal trade patterns have at least two important practical implications. Firstly, the current inefficient allocation of water-intensive production demands a higher level of international cooperation in the field of global water resources. Secondly, countries at lower income levels may face a particularly high risk of water scarcity due to the disproportionally high burden placed on them in the current global water trade system and thus require special support from the international community.

The thesis only provides a starting point for future research into inefficient virtual water trade patterns and water-intensive production outsourcing by introducing the technology-adjusted balance of water embodied in trade to global virtual water trade research. Future research could further decompose the analysis into different economic sectors, individual countries or different types of water. This further decomposition may help to understand the drivers behind the observed unequal trade patterns in order to develop targeted strategies for more efficient global virtual water trade in the future. Lastly, the analysis could be extended to assess global virtual water flows in terms of local water scarcities as suggested by Lenzen et al (2013b) and Hoekstra (2011) as these particularly affect the poorest communities burdened by the current unequal virtual water trade patterns.

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Appendix A: The Eora26 Dataset

Table 6.1 Sectors Covered by the Eora26 Dataset

Eora26 industries
Agriculture
Fishing
Mining and Quarrying
Food & Beverages
Textiles and Wearing Apparel
Wood and Paper
Petroleum, Chemical and Non-Metallic Mineral Products
Metal Products
Electrical and Machinery
Transport Equipment
Other Manufacturing
Recycling
Electricity, Gas and Water
Construction
Maintenance and Repair
Wholesale Trade
Retail Trade
Hotels and Restaurants
Transport
Post and Telecommunications
Financial Intermediation and Business Activities
Public Administration
Education, Health and Other Services
Private Households
Others
Re-export & Re-import

Table 6.2 (Part I) Countries Covered by the Eora26 Dataset

Afghanistan	Cyprus	Kuwait
Albania	Czech Republic	Kyrgyzstan
Algeria	Cote dIvoire	Laos
Andorra	North Korea	Latvia
Angola	DR Congo	Lebanon
Antigua	Denmark	Lesotho
Argentina	Djibouti	Liberia
Armenia	Dominican Republic	Libya
Aruba	Ecuador	Liechtenstein
Australia	Egypt	Lithuania
Austria	El Salvador	Luxembourg
Azerbaijan	Eritrea	Macao SAR
Bahamas	Estonia	Madagascar
Bahrain	Ethiopia	Malawi
Bangladesh	Fiji	Malaysia
Barbados	Finland	Maldives
Belarus	France	Mali
Belgium	French Polynesia	Malta
Belize	Gabon	Mauritania
Benin	Gambia	Mauritius
Bermuda	Georgia	Mexico
Bhutan	Germany	Monaco
Bolivia	Ghana	Mongolia
Bosnia and Herzegovina	Greece	Montenegro
Botswana	Greenland	Morocco
Brazil	Guatemala	Mozambique
British Virgin Islands	Guinea	Myanmar
Brunei	Guyana	Namibia
Bulgaria	Haiti	Nepal
Burkina Faso	Honduras	Netherlands
Burundi	Hong Kong	Netherlands Antilles
Cambodia	Hungary	New Caledonia
Cameroon	Iceland	New Zealand
Canada	India	Nicaragua
Cape Verde	Indonesia	Niger
Cayman Islands	Iran	Nigeria
Central African Republic	Iraq	Norway
Chad	Ireland	Gaza Strip
Chile	Israel	Oman
China	Italy	Pakistan
Colombia	Jamaica	Panama
Congo	Japan	Papua New Guinea
Costa Rica	Jordan	Paraguay
Croatia	Kazakhstan	Peru
Cuba	Kenya	Philippines

Table 6.2 (Part II) Countries Covered by the Eora26 Dataset

Poland	Sweden
Portugal	Switzerland
Qatar	Syria
South Korea	Taiwan
Moldova	Tajikistan
Romania	Thailand
Russia	TFYR Macedonia
Rwanda	Togo
Samoa	Trinidad and Tobago
San Marino	Tunisia
Sao Tome and Principe	Turkey
Saudi Arabia	Turkmenistan
Senegal	Former USSR
Serbia	Uganda
Seychelles	Ukraine
Sierra Leone	UAE
Singapore	UK
Slovakia	Tanzania
Slovenia	USA
Somalia	Uruguay
South Africa	Uzbekistan
South Sudan	Vanuatu
Spain	Venezuela
Sri Lanka	Viet Nam
Sudan	Yemen
Suriname	Zambia
Swaziland	Zimbabwe

Appendix B: Results

Table 6.3 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts, Trade Specialization and Monetary Trade Balance of the High Income Group in Mm^3, 1990-2015 (author's own calculations)

	High Income Group					
	TBWET	TSp	TB	BWET	PBA	CBA
1990	-632,225	-668,718	36,493	-535,329	1,744,775	2,280,105
1991	-900,462	-937,134	36,672	-509,145	1,740,756	2,249,900
1992	-630,996	-684,356	53,360	-553,471	1,740,756	2,294,227
1993	-351,545	-387,818	36,273	-569,551	1,740,756	2,310,306
1994	-231,301	-260,377	29,076	-645,673	1,753,946	2,399,619
1995	-324,484	-265,358	-59,126	-837,755	1,770,777	2,608,532
1996	-290,365	-297,323	6,958	-697,792	1,787,946	2,485,737
1997	-335,106	-327,001	-8,105	-735,146	1,789,853	2,524,999
1998	-329,020	-320,655	-8,364	-719,771	1,773,220	2,492,991
1999	-328,329	-308,650	-19,679	-720,152	1,773,171	2,493,323
2000	-351,402	-329,950	-21,452	-772,601	1,773,418	2,546,019
2001	-374,741	-338,932	-35,808	-799,389	1,789,905	2,589,293
2002	-384,038	-348,625	-35,413	-799,712	1,790,191	2,589,904
2003	-371,665	-341,075	-30,590	-806,419	1,789,954	2,596,373
2004	-321,774	-281,682	-40,092	-737,734	1,802,881	2,540,615
2005	-438,634	-377,580	-61,054	-860,570	1,802,921	2,663,491
2006	-462,239	-409,114	-53,125	-782,293	1,820,191	2,602,483
2007	-432,687	-383,584	-49,103	-961,504	1,855,658	2,817,162
2008	-440,771	-363,871	-76,901	-845,233	1,861,289	2,706,522
2009	-360,367	-326,287	-34,080	-728,352	1,921,695	2,650,047
2010	-357,584	-341,309	-16,275	-679,304	1,917,676	2,596,979
2011	-355,165	-358,633	3,468	-738,419	1,917,676	2,656,095
2012	-330,376	-383,526	53,150	-632,033	2,309,900	2,941,934
2013	-353,597	-389,401	35,804	-655,024	2,309,900	2,964,924
2014	30,204	-16,452	46,657	-338,682	2,551,731	2,890,413
2015	-280,276	-260,972	-19,305	-591,483	1,959,153	2,550,636

Table 6.4 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts, Trade Specialization and Monetary Trade Balance of the Upper-Middle Income Group in Mm^3, 1990-2015 (author's own calculations)

	Upper-Middle Income Group					
	TBWET	TSp	TB	BWET	PBA	CBA
1990	-114,412	-104,452	-9,961	-2,260	1,282,400	1,284,661
1991	-144,926	-141,674	-3,253	25,513	1,441,480	1,415,968
1992	-94,205	-76,905	-17,301	15,982	1,137,688	1,121,706
1993	-33,386	-13,902	-19,484	24,890	1,150,863	1,125,973
1994	-15,426	26,255	-41,681	1,619	1,113,562	1,111,943
1995	11,837	51,599	-39,762	44,159	1,083,442	1,039,282
1996	28,781	44,600	-15,819	84,073	1,129,100	1,045,026
1997	43,179	53,403	-10,223	75,053	1,273,382	1,198,329
1998	39,966	54,174	-14,208	48,614	1,236,734	1,188,120
1999	31,044	34,921	-3,877	67,603	1,208,851	1,141,248
2000	36,828	48,419	-11,591	48,424	1,299,032	1,250,609
2001	47,450	46,981	470	97,919	1,128,655	1,030,736
2002	54,073	46,663	7,409	65,884	657,492	591,608
2003	34,042	26,701	7,341	57,374	657,730	600,356
2004	-968,569	-1,044,890	76,321	-914,540	1,190,560	2,105,099
2005	48,588	23,847	24,741	86,843	1,234,119	1,147,276
2006	65,955	55,404	10,552	163,307	1,780,659	1,617,353
2007	64,221	37,746	26,476	94,375	1,800,886	1,706,511
2008	-60,000	-3,622	-56,378	-41,082	1,913,202	1,954,285
2009	43,494	8,715	34,779	107,038	1,970,727	1,863,690
2010	205,858	195,815	10,043	97,832	3,307,648	3,209,815
2011	200,403	203,620	-3,217	48,812	3,333,521	3,284,710
2012	178,042	227,507	-49,465	63,094	2,978,181	2,915,087
2013	196,234	232,072	-35,839	38,541	2,978,181	2,939,640
2014	-180,569	-132,605	-47,964	-241,876	2,778,192	3,020,068
2015	129,112	120,594	8,517	20,559	3,352,432	3,331,872

Table 6.5 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts, Trade Specialization and Monetary Trade Balance of the Lower-Middle Income Group in Mm3, 1990-2015 (author's own calculations)

	Lower-Middle Income Group					
	TBWET	TSp	TB	BWET	PBA	CBA
1990	712,975	810,808	-97,833	181,545	1,746,098	1,564,553
1991	1,078,294	1,197,352	-119,058	128,790	1,558,096	1,429,306
1992	696,154	749,832	-53,678	166,669	1,851,677	1,685,008
1993	23,791	27,689	-3,899	191,347	2,092,889	1,901,542
1994	83,952	65,265	18,687	215,665	2,079,834	1,864,169
1995	-466,699	-182,422	-284,276	-412,318	2,903,429	3,315,747
1996	75,065	62,108	12,958	200,660	2,061,748	1,861,088
1997	209,130	183,926	25,204	330,863	3,064,954	2,734,091
1998	62,615	57,694	4,921	200,336	1,640,376	1,440,041
1999	190,423	180,969	9,454	273,128	2,677,690	2,404,562
2000	194,978	177,507	17,471	274,862	2,574,871	2,300,009
2001	187,033	186,770	262	218,996	2,804,792	2,585,796
2002	212,998	202,138	10,860	326,039	3,318,072	2,992,033
2003	237,297	216,467	20,830	376,181	3,658,766	3,282,586
2004	1,180,460	1,129,529	50,931	1,233,995	3,126,973	1,892,978
2005	273,456	239,335	34,121	384,243	3,125,344	2,741,101
2006	-205,078	-289,881	84,803	-629,325	2,562,272	3,191,597
2007	316,891	289,625	27,266	378,701	3,701,299	3,322,598
2008	466,213	318,233	147,980	588,741	4,013,470	3,424,729
2009	295,989	296,572	-583	339,171	4,056,158	3,716,987
2010	133,660	122,990	10,670	318,812	2,773,555	2,454,743
2011	132,166	128,190	3,976	269,170	2,744,926	2,475,756
2012	138,380	136,083	2,298	330,596	2,710,797	2,380,201
2013	141,522	138,939	2,583	360,969	2,903,429	2,542,460
2014	144,685	141,515	3,171	353,187	2,880,937	2,527,750
2015	144,661	126,252	18,409	356,219	2,903,429	2,547,210

Table 6.6 (Technology-Adjusted) Balance of Water Embodied in Trade, Production- and Consumption-Based Accounts, Trade Specialization and Monetary Trade Balance of the Low Income Group in Mm^3, 1990-2015 (author's own calculations)

	Low Income Group					
	TBWET	TSp	TB	BWET	PBA	CBA
1990	33,662	20,364	13,298	356,044	3,958,152	3,602,108
1991	-32,905	-36,692	3,787	354,842	3,987,074	3,632,232
1992	29,047	23,694	5,353	370,820	3,996,725	3,625,905
1993	361,141	361,099	42	353,314	3,742,899	3,389,585
1994	162,775	155,052	7,724	428,389	3,798,985	3,370,595
1995	779,346	377,832	401,514	1,205,914	3,748,547	2,542,633
1996	186,519	184,773	1,746	413,058	3,748,613	3,335,555
1997	82,796	83,605	-808	329,230	2,599,218	2,269,988
1998	226,438	194,579	31,859	470,822	3,999,475	3,528,653
1999	106,862	78,859	28,003	379,421	2,970,966	2,591,545
2000	119,596	83,988	35,608	449,315	3,080,086	2,630,770
2001	140,258	88,208	52,049	482,474	3,088,141	2,605,667
2002	116,968	89,884	27,084	407,789	2,959,923	2,552,134
2003	100,326	94,647	5,680	372,865	2,620,957	2,248,092
2004	109,883	104,943	4,939	418,278	2,606,993	2,188,715
2005	116,589	111,241	5,348	389,485	2,565,024	2,175,539
2006	601,361	574,863	26,498	1,248,311	2,564,284	1,315,973
2007	51,574	57,309	-5,735	488,428	1,369,563	881,135
2008	34,559	48,114	-13,555	297,575	939,446	641,870
2009	20,884	25,460	-4,576	282,143	778,826	496,683
2010	18,066	23,154	-5,088	262,659	728,528	465,869
2011	22,597	32,582	-9,986	420,438	731,284	310,846
2012	13,953	22,927	-8,974	238,344	728,528	490,184
2013	15,841	16,618	-777	255,513	717,970	462,457
2014	5,679	10,942	-5,262	227,370	516,546	289,176
2015	6,503	11,297	-4,794	214,704	512,393	297,688

Table 6.7 Total Output per Income Group in thousands of $US, 1990-2015 (author's own calculations)

	High Income	Upper-Middle Income	Lower-Middle Income	Low Income
1990	30,546,347,912.92	3,957,598,402.67	15,686,982,337.13	2,287,042,280.23
1991	31,862,986,199.49	4,503,283,265.99	74,131,028,906.74	2,444,205,820.26
1992	34,428,290,468.87	3,981,091,138.45	9,721,047,214.86	2,724,027,539.15
1993	33,708,759,453.98	4,135,968,264.82	3,072,926,114.53	3,772,351,326.37
1994	37,343,573,722.57	4,335,627,364.39	3,181,675,964.15	2,836,307,720.46
1995	43,487,415,916.07	3,838,392,607.05	2,614,993,534.54	3,808,170,593.52
1996	44,585,574,914.55	4,325,721,416.62	3,770,393,484.24	3,903,592,298.26
1997	43,971,888,284.49	5,171,475,156.39	5,651,568,243.04	1,446,806,691.50
1998	44,102,984,623.11	5,686,691,430.51	2,891,573,518.55	4,414,931,620.30
1999	46,659,572,589.89	5,498,214,821.21	5,713,354,727.88	1,858,297,816.79
2000	47,924,824,479.93	6,462,702,619.82	5,798,973,488.42	1,957,959,009.42
2001	48,510,466,177.32	4,686,326,232.24	6,706,991,611.07	2,034,383,923.02
2002	50,418,429,390.03	3,571,720,786.19	7,827,934,147.37	2,051,776,736.50
2003	56,647,359,521.42	3,834,525,699.10	9,868,818,530.83	1,933,988,403.94
2004	64,342,532,793.87	6,041,252,363.98	11,903,559,892.00	2,210,502,172.18
2005	68,898,013,203.36	7,231,356,413.89	12,373,428,486.44	2,571,567,576.33
2006	73,893,240,909.16	10,263,877,512.66	12,347,452,479.04	3,985,700,954.69
2007	83,073,672,838.36	12,045,906,770.93	18,611,500,138.26	1,510,964,993.67
2008	89,689,719,564.65	15,417,440,645.53	23,435,681,445.04	1,128,364,112.09
2009	82,546,723,778.98	13,053,721,372.55	23,453,848,516.67	782,866,827.18
2010	89,559,627,794.87	34,944,625,181.06	8,924,550,953.35	788,750,639.13
2011	98,498,348,042.76	41,904,344,072.41	10,063,873,526.28	680,900,603.28
2012	103,653,676,626.68	39,064,785,967.05	9,792,969,606.65	918,281,818.04
2013	104,522,456,950.52	42,145,087,238.06	9,814,604,500.98	981,799,428.11
2014	107,560,094,161.14	40,952,158,366.65	10,605,742,102.48	526,134,460.50
2015	95,677,659,917.42	46,102,970,715.55	9,847,571,817.63	532,442,743.54