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Improving the Representation of Maritime Transport in the EXIOBASE MRIO Dataset

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Master in Industrial Ecology
Submission date: June 2013
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"It was with a happy heart that the good Odysseus spread his sail to catch the wind and used his seamanship to keep his boat straight with the steering-oar"

-Homer

NTNU
Norwegian University of Science and Technology

Department of Energy and Process Engineering

EPT-M-2013-116

MASTER THESIS

for

Jørgen Westrum Thoresen

Spring 2013

Improving the representation of maritime transport in the EXIOBASE MRIO dataset
Forbedring av modellen for maritim transport i EXIOBASE MRIO-datasettet

Background
Global production and consumption activities are continuously scrutinized to mitigate mounting environmental concerns, in particular global warming. This scrutiny has also been extended to the interregional and intercontinental transportation system. Concerns are being raised over energy use and associated emissions related to the transport of goods. There are many examples of individual global value chains that are resource and emission inefficient. There is however an economic rationale for this. Access to cheap labour in developing countries and economies in transition provides strong incentives for locating production there. Although there are adverse environmental implications caused by locating production in economies with less strict environmental regulations and longer distances from markets, it is important to recognize that production of goods for western markets provides an opportunity for countries to improve economic growth. That is, the prospect of improving global equity is the main novel motivation for globalization.

The international maritime sector is key in this globalized economy and substantial continued growth in traded volumes is expected. Understanding the overall environmental comparative performance of goods produced in different regions requires an understanding of production as well as transport related impacts.

Aim
The primary objective of this work is to improve the representation of maritime transport in the EXIOBASE dataset. The secondary objective is to assess the significance of transport related emissions for some selected trades and products.

The analysis should include following elements:

1) Development of life cycle inventories for individual ship classes.
2) Integration of individual ship class inventories into the MRIO dataset.
3) Analysis of environmental impacts of selected trades and/or products.
4) Discussion.

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Abstract

This aim of this report is to improve the EXIOBASE dataset by integrating life cycle inventories of 11 individual ship classes. The report then calculated the Global Warming Potential (GWP) of seagoing transport was calculated using Environmentally Extended Multi-Regional Input-Output(EE MRIO) analysis. This work has made it possible to more accurately model the GWP of interregional seagoing transport, and to assess the impact contribution of each vessels, both for total interregional transport and as a product of the import demand of one or more regions.

The report found that the total GWP from international maritime trade is 2.006 billion tons of CO_2-equivalents, a figure that is approximately twice as large than the ones found in similar studies(IMO 2009, Lindstad, Asbjørnslett et al. 2012, UNCTAD 2012).

The results of this report demonstrate that North America, OECD Europe and OECD Pacific have the highest GWP embodied in imports from seagoing trade. Crude oil carriers is the vessel class with the largest GWP, accounting for 40% of the total fleet GWP and with OECD Europe and North America as the greatest crude oil importers.

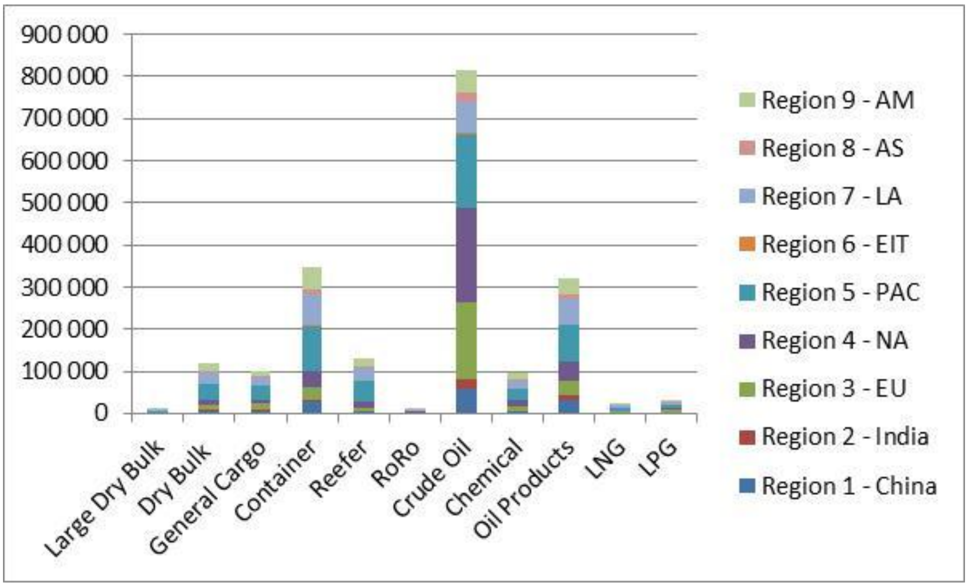

Figure 1 GWP by vessel type (million ton CO2-eq)

Keywords : Maritime transport, GWP, EXIOBASE, EE MRIO,

Acknowledgements

First, I want to thank my supervisor, arguably the busiest man in Norwegian academia, **Professor Anders Hammer Strømman** for his support, enthusiasm and "big picture"-guidance.

I also want to thank my co-supervisors**,** PhD **Haakon Lindstad** and Senior Researcher **Richard Wood** for their invaluable expertise, patience and ability to answer my low-brow questions in a non-condescending manner. My thanks is also directed at the rest of the staff of the Industrial Ecology program for their support.

With this, six years at NTNU comes to and end. The last two years have been a great experience with a lot of hard work, new perspectives and fun times with the fellow IndEcol-students. Big thanks to the crew, **Felipe, Sarah, Magnus, Hyun and Ty** for all the good times. To **Samantha**, for your companionship and your ability to make me focus on the important things.

To **Kine, Karoline, Eivind, Eirik, Stina, Elisa, Lotte and Elin**, thanks for the best time in my life so far. You rock!

The biggest thanks goes to my family, and my parents**, Haakon, Bente and Bjørn** for your support, both emotionally and financially, and for teaching me to think big and work hard. To **Christoffer** and my brother **Herman**, my closest friends. **Tor Westrum**, grandfather and my greatest role model.

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1 Introduction

The global economy is completely dependent on international trade. Every day, raw materials are being mined in one part of the world and refined in another before it is being shipped to its final destination for consumption. In light of the progression of climate change and other environmental consequences, a better understanding of the Global Warming Potential(GWP) from interregional maritime transport of goods and products has grown ever more important.

Since 1990 growth in international trade, of which more than 80% is carried by seagoing vessels (measured by weight), has increased exponentially, nearly doubling the trade volumes(Lindstad, Asbjørnslett et al. 2012). Shipping is estimated to have emitted 1,046 million tons of CO_2 in 2007, which corresponds to 3.3% of the global emissions of 2007(IMO 2009) .This is an increase of 86% from 1990 global emission levels. The exhaust gases are the primary source of emissions from ships where carbon dioxide is the most important greenhouse gas emitted, but other life cycle stages, like construction and end-of-life management also contribute to the total environmental impacts of the vessel(Shipbuilding 2010).

There exists a great consensus that maritime transport emissions are anticipated to increase further by 150%-250% until 2050 on the basis of "business as usual" scenarios with a tripling of world trade(Lindstad, Asbjørnslett et al. 2012). Given a scenario in which all sectors accept the same percentage reductions, total shipping emissions in 2050 would have to be no greater than 15% - 50% of current levels, based on the required 50% - 85% reduction target set by the IPCC (Haakon Lindstad 2012).

The main focus of this report is to improve the representation of maritime transport in the EXIOBASE MRIO dataset. This report utilizes the EXIOBASE dataset to assess the interrindustry flows and requirements between the different world regions, i.e. the amount of goods and services that is traded. EXIOBASE is a global, multi-regional Environmentally-extended Input-Output (EE MRIO) table. The database, funded by the EU, aims at improving insights in external costs if environmental pressures and to overcome significant limitations in existing data sources, such as establishing trade links, harmonizing sector and product classifications, and construct solid environmental extensions(Richard Wood 2013).

This dataset has split the world economy into 9 regions where each region is built up by 138 sectors. The sector "Sea and coastal water transportation service" is used to model all maritime transportation between the regions. In short, this means that all goods that is transported overseas is carried by the same type of vessels, be it coal, wheat, minerals, electronics or crude oil. Ocean- and seagoing transportation is subject to much variation regarding size, load capacity, speed, and fuel consumption. An important aspect of maritime logistics is that some vessels can only transport a specific product, such as crude oil or Liquid Natural Gas (LNG). Others, such as product tankers, container vessels and dry bulk vessels can carry a wide range of products(Lindstad, Asbjørnslett et al. 2012). By differentiating between the seagoing transport vessels and the goods they carry its possible to more accurately model GWP from seagoing transport.

This report focuses on assessing the GWP of maritime transport due to the trade between the different regions of the world. In short, this report will analyze the emissions of CO_2-equivalents from maritime transport necessary to ship goods and products across the oceans to satisfy global demand and production requirements. It is assumed that there is no seagoing transport within each region, and that all interregional transportation is seagoing, i.e. road, rail and airfreight is excluded.

This report will incorporate the EXIOBASE dataset with comprehensive life cycle inventories of a variation of ship technologies, along with price data of transported goods and average trade distances in an effort to calculate the Global Warming Potential(GWP) embodied in imports due to interregional maritime transport of goods and products.

2 Technology Overview

In this study, I have included all cargo vessels described in the paper by Haakon Lindstad et al. 2011, which in turn are based on the vessels listed in the IHS-Fairplay database in December 2007. This study, following the example of Lindstad, excludes vessels that are built for a combination of passenger and cargo, such as Ro-Pax vessels, which transport passengers, cars and cargo onboard trailer units. These vessels emit around 20% of total CO2 emissions by marine transport.

The cargo vessels can be grouped into three subgroups; dry bulk, general cargo and tank (Lindstad, Asbjørnslett et al. 2012).This is based on the cargo type and on how the cargo is handled and transported. The reader should be aware that there exists an overlap, and the different vessel types can carry the same or similar goods. A good example is container vessels which can carry a wide range of cargo and commodities, from grain and steel products to vegetable oils and cars. However, this report assumes that no two vessel classes carry the same type of good.

This next section gives an overview of international seaborne trade, an introduction to the different vessel types and the cargo they [can] carry and significant environmental impacts related to international shipping.

2.1 International Seaborne Trade

Maritime transport is one of the most globalized and international industries around, which makes Jean-Paul Rodrigue and Michael Browne write the following in the book "Transport Geographies: An Introduction":

"A Greek owned vessel, built in Korea, may be chartered to a Danish operator, who employs Philippine seafares via a Cypriot crewing agent, is registered in Panama, insured in the UK, and transports German made cargo in the name of a Swiss freight forwarder from a Dutch port to Argentina, through terminals that are concessioned to port operators from Hong Kong and Australia"(Jean-Paul Rodrigue 2008)

So not only is maritime transport international in the sense that is transports goods from on part of the globe to another, but it connects services and people from almost every country.

An illustration of world seagoing transport can be seen in figure 2, and it is evident that there is no country or island state that is not in some way or another affected by this web of logistics that ties the whole world together.

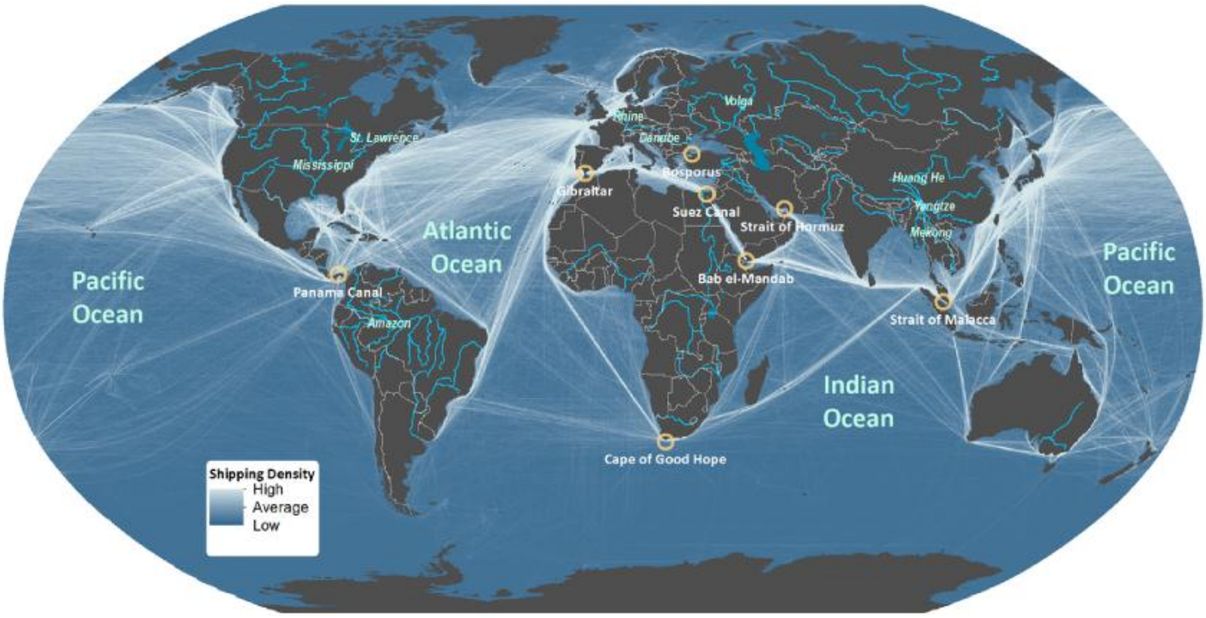
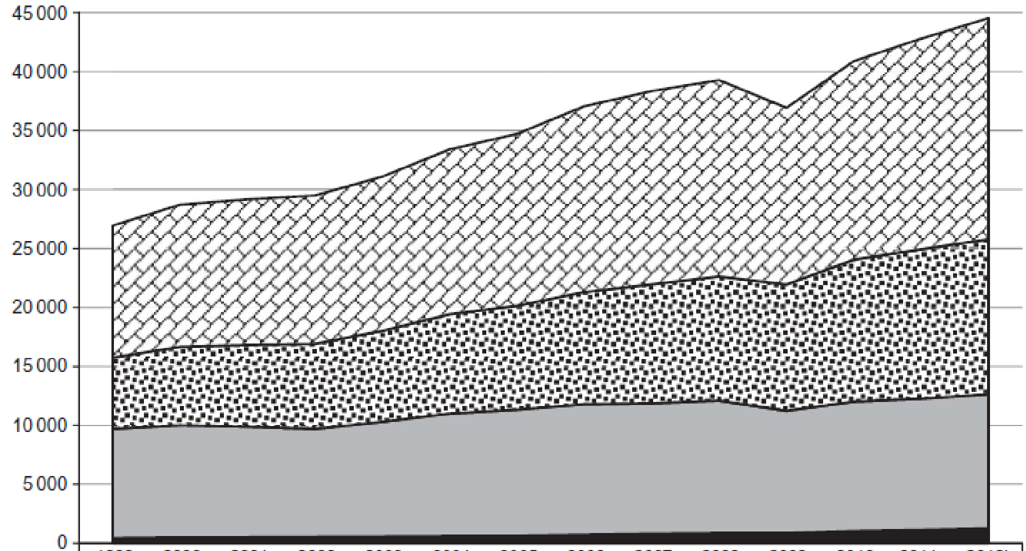


Figure 2 Maritime transport routes

The most trafficked routes is over the Atlantic from Europe to the Americas, trough the strait of Malacca and the Suez Canal and over the Pacific from China and Japan to the US.

As was mentioned in the introduction, seagoing vessel transport 80% of world trade(by ton) and the world seagoing shipment have risen from 2,6 billion tons(metric) in 1970 to 8,7 billion tons in 2011 (UNCTAD 2012). Raw materials continue to dominate the composition of this trade, with tanker trade in 2011 accounting for about 30 % of total tonnage and 'other dry cargo' including containerized cargo accounting for about 40%. The remaining share of 28% was assigned to the five major dry bulks, namely iron ore, coal, grain, bauxite and alumina and phosphate(Jan Hoffmann 2013). In 2007, containerized cargo accounted for about 52% of the total value of seaborne trade, reflecting the higher value of goods carried in containers. Tanker trade accounted for less than 25% while general and dry cargo made up the remaining 20% and 6% of the value, respectively(Jan Hoffmann 2013).

From figure 3 we see that the total cargo ton miles is projected to reach 44 540 billion(!) ton-miles in 2012. Of this, transport of 'other dry cargo' constitute 18 754 billion ton-miles globally (42%), five main dry bulks 13 141 billion ton miles or 29,5%, oil transported 11 367 billion ton miles (25%) and gas is 1278 billion ton-miles, around 2% of total global ton-miles of transport(Jan Hoffmann 2013). Knowing that one English miles is equal to 1,6 km we have that the total cargo ton km is 44 540 * 1,6 = 71 264 billion ton km. 1 ton km is equivalent to transporting 1 ton of cargo 1 km.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011a	2012b
Other dry cargo	11 191	12 058	12 347	12 587	13 072	13 975	14 570	15 759	16 390	16 646	14 988	16 829	17 861	18 754
Five main dry bulks	6 046	6649	6922	7212	7710	8424	8819	9508	10 090	10 523	10 715	12 042	12 666	13 141
Oil	9 249	9500	9376	9146	9723	10 386	10 701	11 067	11 060	11 241	10 371	10 960	11 112	11 367
Gas	456	516	523	552	586	621	631	732	812	865	862	1 059	1 155	1 278

Figure 3Cargo ton-miles by cargo type, 1999-2012 (billion ton miles)

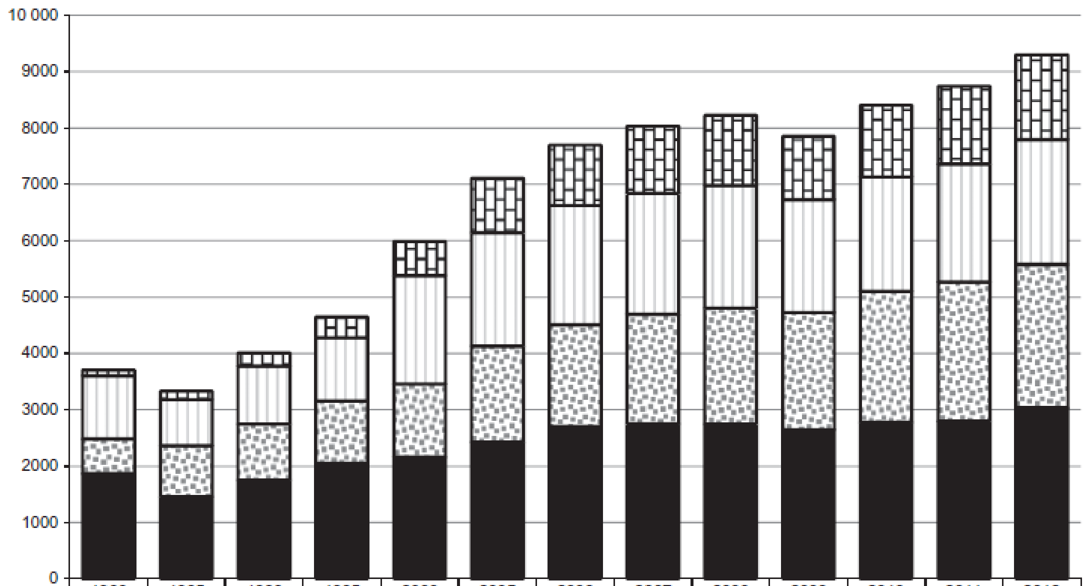
The paper by(Lindstad, Asbjørnslett et al. 2012) reported the following freight work measured in billion ton km for each vessel class.

Table 1 Freight work by vessel type (billion ton km)

	Freight work Billion ton km
Dry Bulk	25 819
General Cargo	3 811
Container	12 002
Reefer	413
Crude Oil	16 098
RoRo	776
Chemical	3 070
Oil Products	2 011
LNG	1 363
LPG	642
Sum	66 005

From table 1 we see that Dry Bulk, container and Crude oil has the highest freight work measured in billion ton km with 25 819, 12 002 and 16 098 respectively. The lowest three are Reefer, RoRo and LPG with 413, 776 and 642 billion tkm respectively.

The international seaborne trade by cargo types, seen in figure 4 project that the total tonnage of cargo reach 9,9 billion tons in 2012(Jan Hoffmann 2013), of this 1 498 billion tons are containerized (16%), 2 219 billion tons is constituted of other dry cargo (23%), the five major dry bulks constitute 2 547 billion tons of the total seaborne carried cargo (27%). Oil and gas constitute 3 033 billion tons or about 32% of the total international seaborne trade by cargo types (Jan Hoffmann 2013)



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012
Container	102	152	234	371	598	969	1076	1193	1249	1127	1275	1385	1498
Other dry cargo	1123	819	1031	1125	1928	2009	2112	2141	2173	2004	2027	2108	2219
Five major bulks	608	900	988	1105	1295	1709	1814	1953	2065	2085	2335	2459	2547
Oil and gas	1871	1459	1755	2050	2163	2422	2698	2747	2742	2642	2772	2796	3033

Figure 4 International Seaborne trade by cargo types (1980-2012)

With growing trade in manufactured and intermediate goods, merchandise is becoming lighter, less transport-intensive per euro shipped, and more time sensitive(UNCTAD 2012).This means that the weight-to-value ratio of international trade declined and air transport emerged as a good alternative for the carriage of high-value/low-volume/sensitive goods- In 2006, airborne cargo was, on average, 67 times more valuable per ton than seaborne cargo(Jan Hoffmann 2013). The average value per ton of cargo of seaborne trade in 2006 was €801 against €53 706 per ton of airborne trade and €1596 per ton of trade carried overland, including by pipelines. In a world economy with intense competition, seagoing transport has the advantage of being relatively cheap, which will be demonstrated in section 4.1.2 in this report, but it has the disadvantage of being more time consuming, especially compared to airfreight.

2.2 World fleet structure and principal vessel types

Following an annual growth of almost 10% the world fleet reached a total tonnage of 1 534 million dwt in early 2012. By the first quarter of the same year, there were 104 305 seagoing commercial ships in service. Dry bulk carriers have the 40,6% of the total world capacity and the world dry bulk fleet has surged by 60% in just four years. Oil tanker capacity accounts for 33,1 % of the world fleet while containerships make up 12,9% of the world tonnage (UNCTAD 2012).

In January 2012 the average age of the fleet per dwt was 11,5 years, while on the other hand the average age per vessel is twice that, at 21,9 years. This gives us an indication that older vessels are much smaller and that newer vessel are comparably larger(UNCTAD 2012), 41,9 % of dry bulk tonnage is less than five years old, a very high share. The youngest fleet is that of containerships with 64% under 10 years while the oldest is the general cargo and other types of vessels.(UNCTAD 2012). Section 2.2.1 will give an overview of principal vessel types while section 2.2.2 gives and introduction to fleet ownership. 2.3 describes significant environmental impacts related to international shipping.

2.2.1 Dry Bulk

Bulk cargo is defines as loose cargo that is loaded directly into a ship`s hold. Bulk cargo is thus a shipment such as oil, grain ores coal, cement, etc., or one which is not bundled, bottled, or otherwise packed and which is loaded without counting or marking. A bulk carrier is therefore a ship in which the cargo is carried in bulk, rather than in barrels, bags, containers, etc., and is usually homogenous and capable of being loaded by gravity. Taking into consideration the definition that is given above, there are two types of bulk carriers, dry bulk carriers and wet-bulk carriers, the latter better known as tanker(Turbo 2012). Dry Bulk carriers were developed in the 1950s to carry large quantities of non-packed commodities such as grain, coal, iron ore, etc., in order to reduce transportation costs.

In order to remain competitive and maintain reasonable profit margins, distant suppliers such as Brazilian iron ore producers see the use of large ships as a prerequisite to achieve economies of scale. Transporting dry bulk in a relatively small Handymax vessel was, in march 2012, three times as expensive per ton km than shipping the cargo in a large Capesize bulk carrier (UNCTAD 2012). Economies of scale also affects the environmental impacts, and the emissions of CO_2 per ton km is also reduced as the dwt capacity of the vessel increases.

Dry bulk is generally split into major and minor dry bulk. Major dry bulks include the five major commodities; iron ore, coal, grain, bauxite/alumina and phosphate rock. Minor dry bulks include agribulks, fertilizers, metals, minerals, steel and forest products. The five major bulks accounted in 2011 for approximately 42 % of total dry bulk cargo, where iron ore account for the largest share of 42,5 %. Global volumes of minor bulks reached 1.2 billion tons in 2011 (UNCTAD 2012). In 2011, the total volume of dry bulk trade amounted to 3,7 billion metric tons (UNCTAD 2012). The transport work performed, measured in billion ton km, dry bulk represents nearly 40% of the total marine transport work performed (Haakon Lindstad 2012).

Bulk Carriers range from small, less than 10 000dwt to very large bulk carriers (VLBC) that can carry more than 200 000 dwt. The largest vessels, Capesize, have an average size of 172 000(Lindstad, Asbjørnslett et al. 2012)dwt and is included in this study. The main Capesize trades are from Australia to Japan, Korea and China in Asia, to Western Europe, and from Brazil to Asia and Western Europe. The transport of dry bulk cargo is mostly done by vessels in tramp operation where their schedule is a function of cargo availability and customer requests (Lindstad, Asbjørnslett et al. 2012).The world`s, so far, largest dry bulk carrier is M/V Berge Stahl with 365 000dwt, built in 1986 and designed for carrying iron ore. The rise in vessel size is an ongoing process and an example of such increases is the introduction of the new Chinamax and Valemax dry bulkers of 400 000 dwt.

2.2.2 General Cargo

The most flexible vessels today are container vessels. These ships where initially used for transport of finished goods packed in containers, but now also transport raw materials and semi-finished goods. Similarly to a bus service, container vessels operate as common carriers in liner services calling at regularly published schedule in ports (Lindstad, Asbjørnslett et al. 2012). The largest vessels in the container segment used to be the 8500 TEU+. TEU is an abbreviation for twenty-foot equivalent units, which is the length of a standard container. Recently, some operators, like Danish Maersk, have ordered vessels of up to 18 000 TEU(Haakon Lindstad 2012). The most common operational pattern for the largest container vessels, 5500 TEU – 8500 TEU+, is to use them in pendulum operation, that is from Europe to Asia and back, Asia to North America and back, and from Europe to East Coast North America. Total container trade volumes amounted to 151 million TEUs in 2011, equivalent to about 1,4 billion tons.

General cargo is basically all cargo types which cannot be handled by grabs, conveyor belts, pumps or pipeline system. This kind of cargo is then transported by general cargo vessels, container vessels, reefer vessels and Ro-Ro vessels. Owners of specialized reefer tonnage have suffered from the competition of containers that also cater for refrigerated containers. Containers today account for about 60% of reefer cargo, and new container ships increasingly include larger reefer capacities(UNCTAD 2012). General cargo vessels are typically used for transport of pallets, bulk products in Big Bags, forest products, steel and aluminum, but also containers (Lindstad, Asbjørnslett et al. 2012). Reefer vessels carry perishables such as food and fresh fruit and frozen products while Ro-Ro vessels transport new and used cars, heavy vehicles and project cargo(large, heavy, high value and/or critical pieces of equipment). Ro-Ro vessels also transport trailer units with cargo.

2.2.3 Tank

Wet bulk cargoes typically consist of liquefied products and gas that are mainly transported in wet bulk tankers, such as crude oil, liquefied petroleum gas(LPG) and liquefied natural gas (LNG), or a family of similar products such as refined oil products by-product tankers and chemical products by chemical tankers. Between 2000 and 2011, crude oil shipments grew annually at an average rate than 1 %, a relatively slower pace than other market segments. In 2011 the total volume of crude oil loaded globally amounted to about 1.8 billion tons(UNCTAD 2012). Tanker trade patterns are changing as crude oil source diversification continues. A new map of crude supplies is being drawn up as new oil discoveries are made in different regions and as new market suppliers emerge. As of now, western Asia remains the largest loading area, followed by Africa, developing America and the transitioning economies. The major importing economies are in ascending order Japan, North America, Europe and developing Asia(UNCTAD 2012).

In 2011, world shipments of petroleum products and gas, including LNG and LPG) increased by 5,1 %, a growth rate that reflects the booming LNG trade. The total shipment to 1,3 billion tons. Natural gas is today the third largest source of energy after oil and coal(UNCTAD 2012).

2.2.4 Ship registration and Ship owning

In 2012, more than 70% of the world`s tonnage had a different nationality of owner and flag state, i.e. the ship was flagged out. Looking at figure 5 we see that over the last few decades, the share of the foreign-flagged tonnage has grown continuously(Jan Hoffmann 2013).

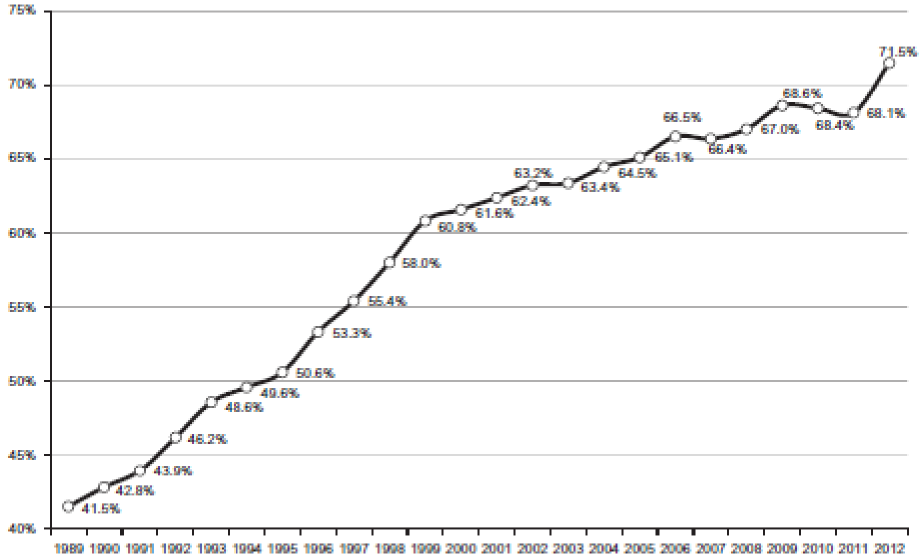


Figure 5 Share of foreign flagged deadwheight tonnage, 1989-2007

In 2012 the share of foreign flagged deadweight tonnage was 71,5 %, an increase of 30 percentage points in just over 20 years since 1989. As more and more registries compete for business, the traditional distinction between 'national' and 'open' flags of ship registration becomes increasingly blurred. Today, almost all registries include national and foreign owners(Jan Hoffmann 2013). Among the top 30 flags of ship registration, three flags cater exclusively for foreign-owned tonnage; Liberia, the Marshall Islands and Antigua and Barbuda. The flags of Panama, Malta, Bahamas and the Isle of Man are also used by national ship owners, but the majority of ships, by far, are foreign owned. The flags of Belgium, India, Denmark, Japan and Germany remain among the very few that are still almost exclusively used by national owners.

Among the top 35 ship owning economies in 2012. 17 were in Asia, 14 in Europe and 4 in the Americas. More or less half of the world tonnage was owned by shipping companies from just four countries, notably Greece, Japan, Germany and China(UNCTAD 2012).

2.3 Environmental impacts related to shipping

As mentioned in the introduction, international shipping contributes to 3,3% of global GHG emissions which is forecasted to increase exponentially in the next 50 years(Lindstad, Asbjørnslett et al. 2012). The greatest environmental concerns associated with shipping are those relating to oil spills from accidents, equipment malfunctions or operational decisions. There is even the concern that noise generated from ships can disturb the marine wildlife. However, there are other core operational activities including loading and unloading and associated service and support tasks than can have environmental and other impacts (Shipbuilding 2010).

Apart from large oil spills and disasters like the Exxon Valdez, GWP related to maritime logistics and the shipping sector have received very little attention relative to the impacts from air and ground transport. Due to growing environmental concerns, on climate change in particular, the attention towards environmental consequences from maritime transport are likely to increase. Shipping is a major emitter of particulate matter(PM) and black carbon(soot) and is also a large contributor of SO_2 and NO_x emissions. Soot from combusting heavy fuel oils (HFOs) has a large content of black carbon. These dark particles, when emitted into the atmosphere, absorb sunlight and is estimated to be the second largest contributor to climate change after CO_2(Shipbuilding 2010).It does not seem that there exists a consensus on the actual emissions from the maritime transport sector. Its share of global CO_2 emissions ranges from 3% to 5%(Lindstad, Asbjørnslett et al. 2011),(IMO 2009),(Vidal 2008) while the sector is estimated to account for 4%-8% of SO_2 emissions and about 15% of Nox emissions(Tzannatos 2010).

Having this in mind, one can summarize the primary environmental challenges in maritime logistics to atmospheric emissions due to the combustion of HFO and impacts from spills of substances like oil, cargo residues, anti-fouling paint and ballast water (Shipbuilding 2010).

Fuel cost can amount up to 40% of a ship`s total operating costs. Large freight ships, like the ones described in this report all run on a particular form of diesel known as bunker fuel or heavy fuel oil. The fuel can only be described as a black mud of hydrocarbons. It is a very dense and highly polluting residual substance from the oil refining process, and the world fleet consume millions upon millions of tons of it every year. Due to the fact that it bunker fuel is a residual substance, it carries everything that does not distil during the oil refining process, including a large number of pollutants. (Shipbuilding 2010). There are ways to remove the number of pollutants in the bunker fuel, but they are not economically attractive. As the residual character of bunker fuel keeps the price low, it does not give any incentives to the shipowners to switch to cleaner fuels(Shipbuilding 2010). They only see an incentive of reducing the bunker fuel use per ton km to reduce costs in an increasingly competitive market, often by building bigger ships and thus achieving economies of scale(Lindstad, Asbjørnslett et al. 2012) or in some cases reducing the speed. Even though they are in early stages, and some are more viable than others, there exists today several alternatives to bunker fuels or ways to reduce the use of it. A few examples are increased use of biodiesel, wind and solar power, LNG, and air lubrication. This without mentioning how innovative ship design can help reduce fuel use, drag and fuel composition(Shipbuilding 2010).

3 Methodology

This chapter aims at giving the reader some insight in the methodologies used to improve the EXIOBASE dataset and calculating the GWP of international maritime transport. The first section explain the fundamental theory of Life Cycle Assessment, its goal, how Life Cycle Inventories(LCI`s) are built and how environmental impacts are assessed. The second section gives and overview of Environmentally Extended Multiregional Input-Output (EE MRIO), the EXIOBASE dataset and how Emissions Embodied in Trade(EET) are calculated.

3.1 Life Cycle Assessment

3.1.1 What is LCA?

According to the book "Methodological essentials of Life Cycle Assessment" by Anders Hammer Strømman, the objective of a LCA is to

"..Perform consistent comparisons of technological systems with respect to their environmental impacts"

LCA incorporates the entire life cycle of a product, from material extraction, production, transport, use and waste which allows us to quantify and analyze the true total environmental impact of a product. It is important to note that a LCA is not necessarily including all of the life cycles phases from cradle to grave. Some studies only include certain life cycle stages, like production and use, but leave out for example end-of-live management. LCA also allows us to deal with the issue of problem shifting (Strømman 2010). Problem shifting is when one, by solving one type of environmental problem, creates or enhances another in the process. For example, if one wish to reduce the greenhouse gas emissions from a crop by reducing the use of artificial fertilizer you might increase the impact on land-use due to the fact that more land area is needed to grow the same amount of output from the crop as you did using fertilizer.

To summarize, LCA is a methodology for the evaluation of potential environmental impacts from a given product system, taking the whole life cycle of the product into account. The common purpose of LCA is to quantify and document the potential environmental impacts as a basis for focus on how to make improvements so to reduce the environmental impact of the product or service, to compare alternative product designs, identify beneficial waste management solutions and get a good basis for external communication or development of policies and actions.

An LCA has four phases:

1. Goal and scope definition
2. Life cycle inventory(LCI)
3. Life cycle impact assessment(LCIA)
4. Interpretation

3.1.2 Goal and Scope

The goal and scope definition starts with defining the problem formulation and system definition, what are the objectives of the LCA and what the decision context of the study is. It also defines the functional unit of the LCA, the system boundaries and data collection strategies. The functional unit defines the function that the product system provides to the users. It is a reference to which inputs and outputs are related, in the way one can determine the reference flows in the product system in order to fulfill the intended functions. The functional unit also specifies in which quantity, for what duration, to what quality, and it also considers changes in the functional performance over time. A functional unit can for example, in the context of maritime transport, be “1 ton km”. In this case, an LCA will find the potential environmental impacts of the given vessel per km one ton of cargo are transported.

3.1.3 Life cycle Inventory(LCI)

The LCI phase quantifies the sum of all elementary flows (inputs from and outputs back to nature) of the product system, according to the chosen functional unit. The LCI is regarded as the most time consuming phase of a LCA. Some data are often available in databases but most commonly the person or group that is performing the LCA need to collect the data required for the special case of the study.

To perform an LCA two types of data are distinguished:

1. Foreground data
2. Background data

There is no sharp distinction between foreground and background data, but generally the foreground data is defined as the system you model and investigate in detail such as direct emissions and use of raw materials. The background data is generic data from existing databases that you use to complete value chains upstream in the process, such as emissions related to the production of raw materials and energy(Strømman 2010).

3.1.4 Impact Categories

When assessing the environmental impacts of maritime transport this report analyze the Global Warming Potential(GWP). This method, applied in Life Cycle Impact Assessment

(LCIA), convert the emissions of hazardous substances and extractions of natural resources into impact categories which are divided into to levels(Mark Goedkoop 2009). The LCIA phase aims to determine the potential environmental impacts caused by the elementary flows from the LCI by using midpoint or endpoint impact category indicators. On midpoint level, a higher number of impact categories is differentiated and the results are more accurate and precise compared to the three areas of protection at endpoint level (Brattebø 2011).

The method used in this report to calculate GWP of interregional maritime transport, the ReCiPe 2008, is comprised two sets of impact categories with associated sets of characterization factors. At the midpoint level, eighteen impact categories are addressed.

1. climate change(CC)
2. ozone depletion(OD)
3. terrestrial acidification(TA)
4. freshwater eutrophication(FE)
5. marine eutrophication (ME)
6. human toxicity(HT)
7. photochemical oxidant formation (POF)
8. particulate matter formation (PMF)
9. terrestrial ecotoxicity (TET)
10. freshwater ecotoxicity (FET)
11. marine ecotoxicity (MET)
12. ionizing radioation
13. agricultural land occupation (ALO)
14. urban land occupation (ULO)
15. natural land transformation (NLT)
16. water depletion (WD)
17. mineral resource depletion (MRD)
18. fossil fuel depletion (FD)

At the endpoint level, most of these midpoint impact categories are further converted and aggregated into the following three endpoint categories:

1. damage to human health (HH)
2. damage to ecosystem diversity (ED)
3. damage to resource availability (RA)

(Mark Goedkoop 2009)

The principal aim of ReCiPe 2008 was the alignment of two families of methods for LCIA: the midpoint oriented CML 2002 method and the endpoint-oriented Eco-indicator.

To perform a Life Cycle Impact Assessment one must transform the LCI results (elementary flows) to midpoint level equivalent values (GWP,EP, AP etc.) through classification and characterization. One environmental stressor, i.e. substance from LCI may contribute to several midpoint indicators. An example is a stressor such as NOx which contributes to both AP and EP. Likewise, several stressors can contribute to the same midpoint indicator, such as a variety of greenhouse gases like CO2 and CH4 which contribute to climate change and GWP (Brattebø 2011).

Table 2 Overview of the midpoint categories and characterisation factors

Table 2.2: Overview of the midpoint categories and characterisation factors.

Impact category		Characterisation factor	
Abbreviation	**Unit***	**Name**	**Abbreviation**
CC	kg (CO_2 to air)	global warming potential	GWP
OD	kg (CFC-11[5] to air)	ozone depletion potential	ODP
TA	kg (SO_2 to air)	terrestrial acidification potential	TAP
FE	kg (P to freshwater)	freshwater eutrophication potential	FEP
ME	kg (N to freshwater)	marine eutrophication potential	MEP
HT	kg (14DCB to urban air)	human toxicity potential	HTP
POF	kg (NMVOC[6] to air)	photochemical oxidant formation potential	POFP
PMF	kg (PM_{10} to air)	particulate matter formation potential	PMFP
TET	kg (14DCB to industrial soil)	terrestrial ecotoxicity potential	TETP
FET	kg (14DCB to freshwater)	freshwater ecotoxicity potential	FETP
MET	kg (14-DCB[7] to marine water)	marine ecotoxicity potential	METP
IR	kg (U^{235} to air)	ionising radiation potential	IRP
ALO	$m^2 \times yr$ (agricultural land)	agricultural land occupation potential	ALOP
ULO	$m^2 \times yr$ (urban land)	urban land occupation potential	ULOP
NLT	m^2 (natural land)	natural land transformation potential	NLTP
WD	m^3 (water)	water depletion potential	WDP
MRD	kg (Fe)	mineral depletion potential	MDP
FD	kg (oil[†])	fossil depletion potential	FDP

** The unit of the impact category here is the unit of the indicator result, thus expressed relative to a reference intervention in a concrete LCA study.*

† The precise reference extraction is "oil, crude, feedstock, 42 MJ per kg, in ground".

The step of classification decides which of the stressors are contributing to which of the midpoint environmental impact categories. In characterization, the relative importance with respect to the impact potential is decided in equivalent units. For example, methane has a global warming potential of 25 CO2-equivalents over a 100years time horizon according to the GWP100 classification method. This means that CH4 is 25 times as potent compared to CO2 with respect to global warming potential, and subsequently has a characterization factor (c) og 25.

3.2 EEIO-MRIO

The application of multi-regional input-output(MRIO) modeling to environmental flows is a useful methodology to evaluate global linkages between consumption and production systems. MRIO studies can assess environmental impacts from individual products, household consumption, transport, and international climate policy(Glen Peters 2009).

Traditional input-output focus on the inter-industry requirements of a single economy, nation or region, i.e., what the different sectors of industry require from each other to produce one unit of output for each industry. MRIO models on the other hand takes it a step further and includes total inter-industry requirements both within and between different world regions to produce one unit of output for each industry, i.e. a MRIO model includes imports and exports.

International trade provides an mechanism to geographically separate consumption and the environmental impacts in production. Through international trade, polluting and low value-added production can be relocated to distant lands, while the domestic economy increases high value-added and cleaner production(Peters 2007). An environmentally-extended MRIO model makes it possible to not only assess the division between low and big value-added production between regions, but also to assess the environmental impacts of the inter-industry requirements between regions. The model also make it possible to go into more detail on specific trade flows, like assessing the trade flows and environmental impacts of seagoing transport necessary to accommodate the inter-industry requirements between regions

In this study EE MRIO is used as an extension of hybrid-LCA to consider regional trade and global emissions. Typically, LCA is focused on individual products or processes, but the production system may still be global.

There are several practical issues that need to be considered when a EE MRIO analysis is performed. According to the paper “The application of Multi-Regional Input-Output analysis to Industrial Ecology” by Glen Peters and Edgar Hertwich one of the greatest challenges to perform a detailed MRIO study is the general data availability. IO data from more or less every country is required, which is generally available for most OECD countries, but for relatively few non-OECD countries. On top of that, regions like OECD Europe and North America submit data using different classifications and formats. There exists several data projects that have built large IO databases for global models such as GTAP(the Global Trade, Assistance, and Production project) and EXIOBASE which is used in this report. GTAP provides data for 87 world regions in 57 sector detail(Glen Peters 2009) while EXIOBASE provides data for 9 regions in 138 sector detail. Already advantages and disadvantages between the models are evident. The GTAP models has a higher resolution on regions but fewer and more aggregated sectors while EXIOBASE have a better resolution on sectors but fewer regions.

Other practical issues regarding MRIO modeling include exchange rates, inflation, and sector aggregation (Glen Peters 2009).

3.2.1 EXIOBASE

To analyze the flows that is transported with seagoing vessels and their environmental impacts, the Input-Output database EXIOBASE will be used. EXIOBASE is a global, multi-regional Environmentally-extended Input-Output (EEIO) table and is result of the EXIOPOL project. EXIOPOL was a EU-funded project that had two main goals. One part of the project aimed at improving insights in external costs of environmental pressures, the other part tried to overcome significant limitations in existing data sources in the field of multiregional environmentally extended Supply and Use tables (MR EE SUTs), that is to produce the EXIOBASE(Richard Wood 2013). Statistical Institutes provide SUT and IOT for single countries, without trade links. Sector and product detail is not as good as it ought to be. Environmental extensions are often lacking or include only a few types of emissions and primary resource uses. Also, there is little or no harmonization of sector and product classification across different countries. It is therefore difficult to assess the extent to which a country induces environmental impacts abroad via trade, or in the case of this report, assess the environmental impacts due to maritime transport of products and goods between regions. The MR EE I-O database, i.e EXIOBASE, that is developed in EXIOPOL aims to make crucial advances in quality. The EXIOPOL project´s aim is really to leapfrog: it gives EU a fully fledged, detailed, transparent, public global MR EE I-O database with externalities, allowing for numerous types of analyses for policy support purposes(Richard Wood 2013). This database covers the entire global economy, which is grouped into 9 regions:

1. India
2. China
3. OECD Europe
4. OECD North America
5. OECD Pacific
6. Other Developing Asia

7. Economies in transition
8. Latin America
9. Africa and Middle East

The database show the complex trade between regions and is ideal to analyze the environmental impacts of maritime logistics due to the trade between regions.

The EXIOBASE dataset is a Supply and Use Table (SUT) that has been converted to a 138 x 138 product Symmetric Input Output Table (SIOT). The product SIOT was selected over the industry SIOT because ships transport products and commodities, not industries. This being said, both the product and industry classification names are the same, and it is often more convenient to think of these "products from an industry" as "industries" themselves.

3.2.2 Emissions Embodied in Trade (EET)

Using x, i.e output required to satisfy demand, we can start to estimate the emissions embodied in trade, more specifically, the emissions from seaborne transport required to transport imported goods. Domestic consumption can be decomposed into the products produced domestically and imports, $y_r = y_{rr} + \Sigma_s e_{rs}$. The exports, e_r, and imports, m_r, are defined in the following way; $er = \Sigma_s e_{rs}$, $mr = \Sigma_s esr$.

$$F_r = S_r * x_r$$

Each element in S represents the stressor emissions per unit industrial output and r indexes the region of interest. The inter-industry requirements can be broken down as $A_r = A_{rr} + \Sigma_s A_{sr}$ where Arr represents the industry input of domestically produced products and Asr represents the industry input of products from region s to region r.

We can the rewrite the first equation to

$$f_r = S_r * x_r = S_r (I - A_{rr})^{-1} * (y_{rr} + \Sigma_s e_{rs})$$

From this point it is possible to model the emissions embodied in trade depending on whether total trade, imports or exports are of interest (Peters 2007).

Assuming that the production technology is based on fixed proportions we can start to break down the last equation into components for domestic demand on domestic production in region r

$$f_{rr}=S_r(I-A_{rr})^{-1}*y_{rr}$$

And the EET from region r to region s

$$F_{rs} = S_r(I-A_{rr})^{-1}* \Sigma_s e_{rs}$$

Adding these gives the total emissions occuring in the country

$$f_r = f_{rr}+\Sigma_s f_{rs}$$

The total Emissions Embodied in Imports(EEI) is obtained by the following summation;

$$F_{mr} = \Sigma_s f_{sr}$$

4 System Description

This chapter aims at clarifying all assumptions, calculations and technical specification used in this report. The first section focus on maritime transport and how the Inventory of each ship is constructed. The second section focus on how the EXIOBASE data set is improved by describing the assumption made and the approach that is taken to calculate the seagoing trade between the regions and the associated environmental impact.

4.1 Maritime Transportation

As mentioned in the introduction, this report use ships found in the study (Lindstad, Asbjørnslett et al. 2012) and (Lindstad, Asbjørnslett et al. 2011). The vessel differ quite considerably in size between classes but the size difference between vessels of the same class can also be large. Smaller vessels, those between 0 – 15000 dwt typically operate in short sea trades or coastal shipping trades while larger vessels operate on the transcontinental trades. The size of the vessels used in this report are close to the average sized vessel of each class, this to be able to model both short and long distance transport.

The ship classes used in this report are the main cargo carrying vessels on the oceans today are the following:

- Large Dry bulk
- Dry bulk
- General Cargo
- Container
- Reefer
- Crude Oil
- RoRo
- Chemicals
- Oil Products
- LNG
- LPG

The following section will go through the assumptions, requirements and calculation steps made to improve the EXIOBASE dataset and calculate Global Warming Potential(GWP) of international seagoing transport.

4.1.1 Flowchart of vessels

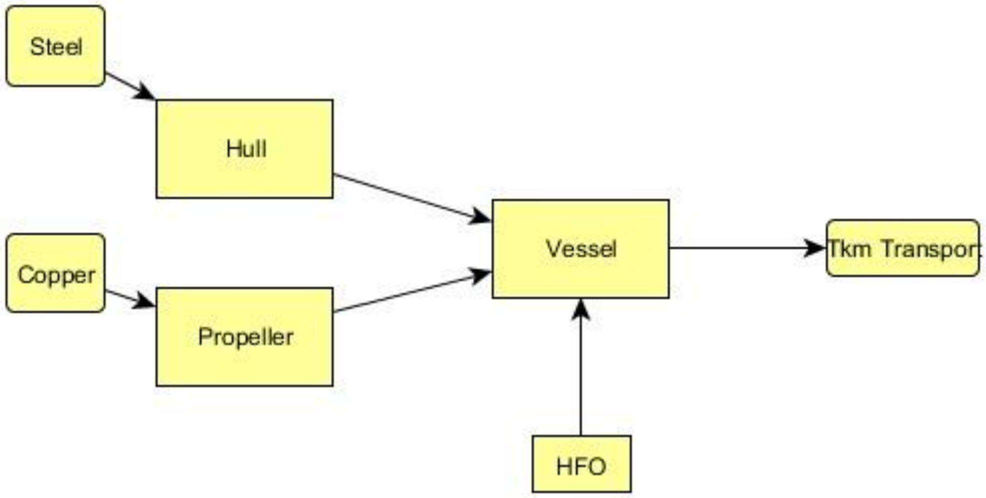


Figure 6 Generic vessel flowchart

Figure 6 shows a simplified flowchart of they key inputs into a seagoing transport vessel. Steel is used to construct the hull, copper to construct the propeller and heavy fuel oil (HFO) is the propulsion energy source. To be able to assess the environmental impacts of 1tkm of transport, a life cycle inventory(LCI) of each vessel has to to be constructed. Constructing a LCI is a detail oriented and time consuming process, and to be able to build LCIs of 11 ships within the time scope of this thesis some assumptions on key material and energy inputs had to made. These assumptions where made in dialogue with my supervisor Anders H. Strømman and co-supervisor Haakon Lindstad. The decision was made to focus on three key inputs

- Steel
- Copper
- Fuel

Steel is, the largest input of a single material in the construction of any vessel as a ship is basically a floating steel structure. Steel production is an energy intensive activity and is responsible for large part of environmental impacts when constructing a ship. A lot of effort has therefore been put on finding accurate numbers of steel use per vessel. Copper is an interesting material to look at, especially since it is rather expensive and thus can have a significant effect on the € input per € of transport. The refining of copper is also quite energy intensive and responsible for considerable emissions of greenhouse gasses. Copper is assumed to be the main input of the construction of the propeller. Fuel consumption is arguably the most import important input and is contribute considerably to both cost and emissions of seagoing transport. Heavy Fuel Oil(HFO) is assumed to be the fuel of choice to power the ships described in this thesis and it is discussed in more detail in the section 2.3. Consumption of HFO varies between the ship classes and is a key component in assessing the cost and emission differences between them.

4.1.2 Technical vessel data

The following section introduces the input data and calculation methods used to derive key numbers like steel, copper and fuel consumption.

Table 3 Overview of vessel data

	Dwt	No. Of ships	Annual ton km	ton km /yr per vessel	Fuel (ton)
Large Dry Bulk	172 000	782	5,77E+12	7,38E+09	13 000 000
Dry Bulk	51 500	1937	3,64E+12	1,88E+09	15 300 000
General Cargo	4 600	7806	3,36E+11	4,30E+07	8 800 000
Container	28 804	789	1,19E+12	1,51E+09	12 900 000
Reefer	8 753	372	1,09E+11	2,93E+08	2 600 000
Crude Oil	150 875	356	1,99E+12	5,59E+09	6 200 000
RoRo	6 500	678	1,35E+11	1,99E+08	4 400 000
Chemicals	44 370	533	1,07E+12	2,01E+09	6 000 000
Oil Products	45 980	630	9,97E+11	1,58E+09	6 500 000
LNG	67 059	229	8,16E+11	3,56E+09	8 600 000
LPG	23 272	60	2,80E+10	4,67E+08	400 000

Table 3 shows each ship class used in the report, the amount of cargo they can carry i.e. deadweight tonnage (dwt), number of ships in the world fleet of that particular class and size, total annual ton km, annual ton km per vessel and total fuel consumption. They data was collected from the paper “Reductions in greenhouse gas emissions and cost by shipping at lower speeds” by Lindstad et.al 2012. The dwt of each vessel within the individual ship classes represent the average size found in the world fleet. The exception is the Large Dry Bulk carrier, a Capesize vessel. This vessel represents the average size of the largest vessels in the dry bulk carrier segment. This ship was chosen to more accurately model the freight of coal and iron ore over large distances. Ton km per year per vessel of each ship class is an average number found by dividing annual ton km on number of sips of each ship class segment.

$$\textit{Annual ton km/yr per vessel} = \textit{Annual ton km} \,/\, \textit{No. Of ships}$$

Table 4 € cost per ton km transport by vessel type

	€ per ton km
Large Dry Bulk	0,0033
Dry Bulk	0,0033
General Cargo	0,0174
Container	0,0080
Reefer	0,0212
Crude Oil	0,0027
RoRo	0,0289
Chemical	0,0098
Oil Products	0,0112
LNG	0,0101
LPG	0,0136

Table 4 shows the cost in € of one ton kilometer of transport of each ship class. The data was found in the paper "Reductions in greenhouse gas emissions and cost by shipping at lower speeds" by Lindstad et.al 2012 and is used later in this section to calculate € of input per € of transport.

Table 5 overview of LSW, Hull weight and propeller weight by vessel type

	Light Ship Weight (LSW	Hull weight (ton)	Propeller weight(ton)
Dry Bulk	29 364	24 959	58,728
Dry Bulk Capesize	87 522	74 394	175,044
General Cargo	2 990	2 542	5,98
Reefer	7 355	6 252	14,71
Container	24 274	20 633	48,548
RoRo	21 010	17 859	42,02
Crude Oil	78 845	67 018	157,69
Oil Products	28 077	23 865	56,154
Chemicals	23 458	19 939	46,916
LNG	111 835	95 060	223,67
LPG	17 980	15 283	35,96

Table 5 shows the light ship weight(LSW) of each vessel, the hull weight and the weight of the propeller. LSW is the actual weight of a ship when complete and ready but empty, that is without cargo, fuel, ballast water or general supplies. The LSW of each vessel is found in the book "Shipbuilding and marine Engineering in Japan 2001" published by Japan Ship exporters' association and The shipbuilders' association of Japan in 2001(JSEA 2001). This publication gives a detailed overview of the ships constructed that year, as well of their carrying capacity and dimensions. As mentioned, the hull is assumed to be constructed of steel and thus the weight of the hull gives a good estimation of the steel consumption to construct each ship. Both the weight of the hull and propeller, an thus the assumed consumption of steel and copper, is calculated as a fraction of the light ship weight. The basis of the fraction used is found in the report “LCA-ship”(Karl Jivén 2004), which documents the assumptions made in a life cycle analysis program for ships. The hull weight is be estimated to be 85% of the light ship weight while the propeller weight is assumed to be 0,2% of the light ship weight.

$$Hull\ weight = LSW*0{,}85$$

$$Propeller\ weight = LSW*0{,}002$$

Table 6 Material requirements per vessel type

Step 1	Steel (ton)	Copper (ton)	fuel per ton km(ton)
Large Dry Bulk	7,44E+04	1,75E+02	2,25E-06
Dry Bulk	2,50E+04	5,87E+01	4,20E-06
General Cargo	2,54E+03	5,98E+00	2,62E-05
Container	6,25E+03	1,47E+01	1,08E-05
Reefer	2,06E+04	4,85E+01	2,39E-05
Crude Oil	1,79E+04	4,20E+01	3,12E-06
RoRo	6,70E+04	1,58E+02	3,26E-05
Chemical	2,39E+04	5,62E+01	5,61E-06
Oil Products	1,99E+04	4,69E+01	6,52E-06
LNG	9,51E+04	2,24E+02	1,05E-05
LPG	1,53E+04	3,60E+01	1,43E-05

Table 6 gives the total steel and copper consumption per vessel and the average fuel consumption per tkm for each ship class. The steel and copper use were calculated in the way described in the previous paragraph. The fuel consumption per tkm was calculated by dividing the total annual fuel consumption per ship class on the total annual ton km of the same ship class. Annual fuel consumption and total annual ton km is found in table 3

$$fuel(ton)\ per\ ton\ km = Fuel(ton)/annual\ ton\ km$$

Table 7 Material requirements per ton km by vessel type

Step 2	Steel (ton) per ton km	Copper (ton) per ton km	fuel(ton) per ton km
Large Dry Bulk	4,03E-07	9,49E-10	2,25E-06
Dry Bulk	5,31E-07	1,25E-09	4,20E-06
General Cargo	2,36E-06	5,56E-09	2,62E-05
Container	1,65E-07	3,89E-10	1,08E-05
Reefer	2,82E-06	6,63E-09	2,39E-05
Crude Oil	1,28E-07	3,01E-10	3,12E-06
RoRo	1,35E-05	3,17E-08	3,26E-05
Chemical	4,76E-07	1,12E-09	5,61E-06
Oil Products	5,04E-07	1,19E-09	6,52E-06
LNG	1,07E-06	2,51E-09	1,05E-05
LPG	1,31E-06	3,08E-09	1,43E-05

Table 7 show the consumption of steel, copper and fuel per ton km. The fuel data on fuel consumption are the same numbers as shown in table 6 while the steel and copper use per ton km are calculated using data on lifetime and average annual ton km data per vessel.

The lifetime of each vessel is assumed to be 25 years(Lindstad, Asbjørnslett et al. 2012) and the average annual ton km per vessel is found in table 3.

$$Steel(ton)\ per\ ton\ km = Steel(ton)*1/(ton\ km/yr\ vessel*lifetime)$$

Table 8 € cost of material requirements per ton km by vessel type

Step 3	€ Steel per ton km	€ Copper per ton km	€ fuel per ton km
Large Dry Bulk	2,28E-04	5,99E-06	1,23E-03
Dry Bulk	3,01E-04	7,88E-06	2,29E-03
General Cargo	1,34E-03	3,51E-05	1,43E-02
Container	9,37E-05	2,46E-06	5,90E-03
Reefer	1,60E-03	4,18E-05	1,30E-02
Crude Oil	7,24E-05	1,90E-06	1,70E-03
RoRo	7,62E-03	2,00E-04	1,78E-02
Chemical	2,69E-04	7,06E-06	3,06E-03
Oil Products	2,85E-04	7,48E-06	3,56E-03
LNG	6,04E-04	1,58E-05	5,75E-03
LPG	7,42E-04	1,94E-05	7,80E-03

Table 9 € cost per ton material

Product	Price per ton (€)
HFO	546,00
Copper	6 310,20
Steel	566,28

Table 8 shows the value in € of the amount of steel, copper and fuel consumed pr ton km. The data is found by multiplying the € value of 1ton of the product, table 9, with steel, copper and fuel consumption per ton km

Table 10 € cost of material per € transport by vessel type

Step 4	€ Steel per € transport	€ Copper per € transport	€ fuel per € transport
Large Dry Bulk	6,95E-02	1,82E-03	3,74E-01
Dry Bulk	9,15E-02	2,40E-03	6,98E-01
General Cargo	7,71E-02	2,02E-03	8,24E-01
Container	1,17E-02	3,07E-04	7,37E-01
Reefer	7,54E-02	1,98E-03	6,15E-01
Crude Oil	2,67E-02	7,00E-04	6,27E-01
RoRo	2,63E-01	6,91E-03	6,15E-01
Chemical	2,76E-02	7,24E-04	3,14E-01
Oil Products	2,56E-02	6,70E-04	3,19E-01
LNG	6,00E-02	1,57E-03	5,71E-01
LPG	5,45E-02	1,43E-03	5,73E-01

Table 10 shows the € value of steel, fuel and copper per € of transport. These numbers are found by dividing the € value of steel, copper and fuel on the general cost per ton tkm of each vessel class found in table 4. This data shows the final input numbers which will be incorporated into the Hybrid-MRIO model which will be discussed in more detail in the next section. In short these number gives the € of input of steel, copper and fuel per € euro transport i.e. output. Through the calculations shown is this section, technical vessel data has been transformed from total requirements of steel, copper and fuel per vessel into input coefficients necessary to complete the model.

4.1.3 Vessel emission intensities

Table 11 CO_2 emissions per ton km by vessel type

	CO2 emitted per freight unit gram per ton km
Large Dry Bulk	8
Dry Bulk	13
General Cargo	59
Container	34
Reefer	81
Crude Oil	10
RoRo	75
Chemical	18
Oil Products	24
LNG	33
LPG	39

Table 11 presents the assumed emission intensities of CO2 in gram per ton km transport. Reefer vessels, general cargo carriers and RoRo vessels have the highest emission intensities pr ton km with 81, 59 and 75 grams of CO2, respectively. The most efficient vessels are the large dry bulk carrier, Crude oil carriers and Oil product carriers with emission intensities of 8, 10 and 24 grams of CO2 per tkm transport, respectively(Lindstad, Asbjørnslett et al. 2012).

4.2 EE MRIO EXIOBASE

In the EXIOBASE dataset the world economy is divided into the following 9 regions

- Region 1 – China
- Region 2 – India
- Region 3 – OECD Europe
- Region 4 – North America
- Region 5 – OECD Pacific
- Region 6 – Economies in Transition
- Region 7 – Latin America
- Region 8 – Other Developing Asia
- Region 9 – Africa and the Middle East

Which countries that are included in each region is not always clear cut. OECD Pacific include among others Japan, South Korea, Australia and New Zealand. Economies in Transition are in the database mostly European ex-soviet countries which are not a part of

OECD Europe like Russia, Slovenia, Bulgaria and Latvia, but the region also include Cyprus and Malta. Other Developing Asia include, to mention a few, Taiwan and Indonesia.

The regions are organized into a 9by9 matrix.

A1,1	A1,2	A1,3	A1,4	A1,5	A1,6	A1,7	A1,8	A1,9
A2,1	A2,2	A2,3	A2,4	A2,5	A2,6	A2,7	A2,8	A2,9
A3,1	A3,2	A3,3	A3,4	A3,5	A3,6	A3,7	A3,8	A3,9
A4,1	A4,2	A4,3	A4,4	A4,5	A4,6	A4,7	A4,8	A4,9
A5,1	A5,2	A5,3	A5,4	A5,5	A5,6	A5,7	A,58	A5,9
A6,1	A6,2	A6,3	A6,4	A6,5	A6,6	A6,7	A6,8	A6,9
A7,1	A7,2	A7,3	A7,4	A7,5	A7,6	A7,7	A7,8	A7,9
A8,1	A8,2	A8,3	A9,4	A8,5	A8,6	A8,7	A8,8	A8,9
A9,1	A9,2	A9,3	A9,5	A9,5	A9,6	A9,7	A9,8	A9,9

Figure 7 EXIOBASE 9 region structure

Each region and its trade flows are given by individual A-matrices. An A-matrix, also called coefficient matrix or requirements matrix, gives us € of input required per € of output. It show what each region require from itself, i.e. its own sectors, from the other 8 regions and what it export to the other regions.

A1,1	A1,2	A1,3	A1,4	A1,5	A1,6	A1,7	A1,8	A1,9
A2,1	A2,2	A2,3	A2,4	A2,5	A2,6	A2,7	A2,8	A2,9
A3,1	A3,2	A3,3	A3,4	A3,5	A3,6	A3,7	A3,8	A3,9
A4,1	A4,2	A4,3	A4,4	A4,5	A4,6	A4,7	A4,8	A4,9
A5,1	A5,2	A5,3	A5,4	A5,5	A5,6	A5,7	A,58	A5,9
A6,1	A6,2	A6,3	A6,4	A6,5	A6,6	A6,7	A6,8	A6,9
A7,1	A7,2	A7,3	A7,4	A7,5	A7,6	A7,7	A7,8	A7,9
A8,1	A8,2	A8,3	A9,4	A8,5	A8,6	A8,7	A8,8	A8,9
A9,1	A9,2	A9,3	A9,5	A9,5	A9,6	A9,7	A9,8	A9,9

Figure 8 Domestic requirements

A1,1	A1,2	A1,3	A1,4	A1,5	A1,6	A1,7	A1,8	A1,9
A2,1	A2,2	A2,3	A2,4	A2,5	A2,6	A2,7	A2,8	A2,9
A3,1	A3,2	A3,3	A3,4	A3,5	A3,6	A3,7	A3,8	A3,9
A4,1	A4,2	A4,3	A4,4	A4,5	A4,6	A4,7	A4,8	A4,9
A5,1	A5,2	A5,3	A5,4	A5,5	A5,6	A5,7	A,58	A5,9
A6,1	A6,2	A6,3	A6,4	A6,5	A6,6	A6,7	A6,8	A6,9
A7,1	A7,2	A7,3	A7,4	A7,5	A7,6	A7,7	A7,8	A7,9
A8,1	A8,2	A8,3	A9,4	A8,5	A8,6	A8,7	A8,8	A8,9
A9,1	A9,2	A9,3	A9,5	A9,5	A9,6	A9,7	A9,8	A9,9

Figure 9 Import requirements

A1,1	A1,2	A1,3	A1,4	A1,5	A1,6	A1,7	A1,8	A1,9
A2,1	A2,2	A2,3	A2,4	A2,5	A2,6	A2,7	A2,8	A2,9
A3,1	A3,2	A3,3	A3,4	A3,5	A3,6	A3,7	A3,8	A3,9
A4,1	A4,2	A4,3	A4,4	A4,5	A4,6	A4,7	A4,8	A4,9
A5,1	A5,2	A5,3	A5,4	A5,5	A5,6	A5,7	A,58	A5,9
A6,1	A6,2	A6,3	A6,4	A6,5	A6,6	A6,7	A6,8	A6,9
A7,1	A7,2	A7,3	A7,4	A7,5	A7,6	A7,7	A7,8	A7,9
A8,1	A8,2	A8,3	A9,4	A8,5	A8,6	A8,7	A8,8	A8,9
A9,1	A9,2	A9,3	A9,5	A9,5	A9,6	A9,7	A9,8	A9,9

Figure 10 Export requirements

To understand the dynamics of this model take a look on the three figures shown above. Figure 8 shows the *domestic requirements* of region 1 i.e. what the domestic sectors require from each other in order to produce 1€ of output. Figure 9 show the *import requirements* of region 1 from the other 8 regions, i.e. what the domestic sectors require from foreign sectors to produce one unit output. Figure 10 shows the *export requirements* from region 1 to the other regions i.e. what the other 8 regions require from region 1 to produce 1 € of output. The rule is that the domestic requirements of each region is found on the *diagonal* of 9by9 region model, the import requirements are found on the *vertical axis* while the regions export are found on the *horizontal axis.*

4.2.1 The A-matrix

Each one of these individual A-matrices shown i figure 11 are structure in one of two ways

Figure 11 Modified Arr matrix

This figure show us in more detail how each on of the individual domestic A-matrices on the diagonal is constructed. The Ar,r is build up by 138x138 sectors whose values are given by €/€. The logic is the same as in the big region matrix shown on the previous page. For a given output of 1€ a sector requires fractions of € from the other sectors. To simplify, one can think of it as a recipe; to produce 1€ worth of paddy rice, you need x€ worth of road transportation, y€ worth of fertilizer and z€ worth of iron ore. The horizontal axis shows what each sector gives to itself and the other 137 sectors while the vertical axis shows what each sector requires from itself and the other 137 sectors to produce 1€ worth of product. The Ar,r matrix represents the diagonal region matrices, i.e. what each region requires from itself. This figure also cuts to the core of this thesis, where one of the main tasks is to improve the representation of maritime transport. The EXIOBASE dataset has one sector, sea and coastal water transportation services, that cover all maritime trade between regions. That means that all goods, iron ore, minerals, crude oil, wheat and electronics are transported in the same boat. The matrix on the right of figure 12, Atr_€/tkm is the improvement of this model. It is a 138 by 11 matrix that shows the requirements in € of each of the 11 vessels from the 138 sectors to transport one ton of goods one kilometer. In short, the matrix is constructed by creating an average "sea and coastal water transportation services"-vector, figure 12, from all the 9 regions and then substituting the €/€ inputs of steel, fuel and copper with the values from the life cycle inventories of the individual ship classes shown in table 10 in 4.1.2. The next step is to convert Atr_€/€ into an Atr_€/tkm matrix by multiplying with the general € cost per ton km of each vessel, shown i table 4.

Figure 12 Modified Atr €/€ matrix

The first step to construct Atr_€/tkm matrix is to insert the €/€ values calculated in table 10 for each of the 11 ship classes into Atr_€/€ matrix illustrated by figure 12. A crucial point is to remember that that we are dealing with coefficients and that the sum of Atri_€/€ and VAi must equal 1. When inserting the coefficients from steel, copper and fuel of the individual ships from table x the sum is no longer equal to one. It is therefore necessary to scale all the other coefficients in the Atr_€/€ and VAi matrix so that the sum again is equal to 1. The next step is to multiply the values in Atr_€/€ with the general € cost pr ton km found in table 4 to be able to construct Atr_€/tkm.

When the Ar,r matrix is constructed in this way it assumes that each regions constructs and run is own fleet so to be able to transport imported inputs from other regions to its own economy. This is a simplification as most new ships are constructed in shipyards in Korea, China and Japan and that individual fleets are run from many different nations (UNCTAD 2012). This assumption makes it easier to analyze multiplier-effects due to increased shipping activity. The lower green matrix in figure 11 shows tkm transport per € and is 0 on the diagonal regions due to the assumption that there is no seagoing transport required within a region.

Figure 13 Modfied Ar,s matrix

Figure 13, Ar,s shows the requirements matrix of what the sectors of region j requires from the sectors region i. Atr_tkm is zero due to the assumption that the importing country builds its own fleet. While we have values in the G_tkm/€. This matrix gives the tkm of transport per € from region r to region s.

$$G\_tkm/€ = G*ai,j*1/p*drs$$

Where G is the transport correspondence matrix, ai,j is the requirements matrix from region r, to region s and 1/p is equal to ton good(product) per € and dr,s is the transport distance from region r to region s. G is presented as table 26 in the appendix. The price, table 24 in the appendix, shows the prices for all goods that can be shipped by any of the 11 ships. Prices for services or organizations was not included in the price-vector as these cannot be imported or exported, least of all by ships.

Table 12 Transport distances in km

Distance in km	China	India	OECD Europe	OECD North America	OECD Pacific	Economies in	Latin America	Other Devel	Africa and Middle East
China	0	7037,6	19446	19631,2	1852	21298	20372	4630	10371,2
India	7037,6	0	14445,6	17223,6	8334	16297,6	16297,6	3889,2	5370,8
OECD Europe	19446	14445,6	0	14445,6	20742,4	2037,2	10186	15927,2	11667,6
OECD North America	19631,2	17223,6	14445,6	0	8889,6	16297,6	13890	14630,8	20557,2
OECD Pacific	1852	8334	20742,4	8889,6	0	22594,4	21112,8	5926,4	11852,8
Economies in Transition	21298	16297,6	2037,2	16297,6	22594,4	0	12038	17779,2	13519,6
Latin America	20372	16297,6	10186	13890	21112,8	12038	0	15742	15186,4
Other Developing Asia	4630	3889,2	15927,2	14630,8	5926,4	17779,2	15742	0	6852,4
Africa and Middle East	10371,2	5370,8	11667,6	20557,2	11852,8	13519,6	15186,4	6852,4	0

(Searates.com 2013)

The transportation distances between the regions can be seen in table 12, and are given in km.

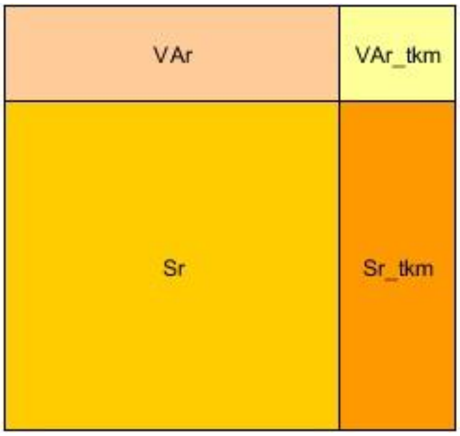


Figure 14 Modified Stressor matrix

The stressor-matrix 738 by 1341 matrix that contains both value added and stressor emissions from the various sectors. Var and Sr gives the value added and stressor emissions due to sector requirements to produce outputs. Var_tkm is the value added per tkm of transport and is a 15 by 11 sized matrix and constructed as an average value added from the "sea and coastal water transportation services"-vector. As mentioned the values has then been scaled to accommodate the requirement for the coefficients to sum to 1 after the LCI data for the individual ships, found in table 10 in section 4.1.3, have been inserted. Sr_tkm is a 712 by 11 matrix that includes the stressor emissions of the individual ship classes from 1tkm of transport seen in table 11. The stressor values are inserted directly from the LCI individual for each ship.

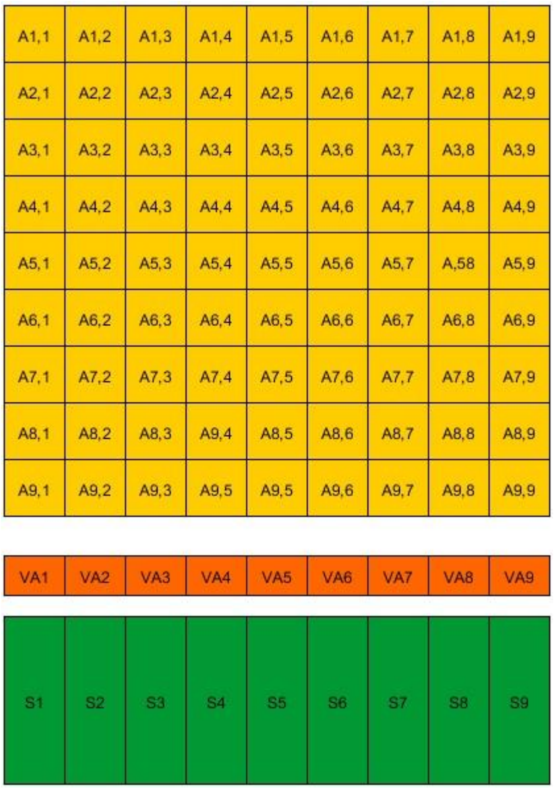


Figure 15 Complete modified system

The final system is illustrated in figure 15. The new big A matrix with the configured individual a-matrices are given in the yellow square, the configured Value Added in the orange rectangle, and the green rectangle illustrate the configured stressor matrix.

4.2.2 The Z-matrix

The next step is to construct the Z matrix. Also known as the inter-industry flow-matrix, seen in figure 16. The Z matrix shows the product flows in euro between the regions and sectors to satisfy demand. It is therefore different from the A-matrix that it shows total flows, not coefficient for one unit of output.

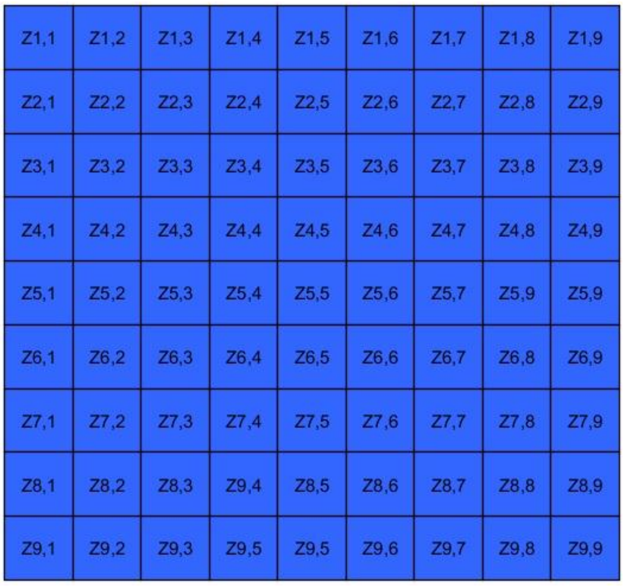


Figure 16 Z matrix

$$Z = A\_new*diag(x)$$

$$\text{Where } x = (I\text{-}A\_new)^{-1}*y_{fd}$$

I is a 1341x1341 identify matrix with ones on the diagonal and y_{fd} is the total final demand which is given by a 1341x1 vector The x gives total production in euro, that is the production of required from the different sectors to satisfy demand and is also a 1341x1 vector. The logic of the Z matrix is similar to that of the A matrix. The diagonal gives the flows in euro of what each region requires from itself to satisfy demand, while to off-diagonal z-matrices gives the flows in euro from region to region form the individual regions to satisfy demand.

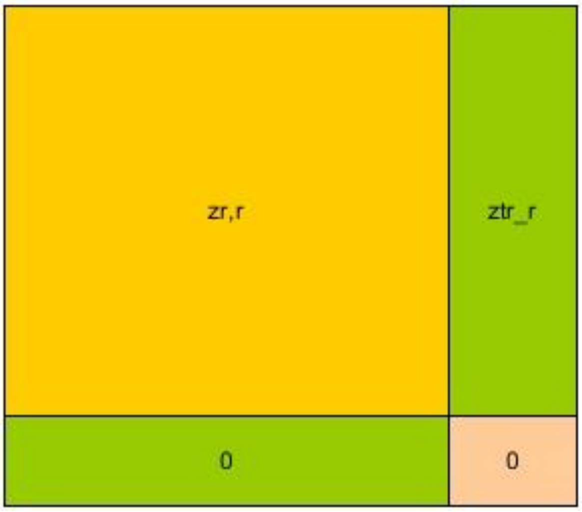


Figure 17 Modified domestic Z-matrix

Since the Z-matrix is the product of the A-matrix and x, the composition of the z-matrices are similar to that of the individual A-matrices. figure 17 is an illustration of the composition of the diagonal Z-matrices, i.e. the flows of what the region require from its own sectors. The rectangular ztr_r shows the flows required from its own region to construct the fleet necessary to satisfy the regions import demand while zr,r gives the required flows from the regions own sectors. The rest is zero as we assume that there is no demand for maritime transport within a region.

Figure 18 Modified Zr,s matrix

Zr,s, figure 18, gives the flows of products from the sectors of region r to the sectors of region s. The rectangle to the right of zr,s is zero as the construction of the fleet is done within each region. Gz_tkm is not zero and gives the tkm transport for each vessel to satisfy the demand of each region.

4.3 Global Warming Potential of International Maritime transport

We can use equation x, as a basis to calculate the GWP of seagoing transport.

$$F_{mr} = \Sigma_s f_{sr}$$

This equation gives the total Emissions Embodied in Imports(EEI), where F_{mr} gives the emissions from imports of region r, and $\Sigma_s f_{sr}$ gives the sum of emissions in seagoing transport from region s to region r. To calculate the GWP we need to multiply this equation with a characterization factor which translates the emissions to CO2-equivalents, as discussed in section 3.1.5 in the methodology chapter. GWP of seagoing transport from importing goods is thus:

$$d_{gwp}r = F_{mr} * C_{gwp} = \Sigma_s f_{sr} * C_{gwp}$$

$d_{gwp}r$ gives the GWP of maritime transport due to transport of imported goods.

5 Results

This section presents the results calculated by using Environmentally Extended Multi-Regional Input-Output(EE MRIO) approach using the EXIOBASE dataset. The section is divided into 4 parts; Total Trade flows, Trade flows transported by seagoing vessels, Total tkm transport between regions, ton km transport by the individual ship classes and global warming potential of seagoing transport.

5.1 Total Trade flows €

Table 13 Regional flows (billion €)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
Region 1 - China	4 229	10	29	39	81	1	27	13	31
Region 2 - India	3	636	12	11	8	1	3	2	3
Region 3 - EU	70	16	10 717	264	197	51	101	33	106
Region 4 - NA	46	6	268	11 709	194	6	59	39	52
Region 5 - PAC	170	23	200	230	7 190	11	612	135	707
Region 6 - EIT	6	1	75	19	21	409	11	2	11
Region 7 - LA	29	11	86	75	553	7	1 364	48	441
Region 8 - AS	51	3	29	42	103	1	48	664	55
Region 9 - AM	37	14	106	81	691	9	475	60	691

Table 13 shows the total trade flows in billion euro between the different regions. It is found by summarizing each if the individual region Z matrices into a single value. The diagonal represents the value flows of what each region requires from itself to satisfy demand, while the off-diagonal values gives value flows between each region. The columns shows what each region requires from other regions to satisfy demand of production, i.e. imports, while the rows shows the value flows that each region exports to satisfy production demand in the other regions.

To familiarize the reader with the table we can take region 1, China as an example. The Chinese inter-industry flows between its own sectors summarize 4 229 billion €, while it require 3 billion € from India70 billion € from OECD Europe, 46 billion € from North America to satisfy demand for production. China also exports 10 billion€ to India, 29 billion € to OECD Europe and so on to satisfy production demand.

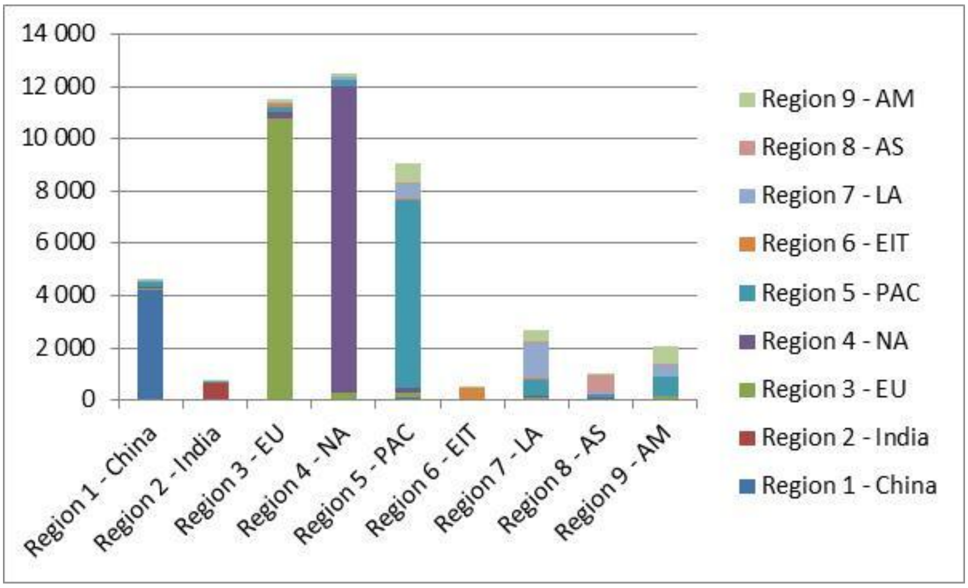


Figure 19 Regional flows (billion €)

Figure 19 gives a graphical representation of table 13. It is evident that the 4 largest economies are North America, OECD Europe, OECD Pacific and China. We also see that the greatest share, by far, of the inter-industry flows is what each region requires from its own sectors. This makes sense because it is difficult for a region to export more than it produces itself. We see that the share of inter-industry flows within a region is reduced as we move towards the developing economies of Latin America, Other developing Asia and Africa and the Middle East. This is mainly because of the reduced data availability in those regions.

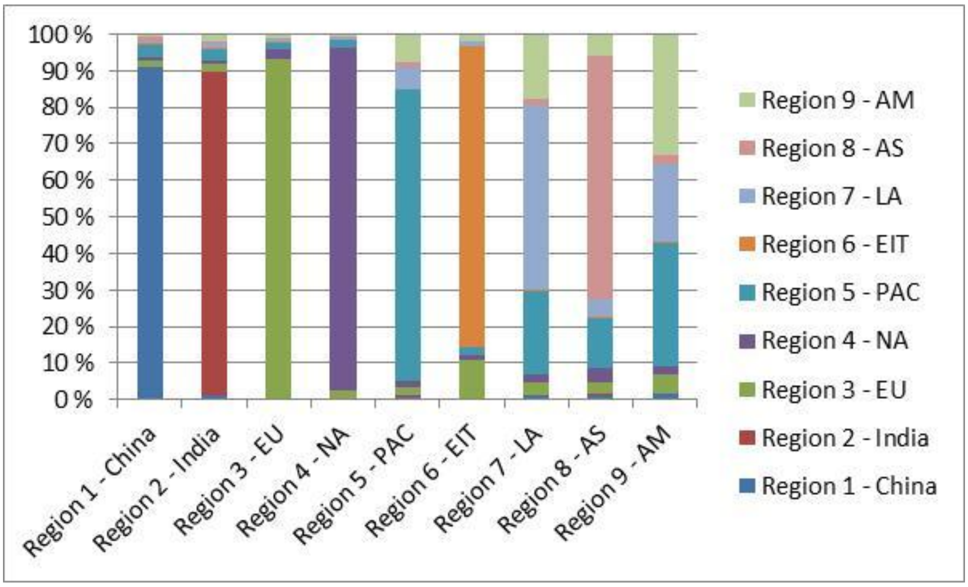


Figure 20 Share regional flows

Figure 20 shows the percentage shares of flows going to different regions. In this figure it is easier to see that, on average, close to 90% of the production flows goes to the regions own sectors. We also see, as mentioned, that the share of inter-industry flows within a region decreases as we look at the developing economies.

5.2 Shipped trade flow €

In this section we study the production flows that are transported between regions by seagoing vessels. Here, two aspects of seagoing transport is presented. Firstly, the total trade flows transported by ships are shown, second, this we analyze the extent of ship classes utilized.

5.2.1 Total trade flows shipped between regions

Table 14 Regional flows with seagoing transport (billion €)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
Region 1 - China	0	2	17	28	65	1	21	10	24
Region 2 - India	1	0	7	8	6	1	2	1	2
Region 3 - EU	62	13	0	167	143	41	71	25	75
Region 4 - NA	35	4	105	0	117	2	32	27	27
Region 5 - PAC	143	19	146	176	0	9	392	102	451
Region 6 - EIT	5	1	53	11	15	0	6	2	6
Region 7 - LA	22	8	66	59	358	5	0	34	272
Region 8 - AS	43	3	20	32	79	1	33	0	37
Region 9 - AM	29	11	83	64	448	8	294	42	0
Sum imports	**340**	**61**	**498**	**544**	**1 232**	**67**	**850**	**243**	**894**

Table 14 shows the value of the production flows transported between the regions in billion euro. The table is similar to Table 13, but with two key differences. The first difference is that the diagonal is zero. This is because of the assumption that no seagoing transport is required to ship goods between sectors within a region. The second difference is that the values in table 14 are lower than the ones you see in table 13. To find the value of the production flows transported between the regions each of the individual Zr,s matrices are multiplied with the seagoing transport correspondence matrix. Meaning that values not transported across the seas are left out, leading to lower values. Other than this, the table is interpreted in the same way as table 13, where a regions import is found reading the columns and the regions export is found reading the rows.

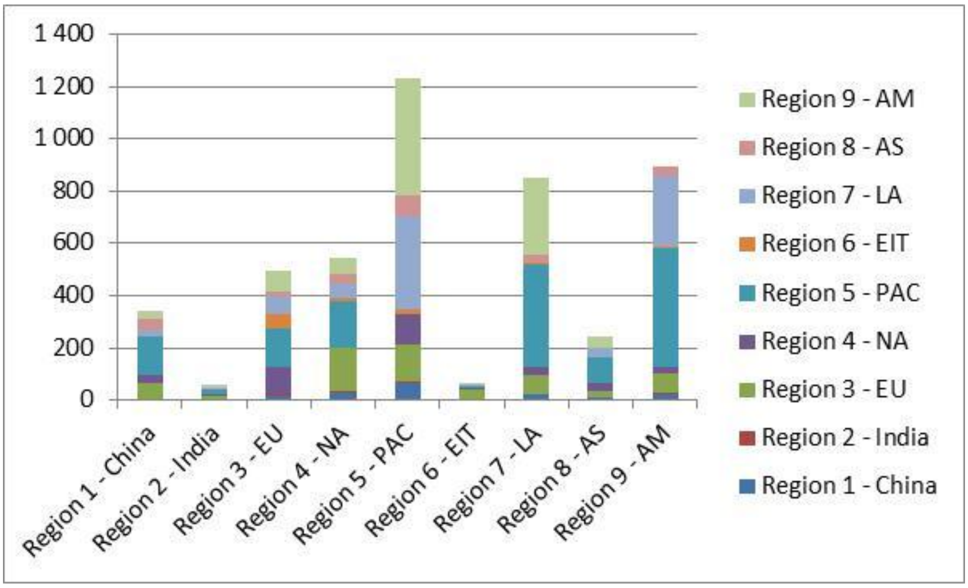


Figure 21 Regional flows with seagoing transport (billion €)

In figure 21 is a graphical representation of table 14. Each column shows the regions import, where we see that OECD Pacific has the largest total import measured in flows of €. Coming in second we have region 9, Africa and the Middle East, third is Latin America and 4th and 5th we have North America and OECD Europe respectively. We see that region 5s import partners are Africa and the middle east, Latin America, Europe and North America respectively. On a whole, we see that all a significant share of all the other regions come import come from OECD Pacific. We also see, as expected, that North Americas biggest trading partner, other than OECD Pacific is OECD Europe and that OECD Europe's imports the most from North America, after OECD Pacific, compared to the other regions.

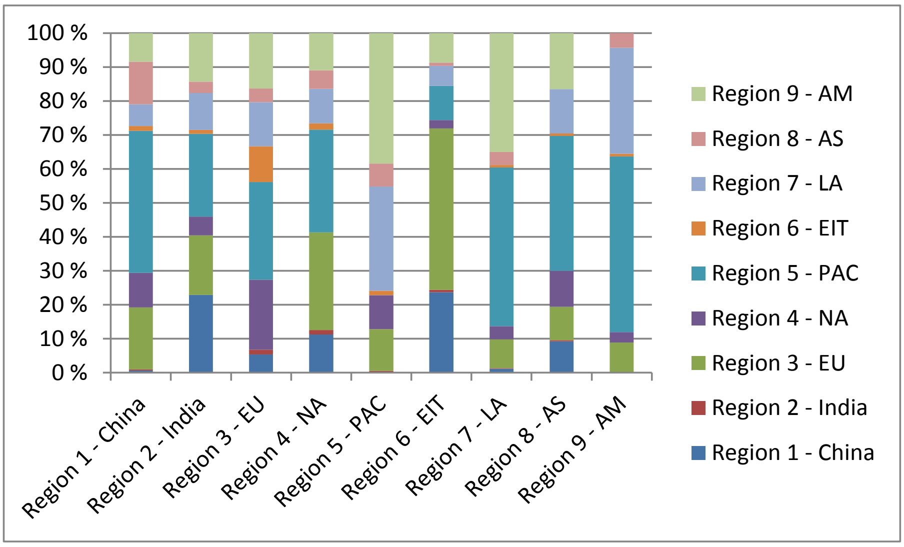


Figure 22 Share egional flows with seagoing transport

In figure 22 we see the trade partners for each region as shares of total import. On a whole we see that OECD Pacific is the greatest exporter and the major import partner of the other regions. The exception is "Economies in Transition" where the largest import share is from OECD Europe and China. For India the import from OECD Pacific is only slightly larger than their import from China and in North America the import from OECD Pacific and OECD Europe is about the same size, covering nearly 60% of its total imports. India and Economies in transition have the lowest import share of all the regions and most of EITs exports are bound to Europe. Africa and the Middle East is an interesting region where as most of their exports, both as shares and in total goes towards OECD Pacific and Latin America, and then has a relative constant average import share of 12-15% in the other regions.

5.2.2 Total trade flows between regions, vessel resolution

Table 15 Regional tradeflows by vessel type (million €)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM	sum
Large Dry Bulk	5 123	354	502	2 868	17 511	8 899	12 846	1 952	18 093	68 149
Dry Bulk	14 545	7 387	54 848	35 938	206 548	29 235	135 627	26 384	166 075	676 587
General Cargo	5 279	809	24 460	21 888	35 237	5 397	26 760	9 768	28 302	157 899
Container	111 782	10 506	274 416	137 405	598 317	10 913	268 252	125 093	312 615	1 849 299
Reefer	6 441	1 596	25 919	18 790	71 736	3 346	55 491	9 446	64 035	256 799
RoRo	8 011	1 187	77 387	48 937	84 388	2 257	19 509	12 408	20 641	274 724
Crude Oil	4 361	0,10	13 821	9 740	134 845	18 344	120 531	15 866	151 274	468 781
Chemical	1 301	140	18 047	14 222	133 647	9 352	94 633	18 193	111 642	401 177
Oil Products	10 042	5 267	107 972	58 203	110 409	8 115	53 412	17 839	61 734	432 993
LNG	508	17	1 287	514	15 864	3 370	15 273	7 460	18 676	62 969
LPG	0,04	0,04	95	56	28 068	29	21 996	2 618	25 890	78 752,53

In table 15 we see the total exports of each region broken down to ship class resolution in million euro. To familiarize the reader with the table we can again use China as an example. The value of the production flows exported using a large dry bulk carrier is 5 123 million euro, containerized cargo exported from China has a value of 111 782 million euro while value products transported by Reefer vessels are 6 441 million euro.

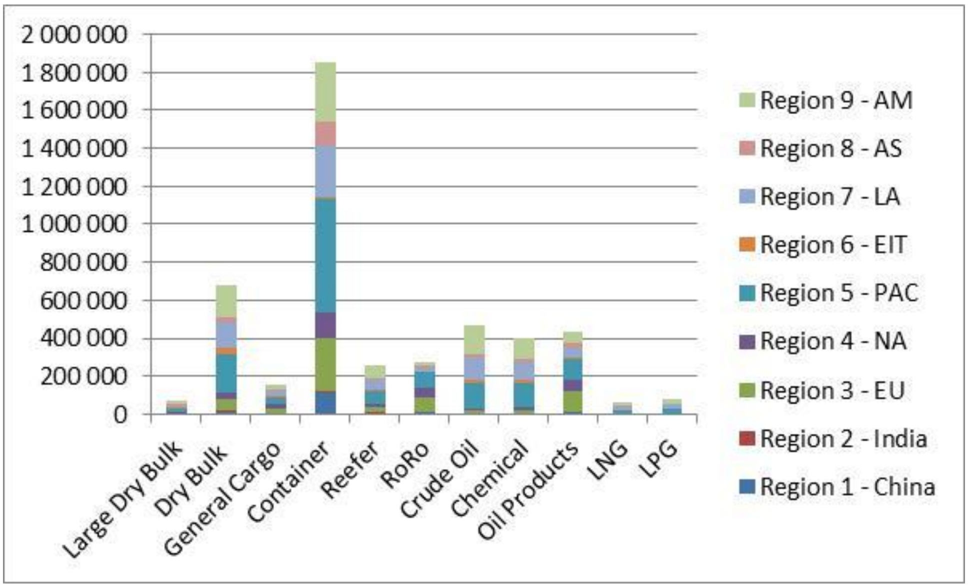


Figure 23 Regional trade flows by vessel type (million €)

Figure 23 is a graph illustrating the results in table 15. Container vessels transport by far the most value of production flows between the regions. This confirms the fact that the high value goods, like electronics, are shipped using container vessels. Second comes dry bulk and RoRo vessels. Goods transported by dry bulk has a relatively low price per ton, but the total volume transported is so great that it translates into a high flow euro value flow. Again, OECD Pacific is the biggest player in the containerized traded followed by Africa and the Middle East, Latin America and OECD Europe. RoRo, Chemical vessels and vessels transporting Oil products transport close to the same value of products, around 400 000 million euros, while very large bulk, LNG and LPG transport the lowest amount of value of product flows between the regions. One reason that container and dry bulk vessels carry the most value of product flows between region is that these vessel can carry a great variation of products while the other seagoing vessels carry a more limited range of products. Vessels like LNG, LPG and crude oil carriers are assumed to only carry one type of product each, namely LNG, LPG and crude oil.

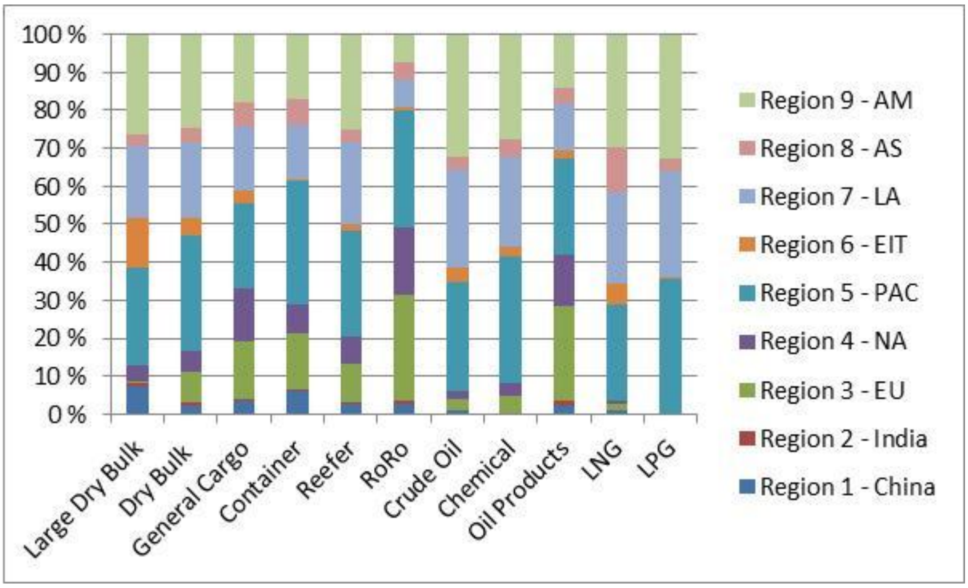


Figure 24 Share of regional trade flows by vessel type

Looking at figure 24 and the shares of the regions utilizing the various vessels classes to transport the value flows of their products between regions we see that OECD Pacific, Latin America, and Africa and the Middle East dominate the figure. Europe has relative larger share on transport using RoRo vessels and Oil product vessels, while not surprisingly Africa and the Middle East are one of the largest Crude oil exporters.

5.3 Total ton kilometer transport

In this section we move away from the value of production flows between the regions and focus on the total ton kilometer transport. The first part focus on the total ton km transport between the regions, their exports and imports. The next section breaks down the trade to ship class resolution and show the total export of each region by vessel.

5.3.1 Ton kilometer transport between regions

Table 16 Interregional seagoing transport (billion tkm)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
Region 1 - China	0	20	216	292	103	17	285	40	166
Region 2 - India	9	0	86	93	49	15	46	5	14
Region 3 - EU	684	295	0	2 143	2 883	68	677	297	730
Region 4 - NA	466	121	1 235	0	1 208	26	481	254	435
Region 5 - PAC	186	202	2 227	1 106	0	301	7 715	500	4 995
Region 6 - EIT	132	21	108	150	393	0	80	23	82
Region 7 - LA	408	207	602	834	7 529	104	0	507	4 075
Region 8 - AS	126	16	171	234	413	16	443	0	223
Region 9 - AM	277	89	945	1 451	5 355	185	4 404	289	0
Sum imports	**2 289**	**970**	**5 590**	**6 303**	**17 934**	**733**	**14 130**	**1 915**	**10 720**

Table 16 shows the total transport between the regions in billion ton kilometer. As in table 15 the diagonal is zero due to the assumption that there is no seagoing transport within a region.

The columns show how much ton kilometer transport of import that is required from the other regions while the rows show the export in ton kilometer transport.

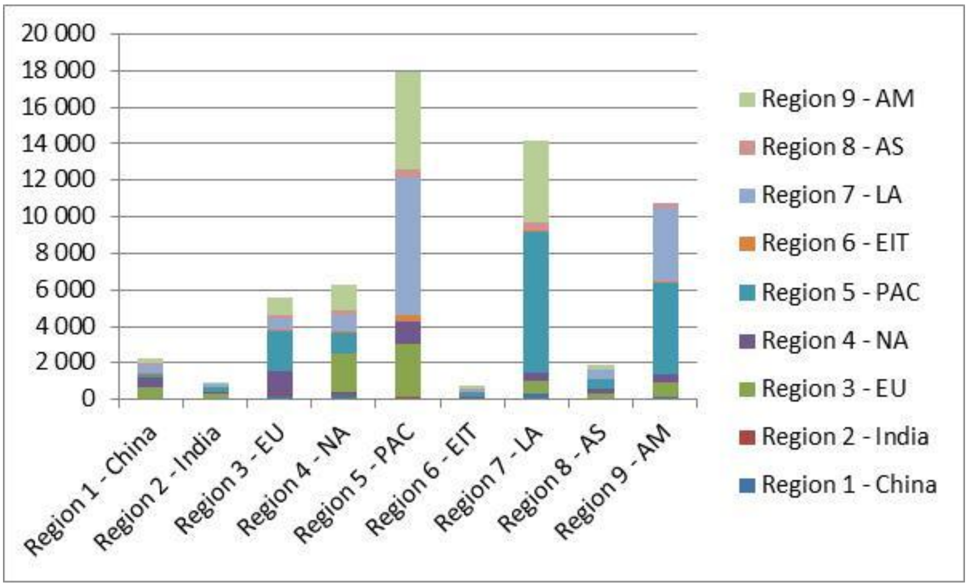


Figure 25 Interregional seagoing transport (billion tkm)

Figure 25 shows the values of table 15 graphically. We see that OECD Pacific has the largest import measured in ton km, followed by Latin America and Africa and the Middle east. The total import of region 5 measured in ton km is massive, 17 934 billion ton km, and so is the ton km of imports of EU and North America as well. As we saw in figure 23 OECD Pacific's major trading partners are Latin America and Africa and the Middle East. OECD Europe is North Americas major trading partner, while Europe's import from OECD Pacific is twice as large as their import from North America measured in ton km transport. In figure 23 looking at the value of the production flows rather than the ton km transport we saw that the share of Europe's imports from North America and OECD Pacific where close to the same value. One reason to why we see this difference lies in the distance between the ports. OECD Pacific is further away from Europe than North America is and the added distance increases the share of imports from OECD Pacific relative to the import shares from North America.

The total seagoing transport between the regions account for 60 000 billion ton km, a total that is lower than the 71 000 billion ton km, reported by UNCTADs review of Maritime transport 2012. One explanation to this deviation is due of the assumption of no maritime transport within each region. Region 5, OECD Pacific are a model of Japan, South Korea, Australia and New Zealand. Japan is the world's biggest steel producers and is together with South Korea one of the world's largest ship builder. Australia on the other hand is the world's largest exporters of coal and iron ore, and Japan is one of Australia's greatest export markets for those commodities. As they are both island states it means that all trade between Japan, Korea and Australia are transported by ships, but this trade is not modeled because of the assumptions made in this report.

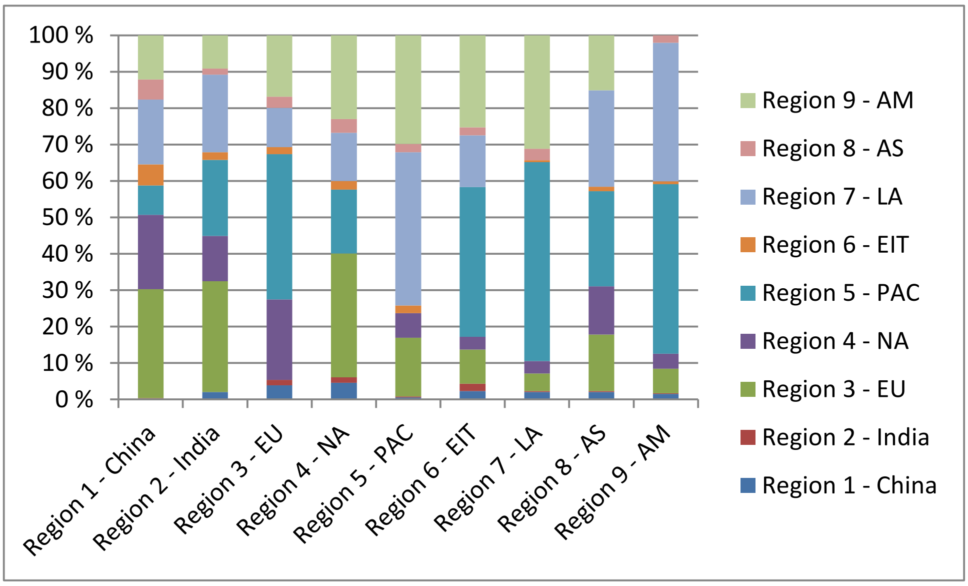


Figure 26 Share of interregional seagoing transport (billion tkm)

Figure 26 shows the shares of imports of each region in ton km. OECD Pacific is a major exporter in terms of ton km and imports from that region makes up a relative large share of total in the other regions. Comparing this figure with figure 24 it is interesting to see the effect distance has on the share of imports from specific regions. In figure 24 the import value from Europe and north America to China is close to 30% while imports from OECD Pacific is about 40% Chinas total imports. Looking at figure 26 we see a different result. Measured in ton km Chinas import from North America and Europe is about 50% while imports from OECD Pacific, which is geographically much closer is only around 10 %. The same trend is evident when looking at region 6, Economies in Transitions. Here imports from Europe was about 50% of EITs total imports measured in euro while the imports from OECD pacific is about 13%. However, imports measured in ton km is now around 40% from OECD Pacific and less than 10 % from Europe. On the other hand, imports from China, which for EIT constituted just over 20% of total imports measured in euro product flows but only account for a few percent measured in ton km. One explanation of this is that the EITs imports from China are comprised of relatively expensive goods, but which are light weight, lowering the ton km share of total imports from China.

5.3.2 Ton kilometer Maritime Transport, Vessel Resolution

Table 17 Interregional seagoing transport by vessel type (billion tkm)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM	Sum
Large Dry Bulk	24 505	1 402	12 064	40 303	604 117	74 950	455 755	39 996	437 843	1 690 935
Dry Bulk	177 679	96 232	712 294	477 983	3 007 042	359 686	2 557 640	241 259	2 494 589	10 124 402
General Cargo	50 634	9 519	314 378	279 074	420 555	42 169	400 243	68 235	309 311	1 894 117
Container	503 405	54 166	1 537 090	584 843	3 709 294	31 581	2 736 648	440 231	2 299 176	11 896 436
Reefer	23 279	6 651	213 993	134 914	466 761	21 369	443 608	34 421	377 175	1 722 172
RoRo	44 063	7 291	401 143	186 240	422 151	6 328	180 176	62 565	153 233	1 463 191
Crude Oil	28 704	1	328 657	170 820	2 585 937	138 395	2 809 572	208 200	2 886 768	9 157 054
Chemical	12 777	1 714	302 006	417 400	2 056 660	59 100	1 775 070	202 358	1 550 602	6 377 686
Oil Products	262 995	139 472	3 925 584	1 931 852	3 314 687	229 893	2 362 790	310 331	2 009 966	14 487 570
LNG	10 084	0,03	29 665	1 454	306 807	24 807	246 375	15 959	213 698	848 850
LPG	0,09	0,07	1 174	829	337 905	97	297 817	18 840	263 437	920 098,47

Table 17 shows the total exports of each region, in million ton km, broken down to vessel class resolution. The columns gives the ton km export of each region while the rows gives the ton km transport of each vessel class.

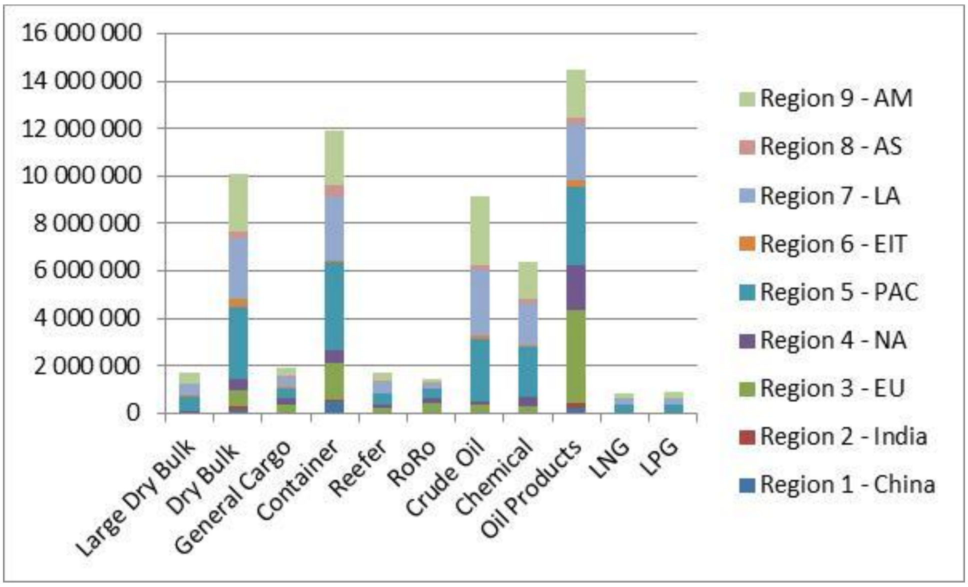


Figure 27 Interregional seagoing transport by vessel type (billion tkm)

Figure 27 illustrate the results shown in table 17. We see that the vessel class carrying oil products has the largest total ton km transport with 14,5 million million ton km. Second we have container vessels with about 11,9 million million tkm and third we have dry bulk with 10,1 million million tkm. Assessing the transport by oil product carrying vessels, we see that OECD Europe is the largest exporter of oil products measured in tkm. The second larger exporter is OECD pacific, third is Latin America and North America and Africa and the Middle East is roughly the same size. As we have seen in the previous graphs and tables, OECD Pacific, Latin America, Africa and the Middle East and, to some degree, Europe are the biggest importers and exporters, both in terms of euro value of production flows between the regions and in tkm transport. China and North America is not as dominating as first anticipated and the author expected to so China as a more dominant force on the export side and North America a more dominant player considering imports from other nations, especially from China.

Let's take a minute to compare figure 27 with figure 23 in 5.3.2. Figure 27, as we just saw, illustrate the exports, given in tkm, of each region broken down to ship class resolution. Figure 27, on the other hand, show the the exports of each region, given in euro value of the production flows, of each region. In figure 23 we saw that containerized shipping transport, by far, the most production flows measured in euro. Dry bulk comes in second while the other vessels, RoRo, chemical and oil products, in particular, carry relatively the same amount of value between the regions. In figure 27, assessing the tkm transport, we see a completely different picture. Here, Oil product carriers transport has the highest tkm transport with 14 487 570 million tkm. Container and Dry bulk have the second and third largest tkm transport with roughly 12 000 000 and 10 000 000 million tkm respectively. A reasonable explanation for these results lies in transportation distance and tonnage. Apparently, the euro value of products being shipped between the regions using oil product carriers, RoRo vessels and vessels who carry chemicals is much less than the combined tonnage and transport distance of the products.

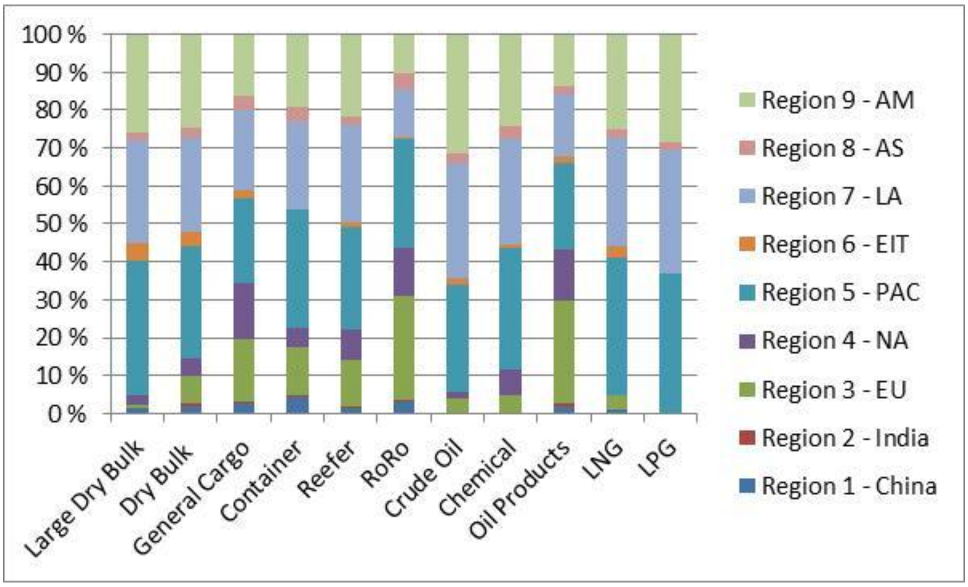


Figure 28 Interregional seagoing transport by vessel type (billion tkm)

Figure 28 shows the share countries utilizing the different vessel classes to export their goods. Again we see that OECD Pacific, Latin America and Africa and the Middle East, together with OECD Europe dominate the figure. Most of Europe's export is carried using RoRo and Oil product carriers while the exports of OECD Pacific, Latin America and Africa and the Middle East is distributed relatively evenly across all the vessel classes.

Looking at the share of exports transported by container vessels, we see a relatively high share is allocated to OECD Europe while China barely registers. We know that China exports a larger volume by Container than what Europe does, but the assumption that the price of the exports are equal in all regions changes this. The € value of Europe's container export is higher than the € value of Chinas Container export 111 000 million € to 275 000 million €, respectively, so assuming the same price for the two export flows translate into lower total tkm by container export from China than from Europe, giving somewhat distorted results.

5.4 Environmental Impacts

This section focus on assessing the Global Warming Potential(GWP), expressed in kg CO2-equivalents, of international maritime transport and international trade. The first part show the total GWP of all the activity, export and import between the 9 regions, the second part gives the GWP of international maritime transport between the regions while the third part gives the GWP of the total imports of each region distributed on the 11 ship classes.

5.4.1 Total Global Warming Potential

Table 18 Total GWP (Billion ton CO2-eq)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
Region 1 - China	9 049 621	91 116	117 370	172 547	286 000	5 974	99 841	41 590	88 085
Region 2 - India	22 572	2 264 491	45 204	41 902	30 876	4 027	15 882	6 375	11 393
Region 3 - EU	62 155	17 663	4 585 779	209 538	174 268	27 710	72 456	22 444	63 976
Region 4 - NA	61 859	9 246	163 541	7 503 037	158 202	4 762	50 228	28 253	38 572
Region 5 - PAC	300 627	40 323	198 795	211 800	3 890 566	10 570	513 309	93 051	460 889
Region 6 - EIT	68 633	12 780	334 333	102 400	137 653	1 721 506	58 063	17 133	48 543
Region 7 - LA	172 296	28 339	116 170	120 593	654 390	7 577	1 632 708	57 476	350 928
Region 8 - AS	55 259	7 702	40 403	52 675	153 146	1 815	80 626	708 186	72 202
Region 9 - AM	123 556	23 815	132 317	139 735	689 548	8 966	408 849	59 952	1 138 493
sum imports	866 956	230 983	1 148 133	1 051 191	2 284 084	71 402	1 299 253	326 273	1 134 588

Table 18 shows the total GWP of all the activity, export and import between the regions in billion ton CO_2-equivalents. The sum of GWP embedded in the imports of each region is seen in the bottom row of the table. To use China as an example, we that the total GWP embedded in the regions import is 866 956 billion CO2-equivalents. The GWP from the regions demand from its own sectors is given on the diagonal of the table, the regions export is given in the rows while the imports are given on the columns.

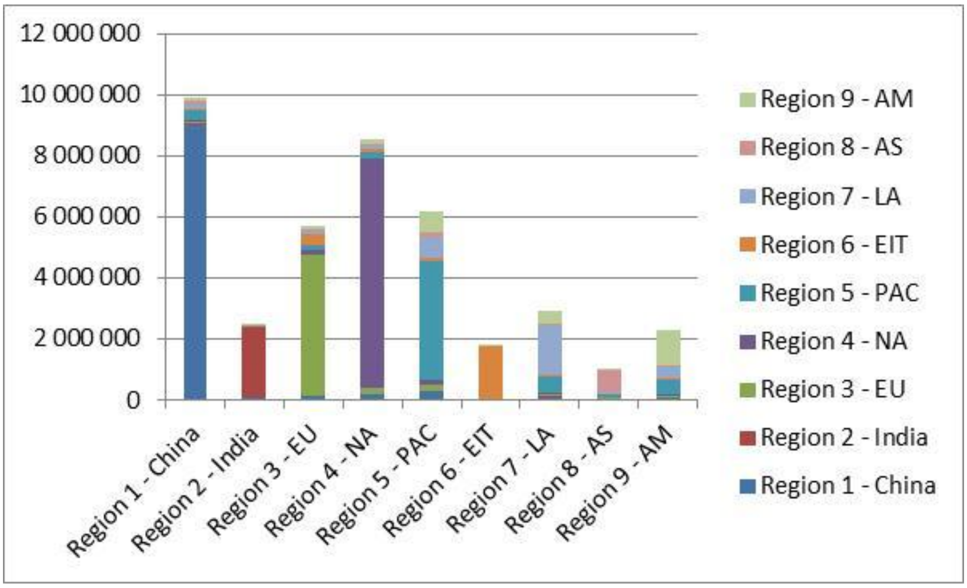


Figure 29 Total GWP (Billion ton CO2-eq)

From figure 29 we get a clearer picture of the total GWP from each region, the share of the GWP that is due to inter-industry demand, that demand from its own sectors and the share of GWP embedded in imports. As we can see, GWP due to inter-industry production is clearly the largest contributor to all of the regions total GWP, with imports only contributing to a relatively small share of the total GWP. China is the region with that produce the highest GWP of all the 9 regions, with North America a small step behind. OECD Pacific produce the 3rd largest GWP potential, just ahead of OECD Europe. Latin America, Economies in Transition and Africa and the Middle East all have a GWP potential around 2000 000 billion CO2-equivalents. Other Developing Asia is the region with the lowest contribution to global GWP with "only" 1 360 000 billion tons of CO2-eq.

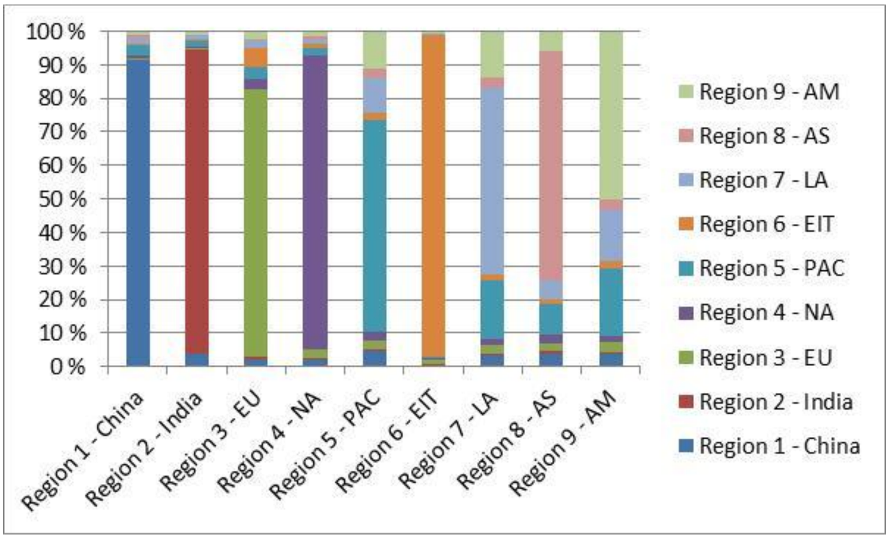


Figure 30 Share of total GWP

In figure 30 we clearly see that the inter-industry demands within each region is by far the biggest contributor to the total GWP. The only real exception is Africa and the Middle East where the share of GWP from production within the region is roughly the same size of GWP due to imports.

5.4.2 Global Warming Potential from Maritime Transport

Table 19 GWP from maritime transport (thousand ton CO2-eq)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
Region 1 - China	826	622	5 702	8 964	6 317	381	6 234	1 145	3 766
Region 2 - India	375	42	1 955	2 213	1 306	252	887	140	402
Region 3 - EU	26 555	8 221	8 491	70 258	69 284	1 776	21 568	7 784	17 811
Region 4 - NA	15 459	4 577	33 060	6 143	35 182	1 117	13 511	5 774	10 462
Region 5 - PAC	22 862	13 836	121 126	85 739	109 858	5 984	152 157	19 849	94 542
Region 6 - EIT	4 831	833	5 670	3 859	9 457	140	3 272	758	2 601
Region 7 - LA	38 089	14 454	58 168	76 702	225 281	3 182	54 440	21 367	81 202
Region 8 - AS	5 234	891	8 494	10 976	15 322	390	9 861	946	5 877
Region 9 - AM	27 890	8 426	66 942	109 719	171 361	3 615	97 612	14 897	38 076
sum import	**141 294**	**51 860**	**301 117**	**368 430**	**533 510**	**16 697**	**305 101**	**71 714**	**216 662**

Table 19 gives the GWP of maritime transport between the regions in thousand tons. Since it is assumed that each region builds in own fleet required to import the goods they demand, we see the GWP of construction required vessels on the diagonal of the table. The bottom row gives the total GWP from maritime transport due to each regions import demand. The GWP of the regions import is given in the columns while the GWP due to export is read from the rows. OECD Pacific has the largest GWP from building its required fleet with an emission of 109 858 thousand tons of CO2-equivalents, second comes Latin America with 54 440 thousand tons of CO2 equivalents while OECD Europe and North America have a GWP between 8 500 and 6 150 thousand tons of CO2-equivalents, respectively.

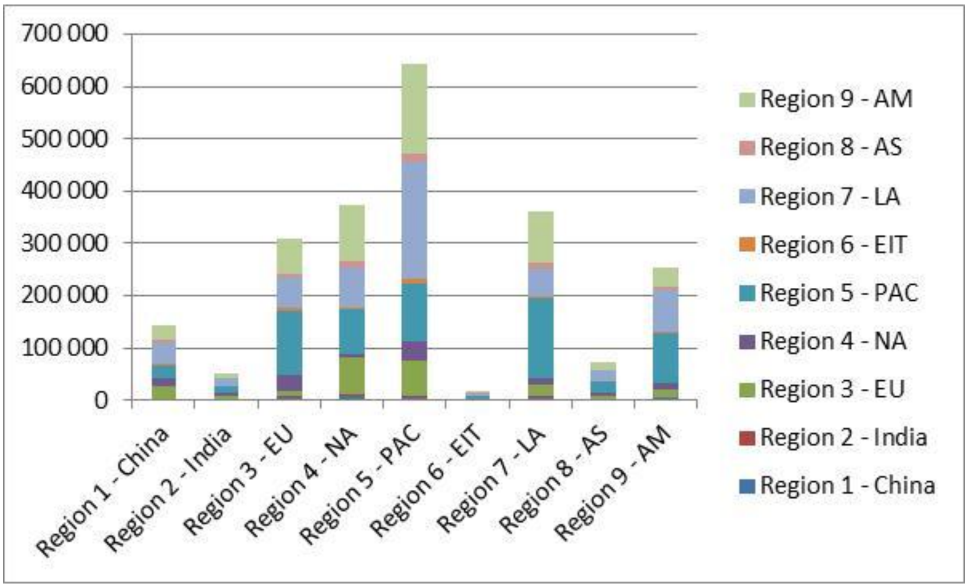


Figure 31 GWP from maritime transport (thousand ton CO2-eq)

From figure 31 it becomes evident that OECD Pacific leads the way in terms of GWP from maritime transport and fleet construction with a total GWP of roughly 630 000 thousand tons of CO_2-equivalents, of which 533 515 thousand tons are due to seagoing transportation of the regions imports. The bulk of GWP from OECD Pacific imports are due to seagoing transportation of goods from Latin America and Africa and the Middle East, and they account for 225 000 and 171 000 thousands of tons, respectively.

North America comes in second with a GWP of about 390 000 thousand tons CO_2-equivalents where 368 000 thousand tons of CO2-eq are due to seagoing transportation of imports, just ahead of Latin America. OECD Europe have a total GWP of 310 000 thousand tons where 301 000 thousand tons are a consequence of the seagoing transport of the regions imports. The share of GWP of maritime transport due to imports from OECD Pacific is quite significant for all the regions. The same is evident for Africa and the Middle East and Latin America but on a smaller scale.

The bulk of GWP due to seagoing transport of Europe’s exports are allocated to North America and OECD Pacific at 70 000 thousand tons of CO_2-equivalents.

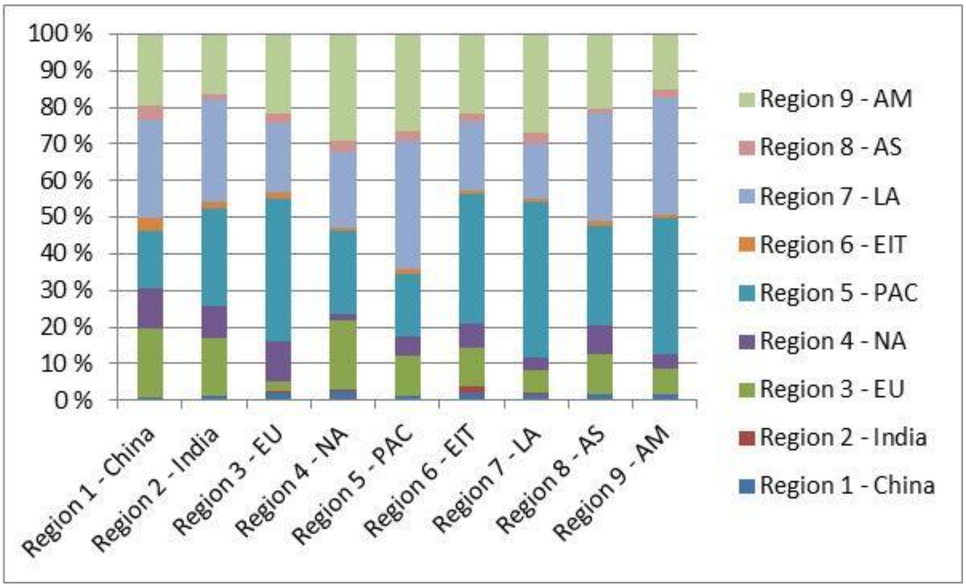


Figure 32 Share of GWP from maritime transport

Assessing figure 32 we see that Latin America and Africa and the Middle East both contribute to a rather large share of each of the other regions GWP imports. This may be due to their geographic position, relatively far away from the other regions. OECD Pacific has biggest share of GWP due to maritime transportation of imported goods in all regions except for China. This may be a consequence of the two regions close geographical proximity. GWP due to seagoing transport of goods imported from Europe contribute to about 15 % on average in each of the regions.

5.4.3 Global Warming Potential embodied in trade, vessel resolution

Table 20 GWP by vessel type (Thousand ton CO2-eq)

	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA	Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM	Sum
Large Dry Bulk	335	91	1 443	616	3 711	770	2 310	416	1 744	**11 436**
Dry Bulk	5 226	3 543	11 669	12 024	36 694	1 791	24 699	4 336	17 828	**117 809**
General Cargo	6 517	4 012	12 155	10 997	32 596	771	17 912	4 028	13 094	**102 082**
Container	26 447	6 212	30 351	39 215	105 942	2 270	72 020	13 060	53 121	**348 637**
Reefer	4 411	609	9 808	12 982	48 042	1 561	28 653	4 106	19 586	**129 757**
RoRo	922	133	1 308	2 017	2 627	131	1 963	321	1 447	**10 869**
Crude Oil	58 793	23 596	180 206	226 999	171 145	5 539	70 602	26 213	49 646	**812 738**
Chemical	4 837	1 426	10 492	13 394	28 964	523	18 428	3 921	14 697	**96 681**
Oil Products	31 484	11 337	34 719	43 939	88 365	2 510	58 271	13 307	38 198	**322 129**
LNG	928	338	3 430	1 936	7 224	572	4 892	895	3 453	**23 668**
LPG	1 395	563	5 537	4 310	8 201	260	5 351	1 112	3 848	**30 576**

Table 20 shows the GWP, in thousand ton, of total seagoing transport of imports to each region distributed on the 11 vessel classes. The rows show the GWP of each vessel to the different regions while the last column show the total GWP of each vessel. To give an example, the consequence of Chinese import demand is a GWP 5 226 thousand tons from Dry Bulk carriers, 6 517 thousand tons from General Cargo vessels and 26 447 thousand tons from Container vessels, given in CO2-equivalents. The sum of GWP of transport by Dry Bulk carriers are 117 809 thousand tons, for General Cargo vessel its 102 082 thousand tons and for Container vessels its 348 637 thousand tons of CO2-equivalents.

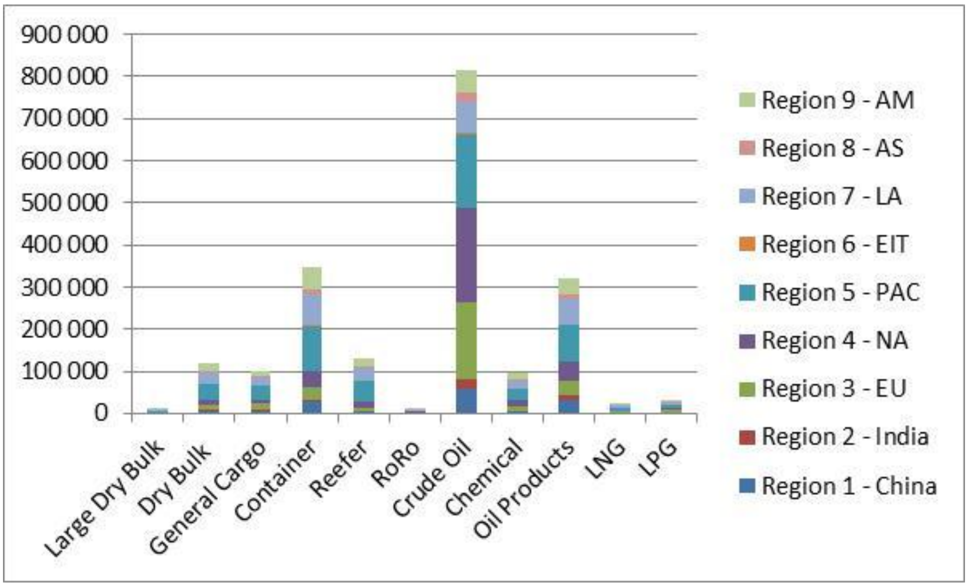


Figure 33 GWP by vessel type (Thousand ton CO2-eq)

Figure 33 shows that its Crude oil vessels that have the highest total GWP with 812 738 thousand tons of CO2-equivalents. OECD Europe, North America and OECD Pacific as the regions with the highest share of oil imports, with a GWP of 180 206, 226 999 and 171 145 thousand tons of CO2-equivalents, respectively. Comparing the total GWP of Crude oil carriers with the GWP reported by Lindstad et.al 2012 in the paper "The Importance of economies of scale for reductions in greenhouse gas emissions from shipping", from table 21, Crude Oil carriers emit roughly 98 million tons of CO2-equivalents each year, which is 8 times lower than the GWP obtained in this study. The emission intensities for Crude Oil Carriers used in this report are the same as the one found in the Lindstad et.al 2012 paper and it is therefore probable that the EXIOBASE dataset estimate a higher trade of crude oil in combination with a more diverse Crude Oil Carrying fleet in the Lindstad paper, with larger ships that has lower emissions per ton km transport. Seagoing transport of containerized goods have the second largest GWP after Crude Oil carriers, with transport of Oil products not far behind.

Table 21 GWP by vessel type (Thousand ton CO2-eq)

Total GWP fleet (million ton) CO2-eq		
	Lindstad et. al 2012	EXIOBASE Results
Dry Bulk	184	129
General Cargo	100	102
Container	261	348
Reefer	22	129
RoRo	37	10
Crude Oil	98	812
Chemical	49	96
Oil Products	31	322
LNG	29	23
LPG	14	30
Sum	825	2006

The first column in table 21 gives the GWP of the fleet in million ton CO_2-equivalents found in the paper by Lindstad et al. 2012 while the second column gives the GWP found in this report. We see that the GWP for Dry Bulk(184 – 129), General Cargo(100 - 102), container(261 – 348), LNG(29 – 23), LPG(14 – 30) and Chemical carriers (49 – 96) all are in the same range. The GWP allocated to reefer transport is in are of 6 times higher than the GWP found in the Lindstad paper while the GWP from Oil Product carriers are 10 times higher. In this study, both Reefer and Oil Product carriers transport a wide range of products, which could be higher than the case in the real world. This, combined with the assumption that all transport between regions are by seagoing vessels, can explain the high values. We also know that perishable goods are transported in an increasing degree by Container vessels in modified containers with refrigeration capabilities, a fact that is not taken into consideration in this report. Accounting for this would lower the GWP from reefer transport

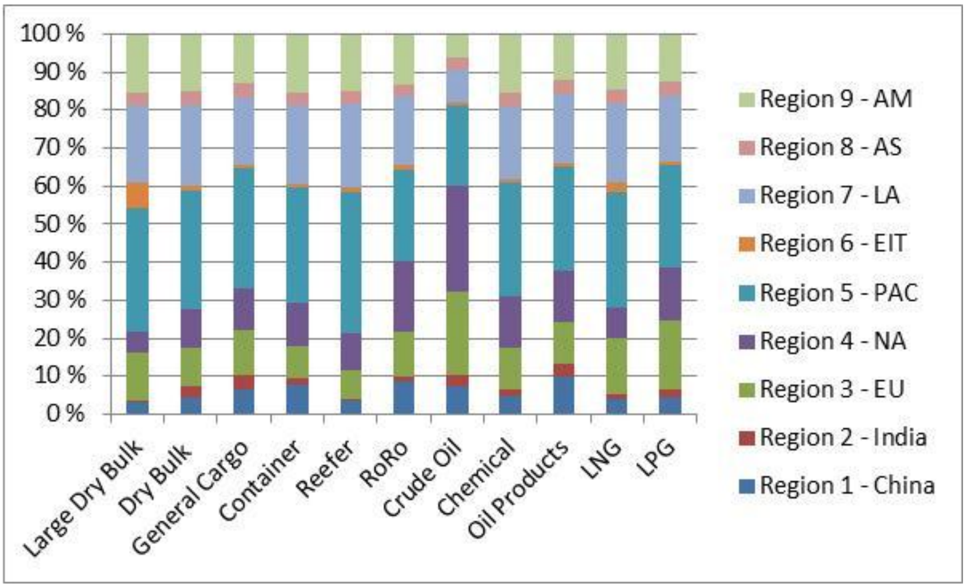


Figure 34 Share of GWP by vessel type

From figure 34 we see that the GWP from seagoing transport of imports are relatively similar on the different vessels. Europe, North America and OECD Pacific are the three regions that have the highest GWP from importing crude oil. Latin America and Africa and the Middle East have relatively similar share across the board, 20% and 15 % respectively.

5.4.4 GWP from Maritime Transportation vs. Total GWP

Table 22 Comparison of GWP by region (million ton CO2-eq)

Million ton CO2-eq	Region 1 - China	Region 2 - India	Region 3 - EU	Region 4 - NA
Total imports	867 424 277	231 023 142	1 149 752 773	1 054 777 245
Total seagoing trans.	141	52	301	368
GWP share	0,0000163 %	0,0000224 %	0,0000262 %	0,0000349 %

Region 5 - PAC	Region 6 - EIT	Region 7 - LA	Region 8 - AS	Region 9 - AM
2 284 804 481	71 428 816	1 299 654 682	326 392 031	1 134 864 038
534	17	305	72	217
0,0000234 %	0,0000234 %	0,0000235 %	0,0000220 %	0,0000191 %

Table 22 gives the GWP, in million ton CO_2-equivalents, of total imports, i.e. the emissions of CO_2-equivalents from producing the imported goods, the GWP of seagoing transport required to transport said imported goods to the region and the share of GWP of seagoing transport of the GWP of total imports. North America, OECD Europe, OECD Pacific and Latin America are the regions with the highest GWP from seagoing transportation with 368, 301, 534 and 305 million tons of CO_2-equivalents, respectively. However, the GWP share of seagoing transport is microscopic for all regions, when it should be between 3%-6%(UNCTAD 2012).

The GWP of seagoing transport is calculated to be between 825 and 1 0046 million tons(IMO 2009, Lindstad, Asbjørnslett et al. 2012) and contribute to between 3%-5% of total world GWP(IMO 2009, Shipbuilding 2010, Lindstad, Asbjørnslett et al. 2011, Lindstad, Asbjørnslett et al. 2012, UNCTAD 2012).

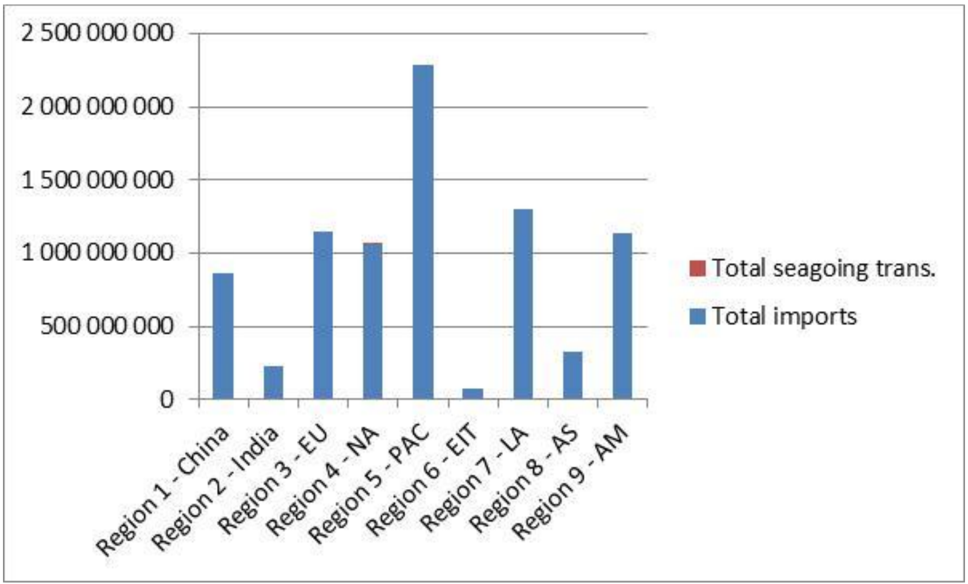


Figure 35 Comparison of GWP by region (million ton CO2-eq)

From figure 35 it is evident that OECD Pacific has the highest GWP embedded in imports of all the regions. Second comes Latin America, closely followed by OECD Europe, North America, and Africa and the Middle East. GWP from seagoing transport as share barely registers in the figure.

Table 23 Comparison of Total GWP (million ton CO2-eq)

(million ton CO2-eq)	GWP	Share of seagoing transport on World GWP
World	40 907 249 753	
Maritime Transport	2 006	0,0000049 %

The same trend can be seen in table 23. Total world GWP is 40 907 249 753 million tons CO_2-equivalents while GWP from Maritime transport is 2006 million tons CO_2-equivalents.

The share of total GWP from maritime transport is 0,0000049%, not even close to 3,3% share reported by IMO 2009(IMO 2009). Models of global production, trade and economic activity like the EXIOBASE dataset are extremely useful when it comes to assess inter-industry requirements between sectors from different regions or to try to get an image of the GWP of seagoing transport. The model is constructed by putting together millions of different pieces of information into a coherent system. Some of the pieces are accurate, measured tables of flows that matches those of the real world, but most of the information that the EXIOBASE dataset builds on are based on many assumptions and approximations. This leads to inaccuracies when the entire EXIOBASE dataset is used to calculate total GWP of all economic activities, which in this case resulted in a GWP that was too high.

6 Discussion

The main objective of this report was to improve the representation of international maritime transport in the EXIOBASE dataset by integrating 11 individual ship class inventories into the MRIO dataset. This report then calculated the global warming potential of seagoing transport as a consequence of interregional trade by an Environmentally Extended Multi-Regional Input-Output(EE MRIO) approach.

The results demonstrate that the total GWP from international maritime trade is calculated to 2006 million tons of CO_2-equivalents. This is about twice as much as the GWP that is reported by IMO and H.Lindstad(IMO 2009, Lindstad, Asbjørnslett et al. 2012, UNCTAD 2012) which is calculated to between 825 and 1 046 million tons of CO_2-equivalents. This report assumes that all trade between the 9 world regions is transported by seagoing vessels and so excludes airfreight, rail and road transportation. The consequence of this assumption is higher GWP from maritime transport, which the results demonstrate. On the other hand, it is also assumed that there is no seagoing transportation within each region. This does not have much effect of inter-industry trade in OECD Europe and North America for example, but for EXIOBASE regions like OECD Pacific, which is comprised of island states such as Japan, Australia and New Zealand, the effect on GWP might be bigger. As discussed in section 5.3.1, the trade within the OECD Pacific region is significant, and contribute to balance out some of the higher GWP due to assumption of seagoing transport being the only form of transport between regions.

The results demonstrate that North America, OECD Europe and OECD Pacific have the highest GWP embodied in imports from seagoing trade. This is expected as these are all regions of highly industrialized countries with a high level of household consumption and manufacturing industries with a high import demand for raw materials from less developed regions. It is interesting to note that Latin America actually has a higher GWP embodied in imports from maritime transport than OECD Europe. This may be a result of extensive transportation distances, seeing that the bulk of the regions imports are transported all the way from Europe, China and OECD Pacific, but it also implies a higher household and industry demand than what I expected.

This report assumes that each region builds the fleet required to transport the amount import demanded by its industries. The GWP of this shipbuilding is seen on the diagonal of table 19 in section 5.4.1 and reflects the ton km of import demanded in each region.

This study found that seagoing transport by crude oil carriers produced the biggest GWP and is responsible for the emissions of 812 million tons of CO_2-equivalents, 40% of the total GWP of 2006 million tons CO_2-equivalents. This GWP is 8 times higher than the one reported by (Lindstad, Asbjørnslett et al. 2012) at 98 million tons CO_2-equivalents. As was discussed in section 5.4.3 it is probable that the EXIOBASE dataset estimate a higher trade of crude oil in combination with a more diverse Crude Oil Carrying fleet in the Lindstad.et al paper, with larger ships that has lower emissions per ton km transport than the one used in this report. The GWP of the other ship classes where comparable with the Lindstad et. al paper. The exceptions, other than crude oil carriers, are reefer vessels and oil product carriers who had 20% higher GWP. It is assumed that crude oil carriers only transport crude oil with OECD Europe, North America and OECD Pacific as largest importers and Africa and the Middle East as the largest exporter of the product.

Looking at the share of exports transported by container vessels in section 5.3.2, figure 27, we see a relatively high share is allocated to OECD Europe while China barely registers. We know that China exports a larger volume by Container than what Europe does, but the assumption that the price of the exports are equal in all regions changes this. The € value of Europes container export is higher than the € value of Chinas Container export 111 000 million € to 275 000 million €, respectively, so assuming the same price for the two export flows translate into lower total tkm by container export from China than from Europe, giving somewhat distorted results. It is therefore suggested that any future study of seagoing transport using the EE MRIO EXIOBASE dataset employ differentiated price tables to further improve the model.

As mentioned in the introduction maritime transport represent approximately 3,3 % of world GWP. This report found that only 0,0000049% of world GWP is due to seagoing transport operations, a quite significant difference. This difference, as discussed in section 5.4.4, might be a consequence of how the EXIOBASE dataset is constructed.

This report finds that the total ton km transported by seagoing vessels is lower than what is found in the study by (Lindstad, Asbjørnslett et al. 2012) and the UNCTAD Review of maritime transport 2012. This result is surprising, considering the fact that this analysis assumes that all interregional trade is transported by sea. These contradictions are not properly assessed in this report, and I propose that they are considered in further studies.

A key component of this report is the correspondence matrix, i.e. the G matrix described in section 4.2.1, that I developed in dialogue with co-supervisor Haakon Lindstad. The G matrix allocates products and goods to the vessels that carry them, and while it is assumed that some vessels are capable of carrying several different types of goods, such as container vessels, it is assumed that no two vessels carry the same good. This is a simplification and we know different types of ships can have overlapping carrying capabilities(Haakon Lindstad 2012). The most versatile of all ships described in this report is the container vessel, which can carry anything from consumer goods to chemicals, perishable products, cars to cardboard all on the same voyage. Other vessels, such as general cargo vessels, bulk carriers and RoRo vessels can all carry some of the same goods(Haakon Lindstad 2012). It is possible to improve the accuracy of the model if data on the distribution of overlapping transport where researched and collected, which the author encourages.

This report has also assumed that the carrying capacity of each vessel is utilized 100%. The utilization factor when loaded can vary greatly between vessels, from up to 98% for crude oil tankers down to 70% utilization for certain container vessels. Neither is duration and number of ballast voyages per vessel, which would further reduce the carrying efficiency of each vessel and most likely increase GWP from seagoing trade if these factors were accounted for in the model.

January 1st of this year, mandatory new measures aimed at improving the energy efficiency of international shipping and reduce emissions of greenhouse gasses entered into force. Energy Efficiency Design Index (EEDI), is made mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships (IMO 2009). The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy-efficiency level is reached, ship designers and builders would be free to use the most cost-efficient solutions for the ship to comply with the regulations. The SEEMP establishes a mechanism for operators to improve the energy efficiency of ships. Ships are required to keep on board a ship specific

Ship Energy Efficiency Management Plan (SEEMP). It is indicated that these measures will reduce the ton km transport by almost 40% versus “business as usual” in 2050, and that EEDI will contribute to 75% of the reduction(Lindstad, Asbjørnslett et al. 2012). It would be interesting to try to implement the effects of these measures into to improved MRIO dataset to see if the GWP is indeed reduced.

7 Conclusion

This report has improved the EXIOBASE dataset by integrating life cycle inventories of 11 individual ship classes. GWP from seagoing transport was calculated by performing an Environmentally Extended Multi-Regional Input-Output(EE MRIO) approach. This work has made it possible to more accurately model the Global Warming Potential(GWP) of interregional seagoing transport. My work has also made it possible to assess the GWP contribution by each vessels, both for total interregional transport and as a product of the import demand of one or more regions.

The report found that the total GWP from international maritime trade is 2.006 billion tons of CO_2-equivalents, a figure that is approximately twice as large those found in other studies (IMO 2009, Lindstad, Asbjørnslett et al. 2012, UNCTAD 2012).

The results demonstrate that North America, OECD Europe and OECD Pacific have the highest GWP embodied in imports from seagoing trade. The vessel class with the largest GWP is crude oil tankers, accounting for 40% of the total fleet GWP with OECD Europe and North America as the greatest crude oil importers.

The study found that total GWP from interregional shipping account for a negligible share of total world GWP. This result does not coincide with results from other studies and may indicate aggregation errors in the EXIOBASE dataset.

This report finds that the total ton km transported by seagoing vessels is lower than what is found in the study by (Lindstad, Asbjørnslett et al. 2012) and the UNCTAD Review of maritime transport 2012. This result is surprising, considering the fact that this analysis assumes that all interregional trade is transported by sea. These contradictions are not properly assessed in this report, and I propose that they are considered in further studies.

7.1 Quality of data

This report assumes that all interregional transport is carried out by seagoing vessels and that there is no seagoing transport within each region. These simplifications produce inaccuracies that do not coincide with real world scenarios as they exclude transport by road, rail and air in addition to excluding maritime transport within regions comprised of island states, such as OECD Pacific. The report has an optimistic approach regarding the load utilization and ballast voyages of each vessel, as it is assumed that the load utilization is 100% for all ships and that no ballast voyages occur.

As has been discussed, the report assumes that no two vessels carry the same good, even though this is the case in the real world. A more accurate picture of the distribution of GWP per vessel due to interregional transport may be acquired if this fact is taken into account.

Price of transported goods are assumed to be the same, no matter where the product is produced. As we have seen in section 5.3.2 this assumption produce inaccuracies. We can reduce these inaccuracies by implementing regional specific price vectors that account for difference in the price of goods produced in the different sectors.

The stressors intensities, i.e. CO_2 emission per ton km transport, were carefully selected by considering vessel size and fleet composition in the report by (Lindstad, Asbjørnslett et al. 2012) and give a good estimation of fleet emissions.

All things considered, this report produced results that, for the most part, are in the same range as the data found in other studies and I am impressed with the capabilities and possibilities that the EXIOBASE dataset have.

7.2 Further study

As mentioned in the discussion, further study is encouraged to improve the cargo correspondence matrix, i.e. the G-matrix, to more accurately model the ton km and GWP distribution between each vessel. Steps should also be taken to account for capacity utilization when the vessel loaded including the amount, number and length of ballast voyages.

An interesting but data intensive proposition is to implement regional specific price vectors that account for difference in the price of goods produced in the different sectors. This may in turn help to more accurately model export and import volumes in interregional trade, and the related GWP of maritime transport.

In this report it is assumed that all interregional trade is transported by seagoing vessels, and that there is no maritime transport within each region. This is the assumption that may have the biggest impact on the result, and it is encouraged that future studies move away from this simplification by including other modes of transportation and domestic seagoing transport.

This report did not assess the GWP of interregional maritime transport of individual goods. It would be interesting to see which products generate the most GWP due to seagoing transport, and which regions contribute to the import of such goods.

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9 Appendix

Table 24 Commodity Prices in € per ton

Sector/Activity	Commodity Price Data €/Metric ton
Paddy rice	439
Wheat	248
Cereal grains nec	210
Vegetables, fruit, nuts	1 014
Oil seeds	949
Sugar cane, sugar beet	60
Plant-based fibers	1 496
Crops nec	191
Cattle	2 127
Pigs	1 565
Poultry	1 716
Meat animals nec	3 338
Animal products nec	6 366
Raw milk	306
Wool, silk-worm cocoons	9 594
Products of forestry, logging and related	606
Fish and other fishing products; services	4 682
Coal and lignite; peat (10)	74
Crude petroleum and services related to	615
Natural gas and services related to natur	162
Other petroleum and gaseous materials	693
Uranium and thorium ores (12)	74 648
Iron ores	120
Copper ores and concentrates	1 297
Nickel ores and concentrates	647
Aluminium ores and concentrates	566
Precious metal ores and concentrates	327 600
Lead, zinc and tin ores and concentrates	3 265
Other non-ferrous metal ores and conce	19 968
Stone	243
Sand and clay	273
Chemical and fertilizer minerals, salt and	376
Products of meat cattle	3 338
Products of meat pigs	5 094

Products of meat poultry	1 716
Meat products nec	5 094
Products of Vegetable oils and fats	858
Dairy products	1 482
Processed rice	420
Sugar	359
Food products nec	5 094
Beverages	1 170
Fish products	4 682
Tobacco products (16)	3 769
Textiles (17)	4 100
Wearing apparel; furs (18)	193 422
Leather and leather products (19)	1 695
Wood and products of wood and cork (ex	606
Pulp, paper and paper products (21)	629
Printed matter and recorded media (22)	4 700
Coke oven products	193
Motor spirit (gasoline)	730
Kerosene, including kerosene type jet fu	788
Gas/Diesel Oil	792
Heavy Fuel Oil	546
Petroleum gases and other gaseous hydr	1 491
Other petroleum products	495
Nuclear fuel	72 223
Chemicals, chemical products and man-n	199
Rubber and plastic products (25)	2 374
Glass and glass products	16 538
Ceramic goods	3 034
Bricks, tiles and construction products, ir	400
Cement, lime and plaster	75
Other non-metallic mineral products	376
Basic iron and steel and of ferro-alloys ar	3 440
Precious metals	57 988 710
Aluminium and aluminium products	1 560
Lead, zinc and tin and products thereof	6 903
Copper products	6 310
Other non-ferrous metal products	138
Foundry work services	0
Fabricated metal products, except machi	3 510
Machinery and equipment n.e.c. (29)	6 474

Office machinery and computers (30)	53 976
Electrical machinery and apparatus n.e.c.	7 410
Radio, television and communication eq	23 400
Medical, precision and optical instrumer	113 609
Motor vehicles, trailers and semi-trailers	20 000
Other transport equipment (35)	15 000
Furniture; other manufactured goods n.e	2 706
Metal secondary raw materials	0
Non-metal secondary raw materials	0
Electricity from coal	0
Electricity from coal w ccs	0
Electricity from gas	0
Electricity from gas w ccs	0
Electricity from biomass&waste	0
Electricity from biomass w ccs	0
Electricity from oil	0
Electricity from nuclear	0
Electricity from hydro	0
Electricity from ocean	0
Electricity from geothermal	0
Electricity from solar pv	0
Electricity from solar csp	0
Electricity from wind onshore	0
Electricity from wind offshore	0
Transmission services of electricity	0
Distribution and trade services of electri	0
Manufactured gas and distribution servic	0
Steam and hot water supply services	0
Collected and purified water, distributio	0
Construction work (45)	0
Sale, maintenance, repair of motor vehic	0
Retail trade services of motor fuel	0
Wholesale trade and commission trade s	0
Retail trade services, except of motor ve	0
Hotel and restaurant services (55)	0
Railway transportation services	0
Other land transportation services	0
Transportation services via pipelines	0
Sea and coastal water transportation ser	0
Inland water transportation services	0
Air transport services (62)	0
Supporting and auxiliary transport servic	0
Post and telecommunication services (64	0
Financial intermediation services, excep	0
Insurance and pension funding services,	0
Services auxiliary to financial intermedia	0
Real estate services (70)	0
Renting services of machinery and equip	0
Computer and related services (72)	0
Research and development services (73)	0
Other business services (74)	0

Table 25 Sources for Price assumptions

Sector/Activity	Comment/source
Paddy rice	WB(World Bank)
Wheat	WB
Cereal grains nec	WB Average of barley and Maize
Vegetables, fruit, nuts	WB Oranges and Groundnuts
Oil seeds	Rapeseed oil, http://www.indexmundi.com/commodities/?commodity=rapeseed-oil&months=12
Sugar cane, sugar beet	Sugar Beet, US 2011, http://usda01.library.cornell.edu/usda/nass/CropValuSu//2010s/2013/CropValuSu-02-15-2013.pdf
Plant-based fibers	Cotton, http://www.bloomberg.com/markets/commodities/futures/agriculture/ (Usd/lb 87,68)
Crops nec	Oats, http://www.bloomberg.com/markets/commodities/futures/agriculture/ (USd/bu 357,75)
Cattle	Live Cattle, http://www.bloomberg.com/markets/commodities/futures/ (USd/lb 122,68)
Pigs	Lean Hogs, http://www.bloomberg.com/markets/commodities/futures/agriculture/ (USd/lb 91,73)
Poultry	WB chicken
Meat animals nec	WB Beef
Animal products nec	Guts, bladders stomach, Eurostat
Raw milk	http://www.indexmundi.com/commodities/?commodity=class-iv-milk
Wool, silk-worm cocoons	Greasy wool, http://www.bloomberg.com/markets/commodities/futures/agriculture/
Products of forestry, loggi	WB
Fish and other fishing pro	Nor farmed salmon http://www.indexmundi.com/commodities/?commodity=fish&months=12
Coal and lignite; peat (10)	WB Australia
Crude petroleum and serv	WB 1mt Crude = 7,33bbl
Natural gas and services r	Natural Gas, http://www.bloomberg.com/energy/
Other petroleum and gase	Gasoil, http://www.bloomberg.com/energy/
Uranium and thorium ore	Uranium, http://www.indexmundi.com/commodities/?commodity=uranium&months=12
Iron ores	WB
Copper ores and concentr	Copper Matte, Eurostat
Nickel ores and concentra	Nickel Matte, Eurostat
Aluminium ores and conc	Alumina, http://www.indmin.com/MarketTracker/197171/AlumniaBauxite.html?id=ABR-C,AL-C
Precious metal ores and c	Silver Powder, Eurostat
Lead, zinc and tin ores and	average price Lead, tin,zinc (unwrought), Eurostat
Other non-ferrous metal	Tungsten powders, Eurostat
Stone	Granite and articles thereof, Eurostat
Sand and clay	Stone, sand, clay, Eurostat
Chemical and fertilizer mi	WB Phosphate rock
Products of meat cattle	WB Beef
Products of meat pigs	Sausages and similar prod, Eurostat
Products of meat poultry	WB chicken
Meat products nec	Sausages and similar prod, Eurostat
Products of Vegetable oil	Products of Vegetable oils and fats(China), Eurostat
Dairy products	Milk and Cream, Eurostat
Processed rice	Thai, 25% WB
Sugar	WB
Food products nec	Sausages and similar prod, Eurostat
Beverages	Beverages(China), Eurostat
Fish products	Nor farmed salmon http://www.indexmundi.com/commodities/?commodity=fish&months=12
Tobacco products (16)	Tobacco, party stemmed and dried, Eurostat
Textiles (17)	Cotton, Eurostat
Wearing apparel; furs (18	Mink, Eurostat
Leather and leather produ	Raw hides, dry salted, Eurostat

Wood and products of wo	WB
Pulp, paper and paper pro	Wood pulp, http://www.indexmundi.com/commodities/?commodity=wood-pulp
Printed matter and record	Books and brochures, Eurostat
Coke oven products	Chinese Coke, http://en.sxcoal.com/NewsDetail.aspx?cateID=170&id=83293&keyword=coke%20price
Motor spirit (gasoline)	Gulf Coast Gasoline, http://www.indexmundi.com/commodities/?commodity=gasoline
Kerosene, including keros	Kerosene Jet fuel, http://www.indexmundi.com/commodities/?commodity=jet-fuel
Gas/Diesel Oil	ULSD, http://www.indexmundi.com/commodities/?commodity=diesel
Heavy Fuel Oil	HFO, http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9041229&contentId=7075080
Petroleum gases and othe	LPG, http://www.mylpg.eu/stations/germany/prices
Other petroleum product	Asphalt, https://www.dot.ny.gov/main/business-center/contractors/construction-division/fuel-asphalt-steel-price-adjustments
Nuclear fuel	Uranium,http://www.metalbulletin.com/My-price-book.html
Chemicals, chemical prod	Chlorine, Eurostat
Rubber and plastic produ	WB Rubber TSR20
Glass and glass products	Cast glass and rolled glass, Eurostat
Ceramic goods	Ceramic parts, Eurostat
Bricks, tiles and construct	Tiles, Eurostat
Cement, lime and plaster	Eurostat, cement trade data
Other non-metallic miner	WB Phosphate rock
Basic iron and steel and o	Ferro-Chrome, http://www.metalbulletin.com/My-price-book.html
Precious metals	WB av. price Gold,plat & silver
Aluminium and aluminiur	WB Al. Ingots
Lead, zinc and tin and pro	WB av. Price of lead, zinc and tin
Copper products	WB ingots
Other non-ferrous metal	WB Nickel Ingots
Foundry work services	
Fabricated metal product	Fabricated metal products, except machinery and equipment (China), Eurostat
Machinery and equipmen	Other special-purpose machinery n.e.c
Office machinery and com	Computers and Periphical equipment, Eurostat
Electrical machinery and a	Electronical equipment, china, Eurostat
Radio, television and com	Consumer electronics(China(, Eurostat
Medical, precision and op	Sheets and plates of polarising material, Eurostat
Motor vehicles, trailers ai	Motor vehicles, trailers and semi-trailers (China), Eurostat
Other transport equipme	Transport vehicle, Eurostat
Furniture; other manufac	Seats, upholstered, wooden frame, Eurostat

Table 26 G-matrix, Vessel transport Correspondence matrix

Sector/Activity	Large Dry	Dry Bulk	General Cargo	Container	Reefer	Crude Oil	RoRo	Chemical	Oil Products	LNG	LPG
Paddy rice	0	1	0	0	0	0	0	0	0	0	0
Wheat	0	1	0	0	0	0	0	0	0	0	0
Cereal grains nec	0	1	0	0	0	0	0	0	0	0	0
Vegetables, fruit, nuts	0	0	0	0	1	0	0	0	0	0	0
Oil seeds	0	1	0	0	0	0	0	0	0	0	0
Sugar cane, sugar beet	0	0	0	1	0	0	0	0	0	0	0
Plant-based fibers	0	1	0	0	0	0	0	0	0	0	0
Crops nec	0	1	0	0	0	0	0	0	0	0	0
Cattle	0	0	0	0	1	0	0	0	0	0	0
Pigs	0	0	0	0	1	0	0	0	0	0	0
Poultry	0	0	0	0	1	0	0	0	0	0	0
Meat animals nec	0	0	0	0	1	0	0	0	0	0	0
Animal products nec	0	0	0	0	1	0	0	0	0	0	0
Raw milk	0	0	0	0	1	0	0	0	0	0	0
Wool, silk-worm cocoon	0	0	1	0	0	0	0	0	0	0	0
Products of forestry, log	0	0	0	1	0	0	0	0	0	0	0
Fish and other fishing pr	0	0	0	1	1	0	0	0	0	0	0
Coal and lignite; peat (1	1	0	0	0	0	0	0	0	0	0	0
Crude petroleum and se	0	0	0	0	0	1	0	0	0	0	0
Natural gas and services	0	0	0	0	0	0	0	0	0	1	0
Other petroleum and ga	0	0	0	0	0	0	0	0	1	0	1
Uranium and thorium or	0	1	0	0	0	0	0	0	0	0	0
Iron ores	1	0	0	0	0	0	0	0	0	0	0
Copper ores and concen	0	1	0	0	0	0	0	0	0	0	0
Nickel ores and concentr	0	1	0	0	0	0	0	0	0	0	0
Aluminium ores and con	0	1	0	0	0	0	0	0	0	0	0
Precious metal ores and	0	1	0	0	0	0	0	0	0	0	0
Lead, zinc and tin ores ar	0	1	0	0	0	0	0	0	0	0	0
Other non-ferrous meta	0	1	0	0	0	0	0	0	0	0	0
Stone	0	1	0	0	0	0	0	0	0	0	0
Sand and clay	0	1	0	0	0	0	0	0	0	0	0
Chemical and fertilizer n	0	1	0	0	0	0	0	0	0	0	0
Products of meat cattle	0	0	0	0	1	0	0	0	0	0	0
Products of meat pigs	0	0	0	0	1	0	0	0	0	0	0
Products of meat poultry	0	0	0	0	1	0	0	0	0	0	0
Meat products nec	0	0	0	0	1	0	0	0	0	0	0
Products of Vegetable o	0	0	0	0	0	0	0	0	1	0	0
Dairy products	0	0	0	0	1	0	0	0	0	0	0
Processed rice	0	1	0	0	0	0	0	0	0	0	0
Sugar	0	1	0	0	0	0	0	0	0	0	0
Food products nec	0	0	0	0	1	0	0	0	0	0	0
Beverages	0	0	0	1	0	0	0	0	0	0	0
Fish products	0	0	0	0	1	0	0	0	0	0	0
Tobacco products (16)	0	0	0	1	0	0	0	0	0	0	0
Textiles (17)	0	0	0	1	0	0	0	0	0	0	0
Wearing apparel; furs (1	0	0	0	1	0	0	0	0	0	0	0
Leather and leather proc	0	0	0	1	0	0	0	0	0	0	0
Wood and products of w	0	0	1	0	0	0	0	0	0	0	0
Pulp, paper and paper pr	0	0	1	0	0	0	0	0	0	0	0
Printed matter and recor	0	0	0	1	0	0	0	0	0	0	0
Coke oven products	0	1	0	0	0	0	0	0	0	0	0
Motor spirit (gasoline)	0	0	0	0	0	0	0	0	1	0	0
Kerosene, including kerc	0	0	0	0	0	0	0	0	1	0	0
Gas/Diesel Oil	0	0	0	0	0	0	0	0	1	0	0
Heavy Fuel Oil	0	0	0	0	0	0	0	0	1	0	0
Petroleum gases and oth	0	0	0	0	0	0	0	0	0	0	0
Other petroleum produc	0	0	0	0	0	0	0	0	1	0	0
Nuclear fuel	0	1	0	0	0	0	0	0	0	0	0
Chemicals, chemical pro	0	0	0	0	0	0	0	1	0	0	0
Rubber and plastic produ	0	0	0	1	0	0	0	0	0	0	0

Glass and glass products	0	0	0	1	0	0	0	0	0	0	0
Ceramic goods	0	0	0	1	0	0	0	0	0	0	0
Bricks, tiles and construc	0	0	0	1	0	0	0	0	0	0	0
Cement, lime and plaste	0	1	0	0	0	0	0	0	0	0	0
Other non-metallic mine	0	1	0	0	0	0	0	0	0	0	0
Basic iron and steel and	0	1	0	0	0	0	0	0	0	0	0
Precious metals	0	1	0	0	0	0	0	0	0	0	0
Aluminium and aluminiu	0	1	0	0	0	0	0	0	0	0	0
Lead, zinc and tin and pr	0	1	0	0	0	0	0	0	0	0	0
Copper products	0	1	0	0	0	0	0	0	0	0	0
Other non-ferrous meta	0	1	0	0	0	0	0	0	0	0	0
Foundry work services	0	0	0	0	0	0	0	0	0	0	0
Fabricated metal produc	0	0	0	0	0	0	1	0	0	0	0
Machinery and equipme	0	0	0	1	0	0	0	0	0	0	0
Office machinery and co	0	0	0	1	0	0	0	0	0	0	0
Electrical machinery and	0	0	0	1	0	0	0	0	0	0	0
Radio, television and co	0	0	0	1	0	0	0	0	0	0	0
Medical, precision and o	0	0	0	1	0	0	0	0	0	0	0
Motor vehicles, trailers	0	0	0	0	0	0	1	0	0	0	0
Other transport equipm	0	0	0	0	0	0	1	0	0	0	0
Furniture; other manufa	0	0	0	1	0	0	0	0	0	0	0
Metal secondary raw ma	0	0	0	0	0	0	0	0	0	0	0
Non-metal secondary ra	0	0	0	0	0	0	0	0	0	0	0
Electricity from coal	0	0	0	0	0	0	0	0	0	0	0
Electricity from coal w cc	0	0	0	0	0	0	0	0	0	0	0
Electricity from gas	0	0	0	0	0	0	0	0	0	0	0
Electricity from gas w ccs	0	0	0	0	0	0	0	0	0	0	0
Electricity from biomass	0	0	0	0	0	0	0	0	0	0	0
Electricity from biomass	0	0	0	0	0	0	0	0	0	0	0
Electricity from oil	0	0	0	0	0	0	0	0	0	0	0
Electricity from nuclear	0	0	0	0	0	0	0	0	0	0	0
Electricity from hydro	0	0	0	0	0	0	0	0	0	0	0
Electricity from ocean	0	0	0	0	0	0	0	0	0	0	0
Electricity from geother	0	0	0	0	0	0	0	0	0	0	0
Electricity from solar pv	0	0	0	0	0	0	0	0	0	0	0
Electricity from solar csp	0	0	0	0	0	0	0	0	0	0	0
Electricity from wind ons	0	0	0	0	0	0	0	0	0	0	0
Electricity from wind off	0	0	0	0	0	0	0	0	0	0	0
Transmission services of	0	0	0	0	0	0	0	0	0	0	0
Distribution and trade se	0	0	0	0	0	0	0	0	0	0	0
Manufactured gas and d	0	0	0	0	0	0	0	0	0	0	0
Steam and hot water sup	0	0	0	0	0	0	0	0	0	0	0
Collected and purified w	0	0	0	0	0	0	0	0	0	0	0
Construction work (45)	0	0	0	0	0	0	0	0	0	0	0
Sale, maintenance, repa	0	0	0	0	0	0	0	0	0	0	0
Retail trade services of r	0	0	0	0	0	0	0	0	0	0	0
Wholesale trade and co	0	0	0	0	0	0	0	0	0	0	0
Retail trade services, ex	0	0	0	0	0	0	0	0	0	0	0
Hotel and restaurant ser	0	0	0	0	0	0	0	0	0	0	0
Railway transportation s	0	0	0	0	0	0	0	0	0	0	0
Other land transportatio	0	0	0	0	0	0	0	0	0	0	0
Transportation services	0	0	0	0	0	0	0	0	0	0	0
Sea and coastal water tr	0	0	0	0	0	0	0	0	0	0	0
Inland water transporta	0	0	0	0	0	0	0	0	0	0	0
Air transport services (62	0	0	0	0	0	0	0	0	0	0	0

Supporting and auxiliary	0	0	0	0	0	0	0	0	0	0	0
Post and telecommunica	0	0	0	0	0	0	0	0	0	0	0
Financial intermediatio	0	0	0	0	0	0	0	0	0	0	0
Insurance and pension f	0	0	0	0	0	0	0	0	0	0	0
Services auxiliary to fina	0	0	0	0	0	0	0	0	0	0	0
Real estate services (70)	0	0	0	0	0	0	0	0	0	0	0
Renting services of mach	0	0	0	0	0	0	0	0	0	0	0
Computer and related se	0	0	0	0	0	0	0	0	0	0	0
Research and developm	0	0	0	0	0	0	0	0	0	0	0
Other business services	0	0	0	0	0	0	0	0	0	0	0
Public administration an	0	0	0	0	0	0	0	0	0	0	0
Education services (80)	0	0	0	0	0	0	0	0	0	0	0
Health and social work s	0	0	0	0	0	0	0	0	0	0	0
Collection and treatmen	0	0	0	0	0	0	0	0	0	0	0
Collection of waste	0	0	0	0	0	0	0	0	0	0	0
Incineration of waste	0	0	0	0	0	0	0	0	0	0	0
Landfill of waste	0	0	0	0	0	0	0	0	0	0	0
Sanitation, remediation	0	0	0	0	0	0	0	0	0	0	0
Membership organisatio	0	0	0	0	0	0	0	0	0	0	0
Recreational, cultural an	0	0	0	0	0	0	0	0	0	0	0
Other services (93)	0	0	0	0	0	0	0	0	0	0	0
Private households with	0	0	0	0	0	0	0	0	0	0	0
Extra-territorial organiza	0	0	0	0	0	0	0	0	0	0	0