CHALMERS

Driving Forces Behind Global Trade with Plastic Waste

Based on Reported Trade Statistics

Bachelor thesis for International Logistics Program

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Göteborg, Sweden, 2023

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Compressed plastic waste at a recycling center (Britannica ImageQuest). Published with permission.

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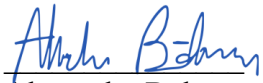
PREFACE

To complete this bachelor thesis as a part of the program Internationell Logistik (International Logistics) at Chalmers University of Technology, we were immensely aided by our supervisor, teachers and colleagues, and we want to especially express our gratitude to Kent Salo, whose supervision and suggestions were extremely helpful.

We also wish to thank Erik Ytterberg, our examinator who gave us notable recommendations and comments through the feedback session. Last but not least we are extremely grateful to all countless classmates, staff and Chalmers University. The three years have gone by quickly and we are undoubtedly indebted for all the advice that has led to this final thesis.

Without your guidance this wouldn't have been possible.



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SAMMANDRAG

Plast är idag en av de viktigaste klasserna av material som behövs för det moderna samhällets funktion. Det används i allt från vardagsprodukter till industriella ändamål, men för närvarande återvinns endast 10% av världens plast. Det är avgörande för både människan och naturens välmående att plasten hanteras ordentligt, och inte bara dumpas någonstans. Eftersom olika länder har olika stränga miljöregler, utnyttjar vissa detta till sin kortsiktiga ekonomiska fördel. Vissa länder genererar mycket plastavfall men hanterar det inte själva, utan exporterar det istället någon annanstans, i en process som som beskrivits som "föroreningsparadis".

Denna studie undersöker trenderna i plastavfallshandel ur perspektiven skillnader i miljöregler samt regionala obalanser i containerflöden. Dessutom är dess syfte att undersöka om dessa är drivande krafter och belysa de processer som orsakar och styr handeln. Data som används i rapporten kommer främst från FNs Comtrade-databas över världshandeln med gods med HS-koden 3915. Data samlades in för åren 2000-2022.

Resultatet av rapporten visar att miljöregler och obalanser i handeln kan påverka den globala plastavfallshandeln, men att det finns flera andra krafter som antagligen gör det mer – inte minst behovet av billiga råvaror i utvecklingsländers industri. Dessutom visar studien också hur det kinesiska importförbudet mot bland annat plastavfall har påverkat det globala handelsflödet. För att minska mängden plastavfall som deponeras i naturen skulle det behövas en enhetlig miljölagstiftning gällande plastavfall som når över gränserna. Utöver detta måste det göras stora finansiella investeringar i teknik och system för att kunna återvinna den plast som genereras i framtiden.

Nyckelord: Plastavfall, Global handel, Logistik, Pollution Haven Hypothesis, OECD Environmental Policy Stringency Index, Comtrade, Drivkrafter, Tompostionering av containrar

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ABSTRACT

Plastics are today a key material necessary for modern society to function, from everyday products to industrial products. At present only 10% of plastics globally are recycled, and it is vital that plastics are processed correctly and not just dumped somewhere. As different countries have different stringency in their environmental regulations, some use this as a competitive advantage. Certain countries generate a lot of plastic waste but do not handle it themselves, they instead export it to somewhere far away to be disposed of unsafely, creating a disparity between developed and developing countries, in a process that has been described in terms of pollution havens.

This study investigates the trends in global plastic waste trade through the lens of differences in environmental regulations and regional imbalances in container flows. Furthermore, its aim is to investigate whether they are the key driving forces and highlight the processes causing the trade. The data used in the report is mainly from the UN Comtrade database of world trade with goods with HS-code 3915. Data was collected for years 2000-2022.

The results of the report show that, while there are some indications that environmental regulations and trade imbalances affect global plastic waste trade, there are multiple other driving forces which likely have a bigger impact – not least the need for raw cheap materials in developing countries' industry. The study also shows how the Chinese import ban on plastic waste have had a clear impact on the global trade flow. To adequately handle the issue of plastic pollution, more effective international frameworks for regulating trade and recycling plastics are needed, as well as greater financial investments in the technology and systems necessary to process the increasing amounts of waste being generated..

Keywords: Plastic waste, Global trade, Logistics, Pollution Haven Hypothesis, OECD Environmental Policy Stringency Index, Comtrade, Driving forces, Empty Container Management

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ACRONYMS AND TERMINOLOGY

BRICS	Brazil, Russia, India, China, and South Africa. An organization dedicated to furthering these countries' development and interests.
Comtrade	A database and sorting tool on global trade, which has been constructed to help researchers and analysts access it as easily as possible.
EPSI	Environmental Policy Stringency Index: An index created by OECD to compare the level of environmental regulation of different countries.
HS	The Harmonized Commodity Description and Coding System: A worldwide system of number codes describing all possible traded goods, to simplify the customs handling.
OECD	The Organisation for Economic Co-operation and Development: An intergovernmental organization of market-democracies.
PHH	Pollution Haven Hypothesis: The hypothesis that heightened environmental restrictions in one country will cause companies there to offshore pollution-heavy aspects of their production to other, less strict, regimes.
PW	Plastic Waste: Plastic that has reached the end of its lifecycle and is scheduled for disposal or recycling.
RHH	Resource Hunting Hypothesis: The hypothesis that the leading cause of waste trade is the demand for cheap materials for industry in developing countries.
WTO	World Trade Organization: An organization of most of the world's countries to facilitate global trade.

1. Introduction

Plastics are one of the main classes of materials essential for modern society to function; they can be found in packaging, construction, textiles, furniture, and in electronics - to name just a few applications (Plastics Europe, 2022). As such, it is vital to have a functional way to handle used up plastic products sustainably. At present, only 10% of plastics globally are recycled, and even then typically only into a lower grade material (Geyer, 2020). This means that in the end, the plastics will be either incinerated to recover the energy or dumped (either in a landfill or simply in nature). All of these options have issues: burning plastics can negatively affect the health of nearby humans, local environment, and global climate, but since plastics are not particularly biodegradable, dumping does not actually remove them from the system and has its own bevy of health concerns (Verma et al., 2016). Additionally the different handling options of plastic waste (PW) can lead to different emissions like carbon dioxide, nitrogen dioxide and sulfur dioxide (Khoo, 2019).

Given all this, and a general public awareness of plastic pollution, it is not surprising that countries have tried to deal with this issue. One strategy that has been developed to mitigate plastic pollution locally is the trade with PW (Ray, 2008). The purported advantage of this is that it allows certain countries or regions to specialize and use their competitive advantages to cost-efficiently handle these and other types of waste, achieving economies of scale and high levels of technical competency. However, different countries have different levels of regulation and enforcement, which leads to some concern over plastics being shipped to less stringently regulated countries (Temurshoev, 2006). In these countries they are processed in unsafe ways, leading to large profits for the “recycling” companies, but significant risk to the health of local people and environment. In the end the problem just moved away, no longer where it was generated, but also not actually resolved.

1.1. Background

Herein follows a description of the background of the aim of the study.

1.1.1. Plastics: Production & Consumption

Plastics is a big family of materials which can be categorized in a variety of ways, ranging from soft plastics to hard plastics with different material characteristics (Geyer, 2020). Depending on the raw source material for plastics it can be categorized into fossil or recently grown biomass. The fossil based source includes natural gas and petroleum while biomass includes corn and sugarcane. Plastics that are used today originate from Polyvinyl Chloride, which was introduced during the 1920s, combined with other materials to become more usable. With it being applicable in a wide range of products and industrial sectors, being versatile, and having a relatively low cost, it has grown to be used in many everyday products. It is projected that by 2050 the total global cumulative primary non biodegradable plastic production since 1950 will reach 34 billion tonnes (Geyer, 2020).

Plastics began being mass produced at the beginning of the Second World War, but production massively increased during the postwar period with the advent of the modern consumer society (Plastics Europe, 2022). With great economic growth for many countries, the plastic production reached two million metric tonnes (Mt) by the year 1950. It has been estimated that between the years 1950 and 2017 there was a compound annual growth of 8.3%. There were some exceptions for the years 1975, 1980 and 2008 which correspond to the oil and/or financial crises.

Data shows that in 2017 global plastics production was 438 Mt and of that about 36% of total production was used for *Packaging*, which was the largest category by far (Geyer, 2020). The second largest category was *Building & Constructions* which represented 16% of total production followed by textile with 14%. The remaining 34% is shared by *Transportation*, *Electrical/Electronic*, *Consumer & Institutional Products*, *Industrial Machinery*, *Textiles,* and *Other.*

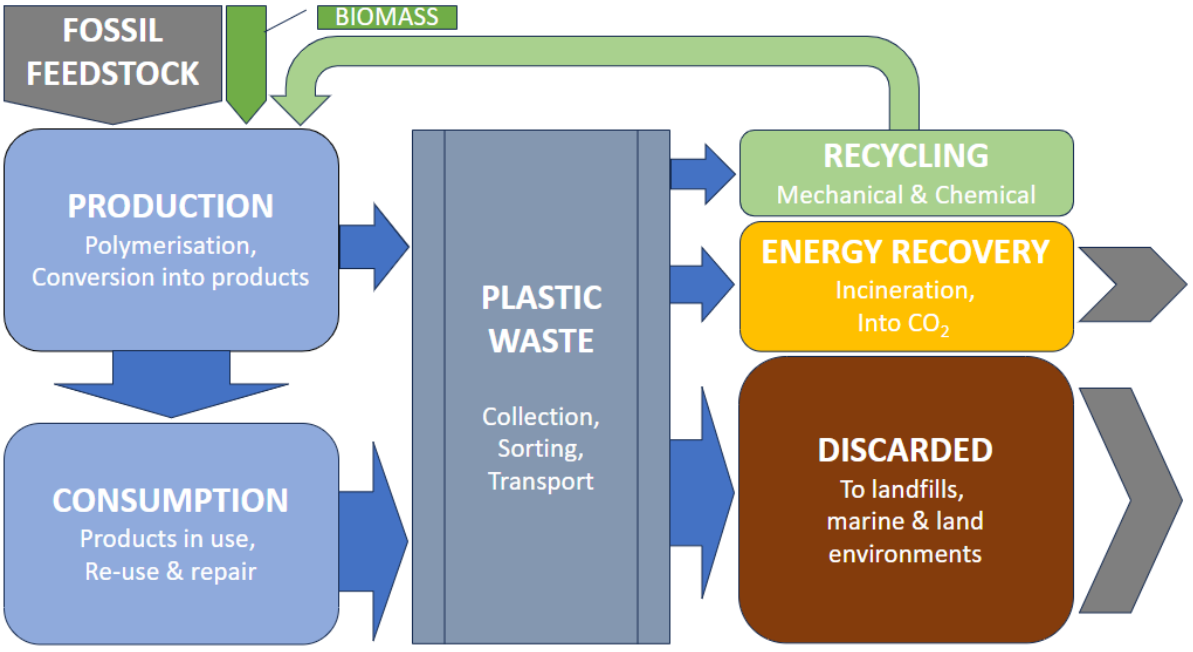
1.1.2. Plastics: Disposal & Hazards

There is an increased consumption of goods across the world (Salhofer et al., 2021). Production countries, which generally are located in the far east, have an increase of demand for plastics as material inputs to the production. This leads to the industry being dependent on importing raw materials or recovering the PW materials.

PW can be generated through different processes, for example as waste material generated during production activities, through wear and tear and the replacement of parts, or at the end of the life cycle of a product (Geyer, 2020). In the different stages where the PW is generated it is not always easy to define what specific class of PW it is, as it is typically contaminated. In addition to contamination, there are only a few options regarding what can be done to the PW. Options including repair, remanufacturing, refurbishing or reconditioning; however these options overlap as the definitions are not precise. Although there is an option to use thermal technologies to convert the PW into different types of fuels, this technology isn't widely used because of the cost inefficiencies (Geyer, 2020). Overall, it can be said that there are three possible ends a plastic product can meet: it can be discarded, repaired, or recycled (see Figure 1.). Between 1950 and 2017, over ¾ of all plastic produced was discarded (Geyer, 2020).

Figure 1. Basic Overview of Plastic Recycling

This figure shows a rough overview of the processes which are part of the life-cycle of plastic products. Most notable are the three boxes to the right, which represent the three possible "end uses" of plastic waste. The sizes of boxes and arrows are not to scale, but do show relative volumes. Adapted from Geyer (2020),



As some of the PW is mixed and challenging to recycle, much of it ends up simply deposited. This can mean landfills, open dumps, or the natural environment (Verma et al., 2016). Data on where it is disposed of is very poor. Depending on where the disposal of waste ends up, it can pose a threat to the human population, the vegetation, health of animals, and the environment as a whole. Waste might also be burnt at landfills, which can release toxic gasses. Polystyrene (a type of plastic) is especially harmful to the human central nervous system, some of the health risks include headaches, damages in kidney or liver, and heart diseases (Verma et al., 2016). Since these hazardous substances are bioaccumulative, organisms at the top of the food chain are the most exposed to the ill effects. Microplastics is another issue regarding pollution, where tiny bits of plastics can end up in the marine environment, this leads to some organisms in the marine environment digesting it (Ivar do Sul & Costa, 2013). Daily products from consumers e.g. facial cleansers in developing countries contain Polystyrene particles which can directly enter the sewage system and then get out into the adjacent coastal environments. Those that get distributed into the environment and can cause serious harm to animals (UN, 2018).

There is great variance between countries, and some research has already been done exploring the specific conditions in many of them. A large amount of PW ends up in Asia, and there is a need for the management of the PW there (Brooks et al., 2018). Here follows a brief overview of the situations in some of the countries.

PW in Vietnam is handled in an informal context, from families to entire villages (Salhofer et al., 2021). In these rural areas families work with recycling activities e.g., waste collection, separation, shredding or extrusion. The handling of PW creates jobs as a complement to the agriculture sector, and according to Salhofer et al. (2021) the Vietnamese industry demands 3.5 Mt of raw materials per year, and the domestic raw materials can only supply 0.9 Mt, which means there is a clear motivation to import. However, with a limited knowledge of what PW disposal does to the environment and ecosystem, the waste is manually processed using outdated technologies. As the handling is very informal and haphazard, it leads to environmental, health, and other issues for the local population. As a result there are reports of contaminated waterways, marine littering and air pollution. Vietnam, according to Jambeck et al. (2015), was ranked top five polluters globally in terms of littering. In another study by Lebreton et al. (2017) the rivers in Asia are also ranked as the most polluted with rivers in Africa ranking second.

In Indonesia only 24% of PW is recycled as 62% of the PW is mixed and thus challenging to recycle and ends up at the landfills, and the remaining 14% is deposited in the environment (Putri et al., 2018). Here, PW recovery is handled by a mix of formal and informal channels. The formal channels are waste banks, where the PW recovery is community-based. At these, individuals, often organized in communities, can visit the waste bank in order to trade the PW in exchange for financial remuneration. The informal sources are scavengers, intermediates, dealers, and grinders. The issue with the PW collection in Indonesia mostly has to do with the fact that its recycling facilities have to be improved. There are some types of plastic, especially low value, flexible, or soft materials, which do not get recycled as they are more difficult to recycle and the facilities simply cannot handle them.

Various countries generate different amounts of PW, and achieve wildly different recycling rates, with Germany, Denmark and Finland having a recycling rate of around 40-50% (Khoo,

2019). Japan stands out for excelling at the conversion of waste into energy. Notably is the UK with its incredible PW generating of around 35 PW kg/capita (2015), worse is Singapore with its 150 PW kg/capita (2016) and only 7% recycling rate. This means that recycling is challenging but possible, there are several techniques to convert PW to energy (Sharma et al., 2021). Some of these techniques are: *Pyrolysis*, *Incineration*, *Gasification, Torrefaction, and Landfill gas utilization.* Pyrolysis, incineration, gasification and torrefaction are techniques converting PW to energy through the process of heating and burning the PW. The differences between these techniques mostly lies in the temperature of which they get heated/burnt at. Some of these techniques are heated to 200-300°C (Torrefaction) while others demand a higher temperature (700-900°C Pyrolysis and incineration). Gasification has a high variation between 500-1800°C. The differences lead to different energy outputs. Pyrolysis and gasification are the ones generating more environmentally friendly products in comparison to the other techniques.

The last technique, landfill gas utilization which is a process of handling the methane and other gasses at landfills (Sharma et al., 2021). The process involves capturing and utilizing the gasses produced at a landfill in order to separate the greenhouse gas emissions that would be released to the atmosphere. This gas instead is captured and then can be used as energy. These different techniques have a drawback, which is that they require huge financial investments in order to build infrastructure and scale up in order to be cost-efficient.

1.2. Aim of the Study

This report investigates the trends in plastic waste trade through the lens of differences in environmental regulations and imbalances in container flows. Furthermore, its aim is to investigate whether they are driving forces and highlight it.

1.3. Research Questions

Main Question: How has the global trade of plastic waste evolved in the last 20 years?
Sub Question: Which countries are the main exporters/importers?
Question two: What are the main drivers that affect the global trade flow of plastic waste?
Sub Question: How much does national regulation affect plastic trade?

1.4. Delimitations

Given realistic limitations, this study cannot pay equal attention to each of the 199 countries[1] which are represented in the Comtrade database. Instead, it gives a broad overview of the total situation, but also more narrowly focuses on major importers and exporters. Specifically, it more closely examines four countries, roughly representing four major geographic regions and degrees of development: The USA, Germany, China, and Malaysia. Additionally the report does not go into details regarding the PW trade for every country and which country it trades with. This study is limited to official reported data on trade flows of PW but generalizes over all categories of PW, and does not go into specifics, except in the case of the four countries mentioned above.

The broad range of time this study spans from 2000 onwards. Limitations in the data mean the study cannot say much about developments past 2021, but this still allows it to cover a short period before China joined the World Trade Organization (WTO) in December 2001, as well

[1] Including some autonomous regions, such as Hong Kong, or Macao.

as the entire period which (according to Brooks et al. (2018), and Wang et al. (2020)) is characterized by China's rise and fall as the world's leading PW importer.

2. Theory

This part lays the groundwork for which theories are used in the report.

2.1. Key Ideas

Presented below are the most important concepts for comprehending this study.

2.1.1. The Harmonized Commodity Description and Coding System

The Harmonized System (HS) was developed by the World Customs Organization to create a unified global standard of codes by which to differentiate all tradable goods (WCO, N.D.). It is made up of a six digit code, arranged in broad chapters (the first two digits), the more narrow heading (second two digits), and a specific subheading (third pair of digits) (Tullverket, 2022). One such example is illustrated below in Table 1 for the UN Comtrade database. In addition to this internationally recognized base, some countries add further digits afterwards for even higher specificity. For example, the EU has increased the number of digits to ten in its system Taric.

Table 1. UN Comtrade HS-Codes 3915 and its subcategories

List of customs codes which relate to plastic waste. Source: the World Customs Organization.

HS-Code	Commodity
3915	Waste, parings and scrap, of plastics
391510	Ethylene polymers; waste, parings and scrap
391520	Styrene polymers; waste, parings and scrap
391530	Vinyl chloride polymers; waste, parings and scrap
391590	Plastics n.e.c in heading no. 3915; waste, parings and scrap

2.1.2. Comtrade

The United Nations Statistics Division (UNSD) collects and compiles information about global trade each year (UNSD Trade Statistics Branch, 2014). This data is then disseminated to the public through Comtrade: a database and sorting tool which has been constructed to help researchers and analysts access it as easily as possible - although the full functionalities are reserved for those paying a subscription fee. Comtrade contains information about the countries involved in trade flows, the volumes (both by weight and by value), the specific HS-codes of the commodities traded, the transport modes, as well as other variables such as which flag it sails under.

2.1.3. OECD Environmental Policy Stringency Index

The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organization dedicated to fostering global trade and economic progress (OECD, N.D.). It aims to accomplish this goal by providing tools and information for governments, businesses and civil society, as well as setting rules and standards (on for example taxation) which member states are bound to follow. This is all ostensibly meant to promote global prosperity, but the organization has come under criticism for enforcing a

neoliberal, technocratic, and numbers-driven approach on governments, undermining democracy and national self-determination (cf. Alawattage & Elshihry, 2017).

One tool the OECD has developed for measuring the relative strictness of different countries' environmental regulations is the Environmental Policy Stringency Index (EPSI) (Botta & Koźluk, 2014). This is a composite of various policies including taxes, trading schemes, emissions limits and subsidies. These evaluate both market-based approaches (for example the tax rates on fuels and emissions, or prices of permits) to incentivize good behavior, and strict limits to fuels and emissions (e.g. maximum concentrations of nitrogen oxides, sulfur oxides, etc. in emissions), both of greenhouse gasses and other pollutants. Additionally, there is a sub-index for technology, and the degree to which government policy supports its development or adoption. Overall, EPSI is mostly concerned with the energy sector, and especially with climate impact, but it has been used as a proxy for general environmental policy before (see 2.5.). According to the EPSI, environmental stringency in OECD countries increased significantly from 2000 to 2020, from an average score of about 1.30, to 3.09 (Kruse, et al., 2022). Most of that improvement happened before 2010 however (at which point the average score had reached 2.78), after which it plateaued.

2.1.4. Linear Regression Analysis

Through the use of Linear regression analysis it is possible to discover if there exists a relationship between two parameters (James et al., 2021). Additionally, it shows how strong of a relationship it is and how much of a linear relationship there exists. A simple linear regression is modeled as: $Y \approx \beta 0 + \beta 1 X$, if there are multiple parameters it can be modeled as $Y \approx \beta 0 + \beta 1 X + \beta 2 X + \beta 3 X + \ldots + \beta n X$. Using the parameters together with different combinations can result in different significance levels, by doing that it is possible to find out the relationship between the combinations.

Using Linear Regression Analysis to be able to analyze data through can result in output such as the p-value (James et al., 2021). The p-value shows if the observing result is to be considered extreme. The p-value will return a value and when the value is lesser than 0.05 or 0.01 it is then considered to be a significant result.

2.2. Pollution Haven Hypothesis

The basic premise of the Pollution Haven Hypothesis (PHH) is that, when companies in developed countries plan to set up new factories or plants, they will find developing countries where it is cheaper to dispose of waste (Temurshoev, 2006). Developing countries offer less stringent laws on labor and environment, which leads more tightly regulated countries to dispose of their waste there instead. These countries could be divided into North-South income gaps, where the North has stringent regulations and the dirty goods are relatively expensive to handle, whereas in the South the regulations are less stringent and it is therefore correspondingly cheaper to handle the materials (Taylor, 2005). According to the PHH, pollution in the northern part of the world thus falls, while the south becomes more polluted due to trade. As developing countries start to grow financially, the laws regarding labor and environment are getting more stringent. Taylor (2005) also states that the factories will (re)locate their waste disposal to other countries which have less stringent laws and are mostly developing countries, the cycle keeps going on.

The PHH is built on the theory of comparative advantage, which states that when a country is choosing between different options for production, they should specialize in the one type of production where they have the highest productivity relative to other countries (Hunt &

Morgan, 1995). This will lead to this specific country gaining relative advantage and then instead trade its goods with another country that does the same for another production, both countries will thus have a higher output of their specific product. This will lead to economies of scale when the countries choose to scale up, and effectively make both countries more productive and richer, but might also cause path dependencies where certain industries become cornerstones of a country's economy.

The disposal of PW is another type of comparative advantage where a country chooses to trade the PW with another country. A country that does specialize in this handling PW can achieve economies of scale. Through the economies of scale one enterprise can have a higher output of product with the same or less input (Silberston, 1972), this is possible through being more productive and effective within the organization. One such example is having a good infrastructure that relies on heavy investment, with the investment in hand it can produce a higher output with the same manpower to maneuver it.

Wu et al. (2021) discuss the case of China, applying the PHH, and their results show that if trade was excluded, China's CO_2 emissions would decrease. The term for this is *Carbon leakage*, meaning decreasing emissions in one location can increase them in another. There was another case in the article where Wu et al. (2021) discuss that for example the US earlier exported products in high-carbon industries to be manufactured in China. This led to the US having a decreased emission and China having an increased emission in CO_2. A similar process is at play with PW trade; exporting PW from one region will decrease the PW in that region but increase the PW in another region. This is an example that follows how PHH would predict PW leakage to other regions. There are however also counterexamples: Higashida and Managi (2013) examined some categories of PW (as well as metal scrap), but could not find any evidence for the PHH. Instead their study showed that more advanced developing countries tended to import more PW than the least developed ones. This is consistent with what Li et al. (2021) term the Resource Hunting Hypothesis (RHH), according to which it is the need for cheap resources in industrializing economies which leads them to import large amounts of recyclable waste.

2.3. The Logistics Behind Empty Containers

Other complex variables in the logistics network are terminals, borders and regulations (Karmelić et al., 2012). There are serious imbalances of trade along the major shipping routes; Far East - the Mediterranean/Europe, Europe - North America and Far East - North America with an imbalance of 53%, 40% and 63% in the same order. These imbalances can lead to difficulties in finding empty equipment to carry export goods, or large stacks standing permanently empty, accruing costs. Planning of empty container allocation is therefore vital to businesses.

With the growth of production in the Far East the imbalances of trade have grown even larger. One example is between the years 1995 and 2005 the imbalances grew for the route Europe - Far East from 27% to 67%. This trade imbalance is further illustrated in Table 2 below with trade flow Eastbound (EB) - Westbound (WB) along the major trade routes (UN, 2021).

Table 2. Container trade along the major sea routes East-West in million TEUs

An overview of imbalances in seaborne container trade, showing that East Asia is the main exporting region in the world. EA = East Asia, NA = North America, NE = North Europe and MED = Mediterranean. Source: Adapted from UN (2021).

	EB	WB		EB	WB		EB	WB	
	EA → NA	NA → EA	Imbalance %	NE + MED → EA	EA → NE + MED	Imbalance %	NA → NE + MED	NE + MED → NA	Imbalance %
2014	16.1	7.9	50.93%	6.3	15.5	59.35%	2.8	3.9	28.21%
2015	17.4	6.9	60.34%	6.4	15.0	57.33%	2.7	4.1	34.15%
2016	18.1	7.3	59.67%	6.8	15.3	55.56%	2.7	4.2	35.71%
2017	19.3	7.3	62.18%	7.1	16.4	56.71%	2.9	4.6	36.96%
2018	20.7	7.4	64.25%	7.0	17.3	59.54%	3.1	4.9	36.73%
2019	19.9	6.8	65.83%	7.2	17.5	58.86%	2.9	4.9	40.82%
2020	20.6	6.9	66.50%	7.2	16.9	57.40%	2.8	4.8	41.67%
2021	24.1	7.1	70.54%	7.8	18.5	57.84%	2.8	5.2	46.15%

Based on a paper by Kuzmicz & Pesch (2018), the problem for importing countries is that the import dominant regions need to get rid of the surplus empty containers, while the export dominant regions lack the availability of empty containers. There is an issue with the positioning of the empty containers and the authors estimate that around 20% of the total maritime transport is for empty containers relocating. For land transportation it is estimated to be around 40-50%. In the same paper Kuzmicz & Pesch (2018) further problematize that not only is the relocating of empty containers complex, there is a distinct lack of data or uncertainty in the data.

Another aspect is the rate imbalances between the head haul and the back haul, where the back haul could be as low as 40-50% (Theofanis & Boile, 2008). The complex repositioning of empty containers is about repositioning from a consumption region to a production region. It affects various stakeholders along the supply chain of empty containers, including e.g. owners/liner container service operators, importers/exporters and local terminal operators (Theofanis & Boile, 2008). Handling empty containers for these stakeholders generates a lower income as fees for handling empties are lower than fully or partly loaded containers. Furthermore the empty containers occupy a slot at the terminal and onboard the vessels, having it loaded or partly will instead generate an income. In a perfectly balanced trade, one imported container would lead to one exported container. Additionally there are different types of containers and additionally special containers that exist less on the market and are more expensive to both handle, lease or own. For all these stakeholders along the supply chain it is therefore more financially profitable that the containers are loaded than not.

2.4. Regulations

A study by the UN Environment (2018) with the title *"Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations"* summarized that among 127 of the 192 countries analyzed there was some form of regulation that oversaw the use of different plastics. From the regulation of plastic bags, plastic products to producer responsibilities. Some of these are new policies but also development of new technology are

necessary actions, to be able to mitigate the risk associated with the handling of waste.

In 2020 the EU released a plan named *"Circular Economy Action Plan"*. The plan covers policies, waste prevention and circularity on electronics, batteries packaging and plastics (Seay & Ternes, 2022). It is recognized that in order to have a sustainable PW handling and mitigate risk to the human health, one's environment and diet, one has to regulate not only the process of collecting and recycling PW, but also regulate the earlier processes in manufacturing. It is crucial that the producer and its extended partners in the supply-chain are covered.

2.4.1. The Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal deals with the management of hazardous waste and came into force 1992, its objective is as follows, quoted from their homepage (United Nations Environment Programme, 1998):

"... to protect human health and the environment against the adverse effects of hazardous wastes."

The convention aims to reduce hazardous waste and promotes the environmental sound management of hazardous wastes (United Nations Environment Programme, 1998). It also restricts and controls international movement of certain waste products, aiming at protecting vulnerable countries from being exposed to the import of hazardous wastes. The Basel convention also works with the training and technology transfers to minimize the hazardous effects on the environment and its regions.

However, the efficacy of the convention has been called into question (Kellenberg & Levinson, 2014). It, like many other international environmental agreements, faces the dual problem of being adopted mainly by countries which already adhere to strong standards, and not having any strong incentives for countries which have not chosen to join. Thus, most progress done by member countries likely would have happened regardless of the convention's existence, and the problem of "free-riders" using lesser regulations as a competitive advantage remains unsolved.

2.4.2. Chinese Waste Policies

China joined the WTO in the end of 2001 as part of the country opening up its economy to the world, resulting in increased imports of PW (along with many other waste imports) (Li et al., 2020). During this period the value of PW import kept on growing until it peaked in 2014 with around 1.7 billion USD. For the five largest exporters of all types of waste China accounted for a total share of 62.6%. This PW was used as a component to the expanding Chinese plastics industry, and during the following decades China was the by far largest importer of PW in the world.

By the late 2000s the Chinese government grew concerned about the environmental effects of the large amounts of waste being imported, and in 2011 a law restricted the import of solid waste to only those with specific permits issued by the Ministry of Environmental Protection (Li et al., 2020). This resulted in a marked decrease in metal and paper waste being imported, though plastic remained unaffected. During the 2010s China continued restricting waste imports, including with the so-called "Green Fence Operation" in 2013, which was a

temporary restriction demanding less contamination in the waste (Brooks et al., 2018). In 2017, this was followed by an "Implementation Plan on Banning Entry of Foreign Garbage and Reforming the Administrative System of Solid Waste Importation", which (among other things) banned a number of waste categories (including eight types of plastics) from being imported from 2018 onwards, and resulted in a 23.9% overall decline in waste imports (by value), and a 90.8% decline of PW (Li et al., 2020).

Since implementing the import ban, the country has also taken measures to reduce the production of certain kinds of PW, and improve the handling of it more generally (Liu et al., 2022). But apart from environmental protection, another major reason for the ban might be that the domestic production of PW has become large enough to meet the recycling capacity (Kumamaru & Takeuchi, 2021).

2.5. Previous Research

The theory and methodology of this study builds on previous research using Comtrade. Pacini et al. (2021) utilize the dataset to create a network model, showing the most central countries in the international system (China, USA, and Germany, each with their own circle of countries). Kellenberg (2012) uses Comtrade data over all types of waste, in conjunction with an "Environmental Regulation Index" (based on perceived regulation strictness), and a gravity model to test the hypothesis that lower relative levels of regulation increase the amount of waste being imported. He finds that there is indeed such a relationship, though China and Turkey specifically play a very large part in the results. EPSI specifically has been used research on the the validity of the PHH in the cases of manufacturing (Liu et al., 2020), global value chains (Kozluk & Timiliotis, 2016), and development of technology (Sadik-Zada & Ferrari, 2020), among other things. Shi et al. (2021) looks at China, and the impact of its policy decisions on the global market, showing that the new regulations (and especially the 2017 ban) have had a strong influence. Overall, these researchers have demonstrated that there can be found a link between differential national conditions and legislation and the flows of waste. Kellenberg (2012) in particular highlights the importance of discussing this in the context of the PHH, arguing that one of the primary ways rich countries avoid polluting their own environments is not just moving dirty production, but physically moving the waste that's left over. This report mainly focuses on the drivers of world trade in PW through investigating environmental regulations and imbalances in container flows. Through the analysis of the different drivers, its end aim is to highlight which are the most important.

3. METHODS

The method used in the report is mainly analysis data from the UN Comtrade database of world trade with HS-code 3915. Data was collected for years 2000-2022. In addition to the data there was a literature review on articles with the keywords mentioned in section 3.1.

3.1. Literature Search

To contextualize the results of this study, a short review of other research is included. The primary objective and criterion for evaluation was to produce a base to start this report on. The literature consists of books and articles which were identified using keywords such as: plastic waste trade, waste trade, waste management challenges, plastic scrap, plastic waste hazards, pollution haven theory, empty containers positioning, plastic waste regulation, comtrade, OECD EPS index, energy plastic waste.

Additionally, articles citing the literature found using the earlier mentioned key words, as well articles which the hosting sites gave as "recommended articles" are also to be examined. The key question the literature is evaluated on relates to what driving forces are identified and examined, as well as what general overview of the current state of the world trade system is presented.

A basic evaluation of the reliability and usefulness of the literature was also conducted. Given the timespan analyzed, it was particularly important to ensure recency. Since some key developments occurred within the last five years, most of the chosen articles on the topic of PW trade are from 2018 or later. For other matters (such as PHH, EPSI, etc.) recency was considered less critical, and older sources have also been used. Most literature cited is published in the form of articles in scientific journals. There are also some reports published by international organizations, which may have specific agendas, but are overall prominent enough that they ought not to publish outright falsehoods.

3.2. Collection & Analysis of Data

To evaluate the impact of regulation on the global PW trade, the trade statistics available from Comtrade were complemented with data on the Gross Domestic Product (GDP), Population Size, and Environmental Stringency of countries. This study uses measurements published by the UN[2] (for trade volumes), the World Bank[3][4] (for size of population and economy), and OECD[5] (for environmental policy). EPSI is only available for OECD countries and Brazil, India, China, South Africa (BRICS), and Indonesia, so these 33 countries were the only ones utilized in this part of the study.

Taken together, these factors were tested for statistically significant relationships, using linear regression, and presented in graphical form. In all, eight models were tested, one for each predictor alone, all three pairs, one with all three, and lastly one with all and also accounting for interaction between population and economy. These were then compared with one another to determine which model performed the best over the period investigated.

[2] https://comtradeplus.un.org/
[3] https://databank.worldbank.org/indicator/SP.POP.TOTL/1ff4a498/Popular-Indicators
[4] https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
[5] https://stats.oecd.org/Index.aspx?DataSetCode=EPS

To be able to compose a deeper analysis of the data collected and create comparisons, it is necessary to categorize which countries are developed or developing. For most purposes of this study, the UN (2022) division of countries into developing and developed countries are sufficient[6]. All graphs were produced by the authors in Google Sheets using the data from the Comtrade database[7].

3.2.1. Case Countries

In addition to the distinction based on development, this study also more closely investigates four "Case Countries". These are China, Malaysia, the United States of America and Germany. They are all major importers and/or exporters, and are meant to somewhat represent different geographic groups (East Asia, South-East Asia, North America, and Europe, respectively) of countries. China and Malaysia are developing countries whereas USA and Germany are both highly developed countries.

China has been a major importer historically, but is aiming to transition away from importing PW and has taken steps to limit its exposure (Liu et al., 2022). Primarily this has taken the form of an import ban, but other measures have also been taken (as discussed in more detail in section 2.4.2.).

When it comes to Malaysia,its PW import has increased dramatically since the Chinese ban in 2018 (Kuan et al., 2021). In 2018 the leading PW exporters to Malaysia were the USA, Japan and the UK. The Malaysian legislation did not develop as fast as its surge in PW import, from having no systematic programmes to low awareness on PW. As of now about 95% is dumped at opening dumping or landfills. There have been many plans set in place in order to have a more sustainable PW management in Malaysia, one such is its "Roadmap Towards Zero Single-use Plastics (2018-2030)". The roadmap's aim is to use more biodegradable alternatives and reduce its single use plastics.

In the USA, there is no national regulation specifically targeting PW pollution, and the material is mostly regulated as "municipal waste", which is handled on a state level (Seay & Ternes, 2022). At the same time, the country releases more PW into the oceans than any other, and the only federal legislation that has actually been enacted is concerned with the plastic in the seas. Overall, the USA can be said to have an inconsistent and patchy policy toward PW pollution.

Germany has a fairly well developed recycling industry, with a recycling rate of 42%, and almost the entirety of the rest going to energy recovery (Plastics Europe, 2022). It is also part of the European Union, and thus must follow its regulations, most recently the 2021 rules on Plastic Waste Shipments, which limits the possibility to export unclean or otherwise hazardous PW, and is built on the latest version of the Basel Convention (European Commission, 2020). This positions it as the most strict of the four countries in terms of regulation.

3.3. Data Ethics

The data used are based on the Comtrade database of world trade and therefore not possible to change. Since it is not changeable for the purpose of the report, its data are only to be

[6] https://www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-2022/
[7] https://www.google.com/sheets/about/

aggregated and broken down in order to analyze and visualize it. Furthermore the data is available for everyone's access and thus creates availability and transparency.

Zook et al. (2017) discuss 10 rules for responsibility when handling big data. Some of the rules include the privacy of individuals in the data. In this dataset there is no data of individuals, only of countries, this is therefore disregarded. Rules 5 (Consider the strengths and limitations of your data; big does not automatically mean better) and 8 (Design your data and systems for auditability) in the article are extremely important due to the fact that the dataset was quite enormous, it is important that the cleaning of data, interpretation and dissemination of results are to be as neutral and precise as possible. Rule 8 is as important as it has to do with the accountability of the report, during the report it is important that the data aggregated and the compiled results are to be double-checked.

4. Results

This section will present the results made from analyzing the data by UN Comtrade's database of world trade.

4.1. Global Plastic Waste Trade Flows

The data shows that a couple years before 2018 (2014-2017) China's share of the total PW export trade value was 1.17% and import was 57.51%. After the Chinese import ban that was implemented as of 31 December 2017 there is distinct evidence how it has influenced the trade flow in the world. China's share of total export trade from 2018 (2018-2021) was 3.36% and its import was only 0.35%.

Figure 2. Exporters & Importers 2014-2017

Here shown are the main countries involved in PW trade just before 2018. Notably, China makes up most of the import side, and imports mainly come from developed countries. . Source: Authors' compilation, March 2023 using Comtrade's database.

Importers **Exporters**

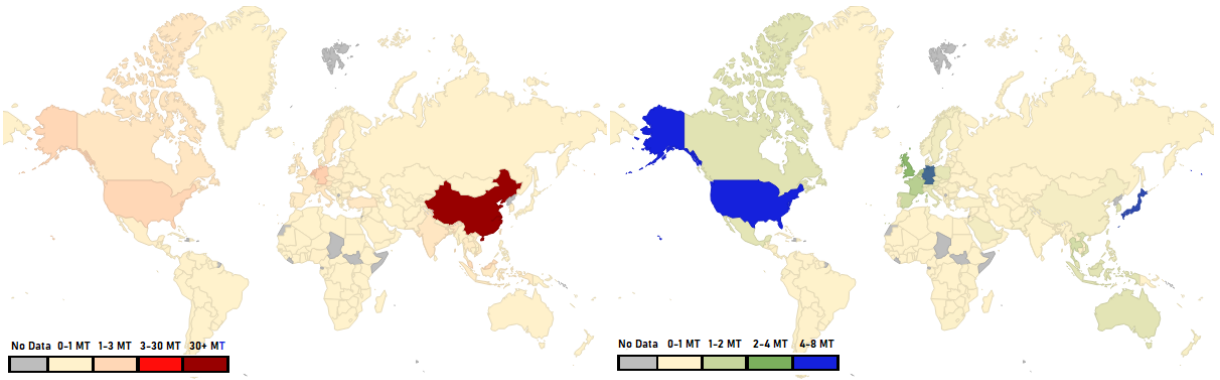
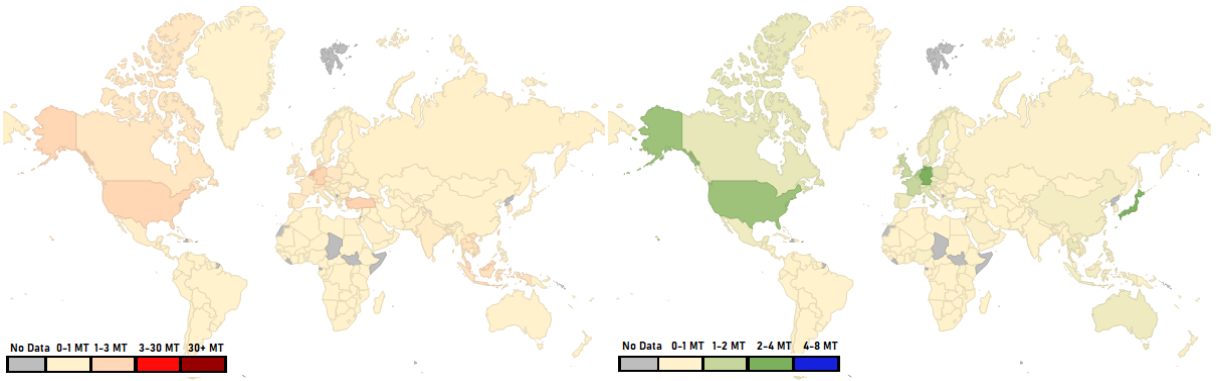


Figure 3. Exporters & Importers 2018-2021

Here shown are the main countries involved in PW trade after 2018. Notably, China no longer imports anything, and exports have decreased. Source: Authors' compilation, March 2023 using Comtrade's database.

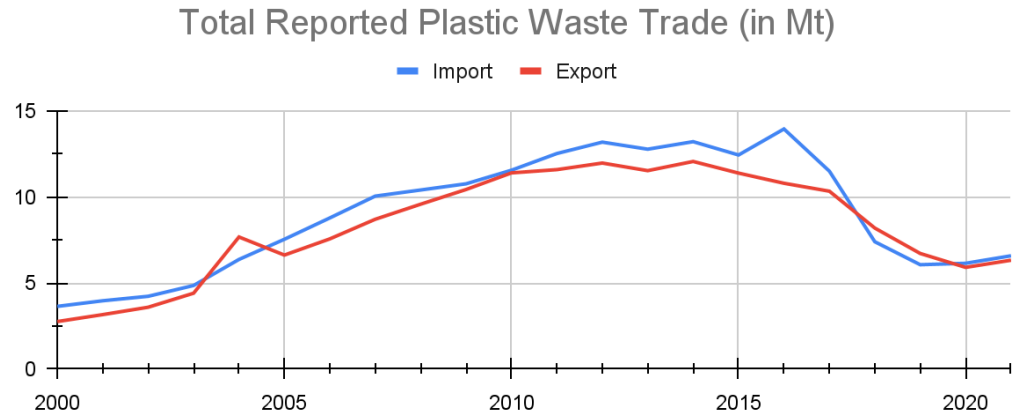
Importers **Exporters**



The flow of PW instead shifted to countries mostly located in South-East Asia but also Turkey (See Table 3 & 4 for details). The countries are Turkey, Indonesia, Malaysia and Vietnam. Looking closely at Figure 2 and 3, one can find that the total amount of PW traded has decreased. The amount of traded value in USD adjusted for inflation (2022) decreased by 50.24% for exports from the years in Figure 2 (21 billions $) to the years in Figure 3 (10 billions $) after the Chinese ban. Furthermore the increment in percentage reached two-digits was not just from 2017-2018. It happened the years before leading up to the Chinese import ban.

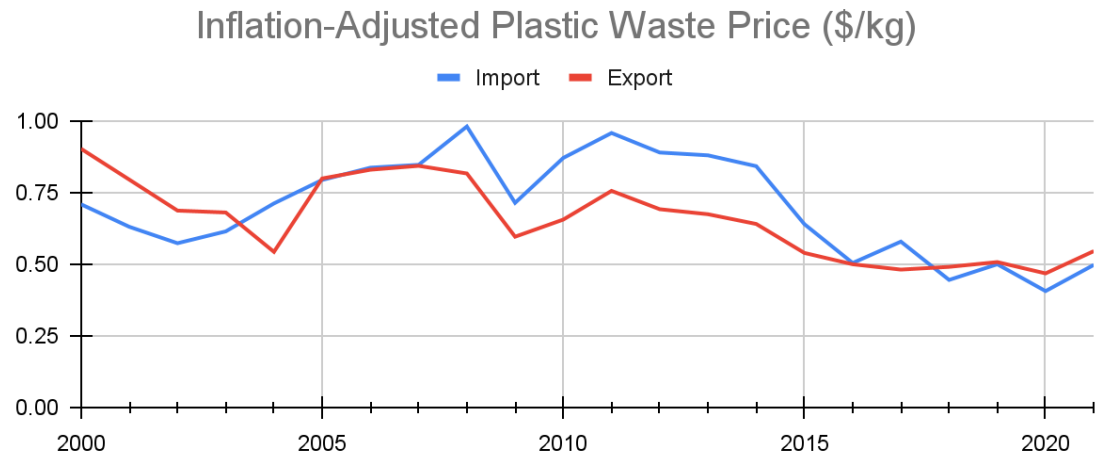
Taken in aggregate, the amount of PW traded globally increased about threefold over the 2000s and early 2010s before plateauing, and plummeting after 2017 (see fig 4). However, the actual collapse only lasted for a short while, and the volumes have stabilized - or even begun rising again.

Figure 4. Total Global Plastic Waste Trade
The reported PW and its increase over the years, showcased in the below figure is how it has increased over the years and then again decreased around year 2016. Source: Authors' compilation, March 2023 using Comtrade's database.



Interestingly, the average prices for PW have not followed the same trends as volumes (see fig. 5). There has been an overall decrease (when adjusted for inflation), but the steepest sustained decrease was from 2014 onwards. There was a significant aberration in 2009, presumably because of the financial crisis, but price changes cannot easily be related to global PW supply.

Figure 5. Price Development of Plastic Waste
Estimated price of one kg of PW over time, adjusted to 2022 dollars. Prices do not seem to match the same trends as total volumes, beginning to drop well before 2018. Source: Authors' compilation, March 2023 using Comtrade's database.

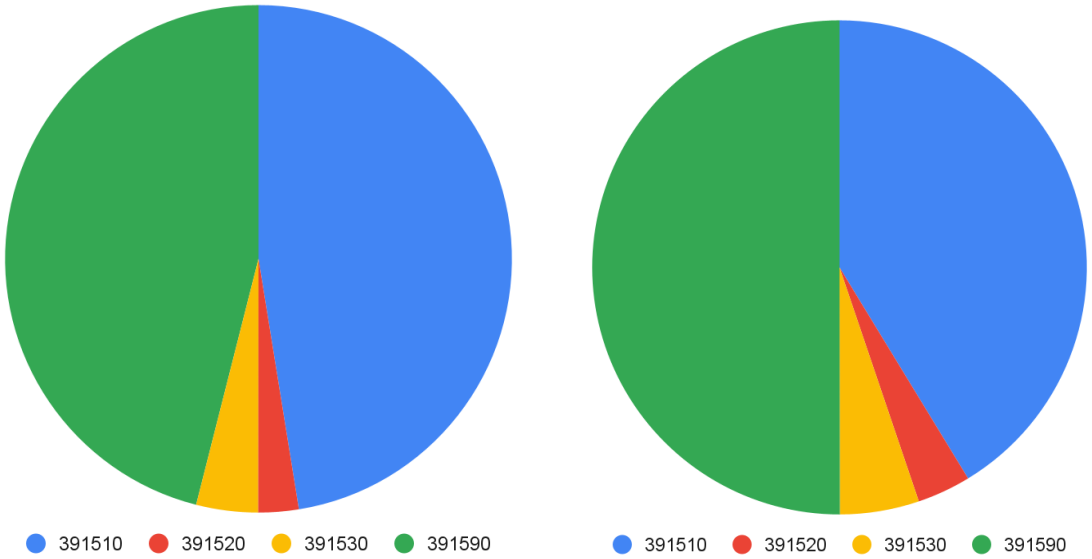


For the four Case Countries, the same general trends of growth and decline hold, but looking at them individually, clear differences emerge. For China, imports became next to nothing after 2018, while exports massively increased over the mid-to-late 2010s. Malaysia, meanwhile sees a very large spike in imports in 2018, which then decreases again - but remains on an overall clear upwards trajectory. Its exports meanwhile peaked around 2013-2014, and have steadily diminished since then. Germany saw a steady growth in imports and exports over the 2000s. Imports have remained relatively level since then, albeit with significant variation between years, but exports have been declining somewhat since 2016. The USA has had a fairly steady level of imports over the entire period, while its exports show a clear peak at 2011, but have again declined to the same volume as 2000. Comparing the two developed countries with the two developing ones, it is clear that China and Malaysia have a much greater proportion of imports than Germany and the USA; especially China, which had over 300 times greater imports in the early 2010s. Malaysia only reached a ratio of around 20:1 and only at the very end of the period. Germany and the USA are fairly alike, having significantly greater exports than imports over most of the period, although the USA did have net imports in 2021 and 2022.

The vast majority of PW was reported as either 391510 ("Ethylene Polymers") or 391590 ("Other"). Over the entire period, the remaining two categories ("Styrene Polymers", and "Vinyl Chloride Polymers") made up only around twelve percent of the total value traded. In recent years it is even less (see fig. 6). There is some difference between the Case Countries here, in that the USA overwhelmingly imports 391590, and that most of its exports over time have been 391590 too (although that proportion has decreased). China also has a preponderance of 391590 reported, but in the exports; its imports are fairly balanced. In Malaysia, meanwhile, imports are mostly 391510 (and exports are fairly evenly divided between the two), and in Germany both imports and exports are a majority 391510. Interestingly, while the price per kg of PW ranges from $0.06 to $9.3, the different categories do not have hugely different price ranges. The most significant difference is that PW categorized under 391510 tends to be slightly cheaper than 391590.

Figure 6. Share of plastic waste categories in case countries in 2021

The diagram is divided into HS-codes with different colors, where 391510 = Ethylene polymers, 391520 = Styrene polymers, 391530 = Vinyl chloride polymers, 391590 = Plastics n.e.c. (See Figure 1 for more details). To the left in weight, to the right in value. Source: Authors' compilation, March 2023 using Comtrade's database.



In the tables (Table 3 & 4) below the countries with the highest amount of exports and imports 2020 in net weight are presented. The countries represented in Table 4 are all countries among the top 10 exporters of PW in (tonnes) and are developed countries. In the import table there are more countries that are still developing. Colored gray with bold letters in Table 3 and 4 are developed countries. Based on the results from the data there are more developing countries in top importers of PW and more developed countries in the top exporters of PW.

Table 3. 2020 Import countries, Net Weight and World Share (tonnes) for PW

The 10 countries importing the most PW in 2020. Developed countries are marked in gray. Source: Authors' compilation, March 2023 using Comtrade's database.

2020 Import	Net Weight (tonnes)	World Share (tonnes)
1. Turkey	756,985	11.74%
2. Netherlands	**619,286**	**9.60%**
3. Malaysia	478,092	7.41%
4. USA	**418,089**	**6.48%**
5. Vietnam	328,875	5.10%
6. Taiwan	286,108	4.44%
7. Germany	**262,538**	**4.07%**
8. Austria	**205,911**	**3.19%**
9. Belgium	**193,116**	**2.99%**
10. Indonesia	181,767	2.82%

Table 4. 2020 Export countries, Net Weight and World Share (tonnes) for PW

The 10 countries exporting the most PW in 2020. Developed countries are marked in gray. Source: Authors' compilation, March 2023 using Comtrade's database.

2020 Export	Net Weight (tonnes)	World Share (tonnes)
1. Japan	**820,742**	**11.91%**
2. USA	**624,511**	**11.49%**
3. Germany	**581,243**	**8.98%**
4. Netherlands	**413,233**	**5.98%**
5. France	**333,749**	**5.39%**
6. Belgium	**309,624**	**4.81%**
7. UK	**226,689**	**4.42%**
8. Slovenia	**181,915**	**4.13%**
9. Austria	**179,323**	**3.97%**
10. Poland	**155,891**	**2.70%**

4.2. Environmental Policy Stringency Index

Using EPSI as a proxy for the strength of national regulations only permitted statistical modeling based on 33 countries. When comparing all of the eight different models (with varying combinations of the three predictors Population, GDP, and EPSI), the best performing one was the one which included all three, as well as interaction between population and GDP. It consistently had the highest statistical significance, though all of its predictors sometimes did not. The EPSI score of a given country had a somewhat variable level of correlation with the amount of PW exported. For the 21 years tested, it varied in p-value from 0.00859, which

is statistically significant, to 0.39943 which is not. Ten had p-value under 0.05 (significant), and an additional five under 0.1 (marginally significant) (see Appendix 2 for some more details). The models themselves had (with two exceptions) high statistical significance, though the most important predictor on PW exports appeared to be GDP. Population size was not found to be significant at all on its own, but did function as a predictor when combined with GDP. Overall the models resulting from this process are similar, but may have up to one factor ten variance on each variable.

4.3. Imbalances in the Trade

The data of the UN Comtrade Database shows that countries with the highest amount of trade value for export of HS 3915 are located in the "western" part of the world. The main regions are Europe and North America, though some countries in Asia also have very large exports. The countries with the lowest trade value were countries in the regions of Africa. The same result could be applicable to the data for trade value with the import of HS code 3915. Tables 5 and 6 show the combined values for the major regions, and the imbalances between import and export. Notably, East Asia imported more than it exported until 2018, whereas the Mediterranean countries first had a higher export than import and then later started to shift from importing more than exporting. This can be showcased from the year 2016 where the imbalances started to shift.

Along the biggest routes which were mentioned in 2.3, Far East - the Mediterranean/Europe, Europe - North America and Far East - North America there was an imbalance of trade. After the Chinese import ban from December 31st 2017, a change in the flow of PW can be seen in the data. The flow mostly shifted to South-East Asia but also to Turkey and Taiwan. The countries that had a significant increase in trade value are countries that are located along the major trade routes in the world or are a country that manufactures goods.

Table 5. PW trade flow among major regions with its imbalances (tonnes)

An overview of PW trade imbalances. Gray fields mark those years with greater import than export. EA = East Asia, NA = North America. Source: Authors' compilation, March 2023 using Comtrade's database.

		Export	Import	Imbalance %		Export	Import	Imbalance %
2014	EA	2,061,275	8,536,190	75.85%	NA	2,634,867	644,365	75.54%
2015	EA	1,977,190	7,645,961	74.14%	NA	2,443,753	688,201	71.84%
2016	EA	2,062,424	9,041,589	77.19%	NA	1,671,023	635,732	61.96%
2017	EA	1,799,491	6,096,629	70.48%	NA	1,998,448	613,729	69.29%
2018	EA	1,198,608	636,728	46.88%	NA	1,356,255	623,013	54.06%
2019	EA	1,035,197	537,745	48.05%	NA	696,236	532,560	23.51%
2020	EA	1,017,795	380,647	62.60%	NA	850,379	650,650	23.49%

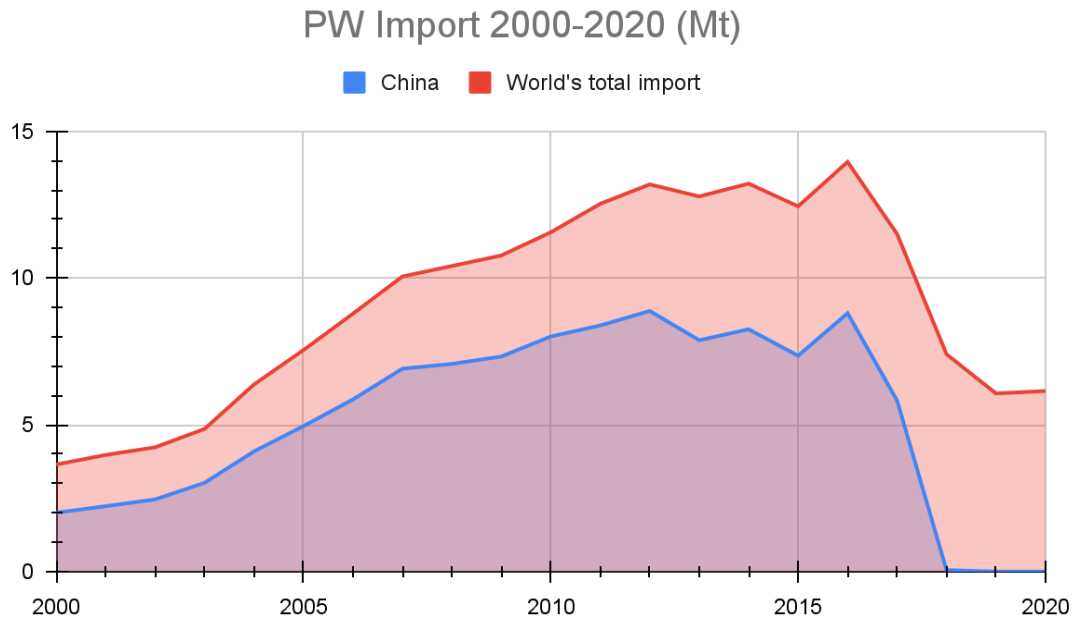
Table 6. PW trade flow among major regions with its imbalances (tonnes)

An overview of PW trade imbalances. Gray fields mark those years with greater import than export. NE = North Europe and MED = Mediterranean. Source: Authors' compilation, March 2023 using Comtrade's database.

		Export	Import	Imbalance %		Export	Import	Imbalance %
2014	NE	3,568,325	1,819,477	49.01%	MED	1,281,174	587,871	54.11%
2015	NE	3,785,807	1,917,941	49.34%	MED	1,284,091	590,851	53.99%
2016	NE	3,594,210	1,930,345	46.29%	MED	1,195,456	695,413	41.83%
2017	NE	3,131,968	1,843,395	41.14%	MED	1,141,979	805,011	29.51%
2018	NE	2,890,835	1,839,565	36.37%	MED	1,099,214	1,019,408	7.26%
2019	NE	2,623,517	1,868,397	28.78%	MED	990,283	749,736	24.29%
2020	NE	2,066,928	1,556,828	24.68%	MED	851,528	1,333,382	36.14%

Figure 7. China's and the world's total import of PW

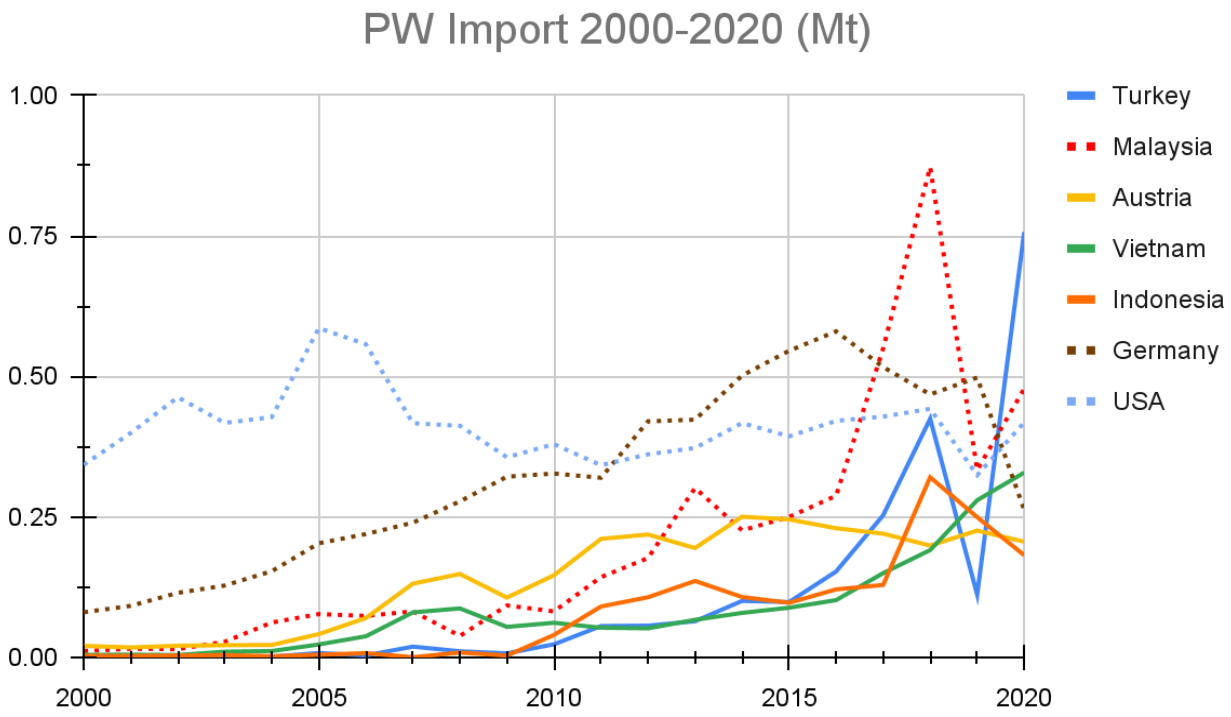
Here shown is China's share of the global PW trade, which up until 2018 is over half. Source: Authors' compilation, March 2023 using Comtrade's database.



As shown in Figure 7, China stood for a majority of the world import of PW until 2018. In Figure 8, some of the other major importers can be seen. Since the 2010s there is a trend upwards for the majority of these countries. For 2018 the countries in the Figure below have a drastic change in import of PW to then in the following year it decreased. Among the five countries in the Figure, Vietnam and Austria are the only countries which have a steady increase in PW import.

Figure 8. Other major importers of PW

The development of PW import for various important countries other than China over the years. Notable are Malaysia and Turkey which had high variance over the last few years. Source: Authors' compilation, March 2023 using Comtrade's database.



5. Discussion

In this part there will be a discussion on different major sections from earlier in the report.

5.1. Results

Here the various results of this study are examined critically and put into the greater context.

5.1.1. Development and Sustainability

One key question is whether the trade with PW constitutes a meaningful step forwards in terms of economic and social development. As previously mentioned, the recycling industry often has very negative consequences for the environment, and for the health of local populations, but is nevertheless considered a useful way to supplement the needs of a plastics industry, and create jobs (cf. Salhofer et al., 2021, Putri et al., 2019). Because of this it is clearly tempting for developing countries to risk damaging their environment to combat immediate problems such as poverty and underemployment.

The case of China shows clearly that it is in fact possible to transition into a heavy PW importing economy, and then out of it again once the domestic plastics consumption reaches sufficient levels. This might be a journey tempting to imitate for other countries, but even after banning import, there remains significant environmental pollution in China, as a result of decades of high imports and low regulations (Liu et al. 2022). The cost of clean-up will likely have to be borne by tax-payers, rather than recycling companies, and it is difficult to estimate the net benefits or detriments.

The importing of PW for developing countries is important for the domestic industry in the developing countries, it is however also in everyone's interest that it does get handled in a more sustainable way (as long as this does not increase costs overmuch). The environmental issues extend over borders and may have huge negative consequences in the future in terms of natural disasters if not handled correctly. The fact is that much of the PW imports to developing countries are originally sourced from developed countries, and the handling of PW is actually not only the end destination’s responsibility, but that of all stakeholders along the supply chain and especially the one generating it.

Both the developing and developed countries have to invest into the infrastructure to be able to recycle more of the PW (Putri et al., 2018). When it comes to regulations there are many new regulations and regulations in progress, this means that it is harder today to export and import PW. This is for the greater good of our planet and it is vital that everyone is on it and takes their responsibility. When it comes to recycling in some developing countries like Thailand and Indonesia there is a need to improve their PW recycling processes (Putri et al., 2018). In these example countries there are PW scavengers which are individuals that sort PW by themselves in order to turn it in for a financial payment. The issue with this is that some of the PW gathered are of low value or challenging to recycle, this leads to the scavengers ignoring it and leaving it be. If for example there is a process to sort out the different types of plastic and it is put in place, there will be a higher percentage of plastic recycled. First of all there needs to be some financial investments in the technology and infrastructure as stated in 1.1.2.

The four Case Countries investigated in this study do show some interesting differences. The thought was that they would represent roughly three different “stages of development”, though with some allowance for regional differences. This was not at all clear, however.

Malaysia could be said to be on the same trajectory as China, only just getting started with its large PW imports where China has already completed the period where it needs these and thus discontinued imports. Germany and the USA, however, do not fit well into that picture. Instead of having very low imports, they both have significant imports and Germany's have been continually increasing over the two decades. This difference likely has something to do with Germany's situation within the EU, compared with the USA's greater capacity for PW generation. The exports corroborate this; All three countries' exports decrease when China's tightened regulations hit, but Germany is the least affected of them.

5.1.2. Impact of Regulation

There are evidently cases where regulation impacts PW trade, but not perhaps exactly in the way one would expect from the PHH. The prime example is of course China, and there a successive tightening followed by a complete ban caused a complete collapse of imports. However, the PHH would cause us to expect PW flows to simply move to the next best target after this, which is not exactly what happened. While it is true that some countries massively increased their imports in the immediate wake of China's ban, it is also true that the total amount traded decreased significantly. In fact, this implies that with the removal of Chinese demand and capacity, there was no longer any economic rationale for much of the exports, which would tend to favor the RHH as an explanatory model. If this is correct, the main driving force in play here is the economic interest of industry in developing countries, rather than that of polluters in developed countries. Still, there is a significant gap between the amount China decreased its imports and the total amounts of PW traded, so clearly some of it was still offloaded to other importing countries.

The analysis of 33 (mainly OECD) countries showed that there did appear to be some correlation between strong regulations and large exports, especially during the middle years of the period (~2005-2015). The results were however inconsistent, so while it might be possible to claim there is some connection there, it is not enough to conclusively state that EPSI is a useful predictor of PW exports. Comparing the performance of the model with the overall developments in the global PW trade, it is interesting to see that the period where it was most persuasive was roughly the same period as China had its greatest share of the import market. Since the early 2010s is also when these countries had their greatest combined PW exports, it does appear that this is not entirely coincidental.

5.1.3. Global Logistics Flow

Based on the reported data, the PW trade has decreased in total amount (Net Weight) after 2018, as can be seen in Table 5. Although the plastic consumption still has increased, the total amount of PW trade has decreased. According to the data the top exporters of PW did export less amount of PW, as a consequence we can see that the exported amount of PW also has fallen. This fall in PW trade is correlated to the Chinese waste import ban. The major countries that export PW are still among the developed countries. As the use of plastics still has been growing and PW export has fallen, it means that the developed countries which have been generating the PW are now instead handling it domestically. It is very likely that they now have developed or upsized a domestic industry for handling the PW.

Our hypothesis was that because the global trade flow of containers was unbalanced (more container flow one direction) it would mean that the empty container relocation would be a driving force in PW trade. In our result we found that this correlation was low and thus not a significant factor. One reason could be that we did not go into specifics of how the countries traded with each other. Another reason was that the categorization of countries could be

investigated further and analyzed in more details, this was partly due to it being out of scope for this report that it was not done.

In an article by Kellenberg (2010) it was concluded that if there is a trade deficit between two regions in the world, it would be cheaper for one region to ship wastes to the other (Kellenberg, 2010). The differences between the article by Kellenberg (2010) and our report is that they compare the prices in freight rates and mostly investigate the route between USA - Asia. Furthermore the author found out that, if the marginal costs of shipping would decrease, then the backhaul rate would also decrease and this would lead to the improvement of one region's environmental arbitrage condition to ship wastes to the other region.

5.2. Method

This section specifies the details behind how the method was used, the underlying reasons behind the choice of method, and some problematic aspects of it.

5.2.1. Data Collection, Cleansing, and Categorization

The primary data for this study is the UN Comtrade database of world trade. This data, however, is not entirely suitable in its raw form. The main things that are relevant to this study are the reporting countries, the quantities (in kg), and the monetary values of the plastic flows. Much of the information provided is superfluous (such as mode of transport, alternative units) or duplicative (such as imports and exports both counting the same physical transactions).

For instance, Hong Kong is included in this data as a "country", however it is known to mostly function as a transhipment port (it exports almost as much as it imports, which mostly holds true at least for the years before 2018) and would therefore count the trade flow data double. The study therefore disregards Hong Kong, under the assumption that its imports are largely counted into China's total. There are other transshipment ports in the world, and cases of reexportation of PW, however the case of Hong Kong is especially important to consider, as it would otherwise be the second largest importer and single largest exporter for several years. In other words, it would lead to a significant overcounting, and skew the results more than any other cases of re-exportation can be expected to do.

As an opposite problem, Taiwan does not exist in the data at all – at least officially. Instead It is labeled "Other Asia". This is not ideal, but since every other country is already accounted for, that label should correspond with what Taiwan has reported (Nyirongo & Mendoza, 2021).

One weakness of Comtrade, is that it is not particularly fast at updating. At the time of data collection, only a few countries had reported their statistics for 2022, which meant that the study had to stop at 2021, to not give an incomplete view for the last year. Even 2021 did not actually have statistics reported from all countries, but since every country does not submit statistics every year, and the largest and most significant countries do, the reported values for 2021 should not be too off-mark.

The trade statistics were then used in conjunction with EPSI, as well as GDP, and population, to analyze any relationship between trade with PW and environmental policy, when taking into account the relative sizes of the countries. EPSI only exists for OECD countries, BRICS, and Indonesia, however, which limits this part of the study to only these 33 states. This means Vietnam, Malaysia and Mexico, which would otherwise have qualified as interesting, could

not be analyzed. The fact that EPSI was the main limiting factor in selecting countries, yet was less significant than GDP on its own, is a major point against it. If any other proxy had been readily available, covering more countries, it might make for a better predictor; or at the very least allow for a larger data set.

Additionally, the problem of EPSI's specific construction remains. It is, by design, primarily an indicator of climate change-related regulations (Botta & Koźluk, 2014). This means that it does not directly measure solid pollutants impacting the local environment, nor the release of pollutants into the ocean. PW thus seems like a fairly poor match for EPSI, though of course some aspects, such as incineration, are directly covered. Still, taking EPSI as a generalized proxy for the environmental ambitions of a country is at least somewhat informative, though it should ideally be complemented with regulations on solid waste disposal.

The four "Case Countries" were chosen to be somewhat representative of their respective regions, but also because they were extraordinarily large players in the PW trade. These two criteria are in some ways directly opposed to one another - one cannot be simultaneously typical and atypical. To some extent this is simply because they are unusually large countries, but this is not the entirety of the explanation. Malaysia for example, is in fact not particularly populous or rich, but imported more PW than neighboring Indonesia (with eight times the population and three times the GDP) every single year of the period. Even when size undoubtedly plays a role, such as with China, this does not change the fact that different countries have very different circumstances. It is highly doubtful that any other country (with the possible exception of India) could imitate it and single-handedly steer the course of the global PW market for two decades. The internal progression from an import-focussed to a domestically produced plastics recycling industry might still be analogous to that of other developing countries, however.

5.2.2. Price and Unreported Quantities

Another issue that was encountered, is the occasional absence of any reported weight in the data. This is a very significant problem, since it could lead to a massive underestimate if ignored, and it is difficult to accurately assess what it ought to be. Some countries were more consistent in their reporting than others. In total, there are 269 reports without any measure of weight (out of a total of 7006) and the country most frequently lacking values is Switzerland, on 22 occasions (11 exports, 10 imports, 1 re-import). More concerningly, however, is the fact that China has 2 missing values, the USA and the UK each 5, Germany, France, the Netherlands, and Vietnam 2 each, Turkey 1, Italy 13, and Mexico 16. Given that these countries are all among the top 10 greatest importers or exporters (by value), this missing information is potentially very damaging to the overall results.

The principle chosen to address this was calculating the average prices of exported and imported PW respectively, for each country, and, using this with the reported total sum of trade value, estimate a weight for the missing data points. This method is not without its faults, as it assumes a relatively stable average price (adjusted for inflation), which was shown to not be completely accurate (c.f. Fig. 5). It might have been better to calculate what the trend is, and use that for estimates, but given how few data points there are (maximum 20), and the sometimes large fluctuations, that would not necessarily have given more accurate results. As can be seen in Figure 4, the estimated imports and exports do not entirely match up. It is likely that this method of compensating for missing data might contribute to that, but

even for years with only very minor countries missing net weight there is a difference between the two.

5.2.3. Other Missing Data

The report is unable to directly answer any questions related to illegal transfers of waste or plastics included in other categories of waste (such as electronic waste). These other categories can also be incredibly harmful to the environment, and do include significant quantities of plastics, but it is rarely the plastics that are the most dangerous constituent material (Siddique & Siddique, 2019). On the one hand, this makes it very reasonable to prioritize the handling of those substances which can be carcinogenic, hinder growth and development, or are otherwise toxic, but it also might mean that the plastics in question end up deprioritized and forgotten.

6. Conclusion

The main takeaway of this study ought to be that there are multiple factors driving the direction and size of PW trade flows. National legislation can do much to limit imports, and there is some indication that the relative level of regulation does affect from where PW is exported. The demand for plastic as a raw material, and the domestic supply of PW do seem more influential however, and it is perhaps unrealistic to expect governments to aggressively ban PW imports if it would negatively impact PW-dependent industries.

To conclude, there are many things that need to be done in order to become a more sustainable world. In our opinion there needs to be a system where the producer of plastics products and PW needs to take more responsibility. Ideally, this would take the form of a more collaborative and uniform international regulation, with global effects. It would however likely need to have some form of incentive or enforcement mechanism, which would restrict trade with non-party states, to prevent any “plastic leakage” out of the well-regulated countries. Lastly there would need to be large amounts of financial investments in recycling infrastructure and technology in order to handle the PW, especially in developing countries.

6.1. Recommendations for Further Research

Continued research is required to determine whether the logistics behind empty containers truly influences how the PW is traded, as this report was insufficiently granular and inconclusive. It would therefore be interesting to understand more about the global imbalance's influence on PW. In addition to that, the index used in this report to measure the stringency of environmental regulations (OECD EPSI) severely limited its scope. It would be of interest to determine the effects of the environmental regulations, by using other ways to measure the strength of the national regulations.

Lastly this report only focused on a couple of potential drivers of PW trade, further research should look into other main drivers as a complement.

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Appendices

Appendix 1 Country Categories

SEA	EA	NA	NE	MED
Brunei Darussalam	**China**	Canada	Denmark	Spain
Cambodia	Macao	Mexico	Estonia	France
Indonesia	Japan	**USA**	Faroe Islands	Italy
Lao PDR	South Korea		Finland	Malta
Malaysia	Mongolia		Greenland	Monaco
Myanmar	Taiwan		Iceland	Slovenia
Philippines			Ireland	Croatia
Singapore			Latvia	Bosnia and Herzegovina
Thailand			Lithuania	Montenegro
Timor-Leste			UK	Albania
Vietnam			Norway	Greece
			Sweden	
			Germany	Turkey
			Netherlands	Syria
			Poland	Lebanon
			Belgium	Israel
				Palestine
				Cyprus
				Morocco
				Algeria
				Tunisia
				Libya
				Egypt

Appendix 2 Significance of EPSI as a predictor of PW exports

Year	p-value of EPSI	R2 of model	Coefficient of EPSI
2000	0.39943	0.7885	1.63E+07
2001	0.257	0.873	2.24E+07
2002	0.2262	0.8446	2.42E+07
2003	0.3461	0.8259	2.18E+07
2004	0.0264	0.8451	5.30E+07
2005	0.00859	0.8547	7.35E+07
2006	0.0493	0.7227	8.36E+07
2007	0.0618	0.7529	8.67E+07
2008	0.04195	0.8451	9.13E+07
2009	0.08592	0.832	7.72E+07
2010	0.01197	0.8268	1.27E+08
2011	0.02232	0.8458	1.06E+08
2012	0.02211	0.813	1.11E+08
2013	0.0395	0.7732	1.08E+08
2014	0.061444	0.7907	9.50E+07
2015	0.065711	0.7693	9.45E+07
2016	0.1286	0.5644	9.42E+07
2017	0.11247	0.7244	7.86E+07
2018	0.0524	0.6374	8.06E+07
2019	0.04925	0.3473	9.07E+07
2020	0.0335	0.5206	6.58E+07

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