Environmental impacts of the global plastic waste trade: assessment and mitigation

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Chapter 1

General Introduction

1.1 Global plastic waste trade

Plastic waste has emerged as a global concern due to the rapid rise in plastic production. In 1950, the world produced about two Mt (Mt) of plastic; by 2019, this number had surged almost 230-fold to 460 Mt (Geyer et al., 2017). This exponential growth has put significant demands on waste management systems worldwide. We see in practice that many developed countries have turned to exporting part of their plastic waste, especially when domestic recycling is economically less attractive compared with recycling abroad (Subramanian, 2022). These exports are in part encouraged by factors such as lower labour costs, no or lower environmental taxes, and less stringent treatment standards, typically leading to lower gate fees at treatment facilities in importing countries (European Environment Agency, 2023).

As a result, many wealthier nations are net exporters of plastic waste, often sending a significant portion of their total waste abroad. For example, the UK generated around 4.93 Mt of plastic waste in 2010, of which 838,000 tonnes (17%) were exported. Similarly, the United States exported about 5% of its plastic waste that year, France exported 11%, and the Netherlands exported 14% (Jambeck et al., 2015).

The trade of plastic waste raises complex environmental and social questions. On the positive side, the relatively low costs for recycling abroad can imply that the export of plastic waste may lead to higher overall recycling rates, and hence contribute to a circular economy by enabling material recovery and reducing the need for virgin resources (European Environment Agency, 2023). However, challenges remain regarding the fate of exported waste, as certain portions may ultimately go unrecycled, depending on the recyclability of the waste and the mix of waste treatment methods employed in the importing countries (Wen et al., 2021). Particularly when such exported plastic waste is inadequately processed or mismanaged via e.g. dumping or open burning, this can result in environmental issues such as soil and water contamination, the release of harmful emissions, and impacts on biodiversity (Environmental Investigation Agency, 2021). Such environmental challenges are particularly significant in less affluent nations, where regulatory oversight may be limited, which increases the potential for pollution and long-term ecological harm. In this way, plastic waste exports lead also to environmental justice concerns. Shifting waste to countries with fewer resources and less stringent regulations can disproportionately affect local communities by increasing exposure to pollutants and health risks linked to unregulated waste disposal practices (Stoett et al., 2024).

In response to the growing challenges associated with the plastic waste trade, several policy initiatives have been taken to reshape global trade patterns. One of the most significant shifts occurred in 2018 when China introduced a ban on plastic waste imports, which reduced its share of global plastic waste imports from over 50% in 2016 to less than 1% by 2018. The plastic waste refers to waste PE, PS, PVC, and others under the Harmonized System (HS) commodity code 3915. This policy triggered a 45% drop in global plastic waste imports, from 12.83 Mt in 2017 to 7.27 Mt in 2018. Following China's ban, plastic waste exports were redirected to other Asian nations, particularly Malaysia, Turkey, Indonesia, and Vietnam (Our World in Data, 2022). Since 2019, global plastic waste imports have stabilized at around 5 to 6 Mt annually.

Following China's 2018 ban, the Basel Convention Plastic Waste Amendments (referred to as "the amendments") implemented in 2021 took additional steps to regulate the global plastic waste trade. The Basel Convention is an international agreement aimed at controlling the transboundary movement of hazardous waste (Basel Convention, 1989). The primary change under the amendments is that exports of mixed plastic waste now require prior informed consent (PIC) approval, while plastic waste that is sorted by polymer type, intended for recycling, and nearly free from contamination is exempt from this requirement.

The amendments also led to stricter regulations on plastic waste shipments, particularly within the EU and OECD. In 2021, the EU aligned its waste shipment regulations with these amendments, fully banning exports of mixed plastic waste to non-OECD countries. Similarly, the OECD updated its registration system in 2021 to comply with PIC procedures, requiring contact information for regulatory authorities and pre-approved recovery facilities (OECD, 2021). These policy changes are expected to shift trade patterns toward more exchanges within the Global North, contrasting with the historically prevalent North-to-South trade flows.

Therefore, the plastic waste trade may enable recycling at low costs and hence lead to higher overall recycling rates. However, there are significant concerns that exporting plastic waste could increase environmental impacts. The question hence remains under which conditions plastic waste trade can contribute to environmental benefits rather than burdens, which is the focus of the research in this thesis.

1.2 Environmental impacts of plastic waste trade

To fully understand the true impact of exported plastic waste, we must gain insights into trade volumes, recycling rates, impacts of plastic waste treatment methods, and how policies on plastic waste trade influence the former factors. We will discuss these elements in the sub-sections below.

1.2.1 Trade volumes

The United Nations Comtrade database is one of the most comprehensive sources to monitor the international trade of commodities, including plastics and plastics waste. It is managed by the United Nations Statistics Division (UNSD) including statistics on over 5,000 commodities from approximately 200 countries since 1962 (UN Comtrade, 2024). It includes both annual and monthly bilateral trade data, detailing the reporting country's role as either importer or exporter, its trading partners, commodities, trade volumes (with over 60% measured in kilograms and the rest in units, litres, etc. (Zhang et al., 2022)), and trade values expressed in terms of Free on Board (FOB) or Cost, Insurance, and Freight (CIF) prices.

A problem with relying on UN Comtrade to monitor plastic waste trade flows is that the database suffers from bilateral trade reporting asymmetries. Such asymmetries occur when a country's reported trade statistics do not align with the corresponding data reported by its trading partners (Cuñat & Zymek, 2023). Ideally, a country's reported exports (including both trade values and volumes) to a partner should match the partner's reported imports from that country, and vice versa. The mismatches in Comtrade can occur due to pricing systems (with trade values often recorded as FOB for exports and CIF for imports), the misclassification of the same product under different commodity codes by the country of import and export, transit trade, time lags, or intentional misreporting, such as fraud, corruption, and smuggling (ESCAP, 2016).

According to UN Comtrade, global plastic waste imports reached a peak of 16.51 Mt (Mt) in 2016, with China and other Asian countries accounting for 53% and 24% of these imports, respectively. However, reported global plastic waste exports for the same year totalled only 11.31 Mt. This significant gap underscores the issue of bilateral trade reporting asymmetries.

In environmental assessments, linear scaling between impacts and the quantity of product, material, or service analyzed is commonly assumed (Rebitzer et al., 2004). Consequently, overestimating or underestimating trade volumes could result in biased estimates of the environmental impacts associated with plastic waste trade. Therefore, reconciling waste trade and reducing these asymmetries are crucial prerequisites for accurately quantifying environmental impacts.

1.2.2 Recycling rates

The recycling rate of imported plastic waste serves as a critical indicator for evaluating the environmental impacts of the plastic waste trade. Higher recycling rates indicate that a greater proportion of plastic waste is being properly recycled, leading to lower mismanagement rates and reduced environmental impact. Conversely, lower recycling rates suggest a higher likelihood of mismanagement, meaning a larger portion of imported plastic waste may end up being incinerated, landfilled, dumped, or burned—activities that contribute to environmental impacts to varying degrees.

Existing studies often rely on domestic plastic recycling rates or broadly estimated scenario-based rates, which lack precision for evaluating the fate of imported plastic waste. For example, Wen et al. (2021) examined the environmental impacts of plastic waste imports shifting from China to Southeast Asia after 2018, using domestic recycling rates ranging from 10% to 40% for five Southeast Asian countries. Similarly, Bourtsalas et al. (2023) estimated the environmental impact of treating imported plastic waste in the USA using recycling rates between 8.7% and 50%. Bishop et al. (2020) used a low-to-high range of recycling rates from 50% to 90% due to a lack of official data on exported plastics from Europe.

Using the domestic recycling rate for imported plastic waste is problematic for two main reasons. First, domestic plastic waste often comprises difficult-to-recycle mixtures collected from various sources, particularly in regions with inadequate waste collection and sorting systems. In contrast, imported plastic waste is typically more homogeneous, having been pre-sorted for export (Australian Government, 2024; United States Environmental Protection Agency, 2021). Second, trade data from the UN Comtrade database shows that importing countries pay for plastic waste, reflecting its economic value. If the imported waste were not converted into valuable recyclates but dumped or incinerated, importing companies would incur significant financial losses, making such practices unsustainable. Thus, any viable approach must ensure that a sufficient portion of the imported plastic is recycled into economically valuable products to offset the initial costs.

1.2.3 Life cycle impacts of plastic waste treatment methods

A country's plastic waste treatment mix represents the distribution of various plastic waste treatment methods used domestically. Environmental impacts from plastic waste treatment are shaped not only by the recycling rate but also by the proportions of other treatment methods, which differ according to each country's specific treatment practices. For instance, if the estimated recycling rate for imported plastic waste in the USA is approximately 60%, the remaining 40% of non-recycled waste is likely landfilled. In 2018, the U.S. plastic treatment mix was composed of 76% landfilling, 16% incineration with energy recovery, and 8% recycling (United States Environmental Protection Agency, 2020).

Each waste treatment method has distinct life cycle environmental impacts. Incineration methods vary significantly: incineration with energy recovery has a smaller climate impact compared to incineration without energy recovery, while open burning shows the greatest contributions to climate change, ecotoxicity, and human toxicity (Pathak et al., 2023). Landfill methods also differ in impact. Sanitary landfills, where landfill gas is captured and leachate is treated, have a smaller environmental footprint compared to unsanitary landfills and open dumping. In unsanitary landfills, waste is merely covered and compacted, whereas open dumps leave the waste unprotected, both of which result in increased environmental exposure (Doka, 2018). Mechanical recycling, by contrast, generally results in lower life cycle environmental impacts compared to other methods because it reduces the need for virgin plastic production, which is associated with higher pollution levels and greater environmental impacts (Ragaert et al., 2017).

It is further essential to capture the varying environmental impacts of the same treatment method across different countries. For instance, incineration with energy recovery produces different amounts of recovered energy depending on a country's energy mix and the efficiency of its energy recovery technologies, directly influencing the environmental outcomes (Lombardi et al., 2015). Similarly, the environmental benefits of mechanical recycling depend on the level of avoided virgin plastic production, which varies across countries due to differences in production practices (Schwarz et al., 2021). Thus, a comprehensive environmental assessment of plastic waste treatment must consider both the treatment mix and the distinct life cycle impacts of each treatment route across different geographic contexts.

1.2.4 Impacts of policies

Trade policies can directly influence plastic waste trade volumes and patterns, thereby impacting environmental outcomes. Among all national and international regulations, China's import ban stands as the most significant intervention, leading to a sharp decline in plastic waste trade volumes (Brooks Amy et al., 2018). Wen et al. (2021) found that after the implementation of the Chinese import ban the global plastic waste trade dropped by 45.5% in 2018 compared to the baseline period (2008–2016). Their modelling further suggested this drop in trade also leads to lower life cycle impacts on four key environmental impact categories—fine particulate matter formation, freshwater ecotoxicity, human carcinogenic toxicity, and water consumption.

In contrast, the environmental consequences of the 2021 Basel Convention Plastic Waste Amendments have not been thoroughly researched yet. As discussed in Section 1.1, these amendments may accelerate a shift in trade patterns from the traditional "North-to-South" flows to more "North-to-North" trade. In principle, one could argue that this will lead to lower impacts of plastic waste treatment: waste management systems in the Global South are often underdeveloped. Open burning, which significantly contributes to climate change and ecotoxicity, is common in major importing countries such as Indonesia, Vietnam, and Malaysia (Pathak et al., 2023). However, the changes in environmental impacts remain uncertain. Imported plastic waste is often pre-sorted and sent directly to recycling facilities, which reduces the likelihood of improper treatment. Moreover, the lower gate fees in the Global South may result in overall recycling rates that are comparable to those in the Global North. It is hence important to assess how policies lead to changes in trade patterns, overall recycling rates and treatment patterns and related environmental impacts of traded plastics waste.

1.3 Research gaps and methodology

To assess the environmental impacts of plastic waste trade and to understand how to mitigate them, several research gaps related to the key elements identified in Chapter 1.2 must be addressed.

1.3.1 Reconciliation of plastic waste trade data

Accurate trade volume of bilateral trade requires reconciliation methods. The Base pour l'Analyse du Commerce International (BACI) database (Zou et al., 2023), developed by the Centre d'Études Prospectives et d'Informations Internationales (CEPII) (Gaulier & Zignago, 2010), is probably the most widely used global trade database in which trade reporting asymmetries have been reconciled.

However, two major issues arise with BACI’s approach. First, it does not adequately account for systematic reporting errors, where a country consistently over- or underreports trade volumes. For example, if a country persistently underreports its plastic waste imports by 500 tonnes compared to its trading partners to evade environmental regulations, BACI’s method may still assign greater weight to this country. This is because the method relies on the variance of trade reporting discrepancies, and the consistent underreporting leads to low variance. Second, BACI applies a country-specific weighting factor without distinguishing by commodity, reporting period, and the country's role as an importer or exporter. Therefore, reconciliation methods that address systematic reporting errors and differentiate between countries, their trading roles, commodities, and reporting periods are needed.

Several other reconciliation methods have been reported in the literature. Some authors suggest relying solely on import data, as imported goods are often subject to tariffs, which provide authorities with an incentive to monitor these imports closely (Feenstra et al., 2005). Another approach suggests analyzing implicit prices in Comtrade by comparing monetary and physical trade data, and then trusting countries that report an implicit price close to the world average (Chatham House, 2024). However, all these methods share similar limitations to BACI, such as overlooking systematic reporting errors and relying on generalized country-specific weighting. Moreover, there is a lack of systematic comparisons of trade reporting reconciliation methods in the scientific literature. This underscores the need for more refined and reliable reconciliation techniques, building on existing methods.

1.3.2 Evaluation of the recycling rate of imported plastic waste

Determining the recycling rate of imported plastic waste can be approached in several ways. Ideally, on-site monitoring of how the imported plastic waste is processed by importers using a mass balance approach would yield the most accurate results. This requires however laborious field work and accounting activities across a large number of firms abroad, which is not a viable working method for this thesis project. As indicated, other researchers used as next best the average recycling rate of nationally generated plastic waste in a country (Wen et al., 2021), which is highly problematic for the reasons discussed in section 1.2.2.

An alternative approach is via mapping the costs and benefits of recycling, allowing the derivation of a minimum recycling rate needed for economic feasibility. Although the cost-benefit analysis may not achieve the same level of accuracy as physical measurements, it offers a standardized and comparable recycling rate across different countries, types of plastic waste, and reporting years.

1.3.3 Modelling the environmental impacts of plastic waste trade

For modelling the life cycle impacts of plastic waste trade, we need information on the treatment mix of imported plastics in a country and insight into the impacts of the treatment process. Regarding the treatment mix, Section 1.3.2 has already outlined the approach proposed in this thesis to assess the recycling rate of imported plastics. For the remaining waste treatment, data is available for most countries, typically expressed as an average treatment mix across technologies such as incineration, controlled landfill, uncontrolled landfill, and others.

For specific waste treatment technologies, Life cycle assessment (LCA) is the to-go method to get insight into the life cycle environmental impacts of waste treatment. For this, we need insight into the direct impacts of the technology (foreground process), and the life cycle impacts of inputs in the waste management technology (e.g. electricity; so-called background processes). This description already makes clear that the life cycle environmental impacts of plastic waste treatment methods can vary across countries: both the foreground and background processes may differ.

However, existing LCAs on plastic waste treatment usually do not differentiate Life Cycle Inventory (LCI) data by country, since the most used databases tend to have limited geographical coverage. For instance, Wen et al. (2021) applied LCA to quantify the environmental impacts associated with the treatment of traded plastic waste. By using LCI data directly sourced from the Ecoinvent database without further adaptation, most non-European countries share the same per-unit environmental impact for waste treatment, which can inevitably skew their assessment results. Similar issues are found in Bourtsalas et al. (2023) study on the environmental impacts of the USA's plastic waste exports, where the LCI used in their LCA lacks adaptation for scenarios involving the import and handling of waste in other countries. Therefore, adapting the original LCI data to reflect the specific conditions of various countries is essential for improving assessment accuracy.

1.3.4 Assessing the environmental impacts of policy interventions

As discussed in section 1.2.4, policy interventions such as China’s 2018 ban on plastic waste imports and the 2021 Basel Convention Plastic Waste Amendments had a major influence on plastic waste trade patterns.

While China’s import ban has been widely studied for its immediate effects on trade volumes (Brooks Amy et al., 2018; Wen et al., 2021), research on structural shifts in global trade patterns following the 2021 amendments remains limited. These amendments may have introduced less obvious but still important changes, with trade volumes stabilizing between 5 to 6 Mt annually since 2018, potentially masking shifts in trade routes and dynamics. Furthermore, there are suggestions to ban the North-South plastic waste trade almost in full and to ensure that plastic waste is recycled or treated in the country or country blocks of origin.

Additionally, comprehensive assessments of the environmental benefits and drawbacks of such policy-induced shifts in trade are lacking. By filling the knowledge gaps identified in the former section on trade volumes, specific recycling rates of imported plastic waste, and life cycle assessment information on the treatment of plastic waste, it becomes possible to conduct such thorough assessments. For this, the estimated life cycle impacts of plastic waste treatment given the actual/baseline trade patterns, are to be compared with the life cycle impacts of plastic waste treatment with scenarios of alternative trade patterns that are the result of specific policy interventions.

1.4 Overall research question and sub-questions

In sum, the central research question can be summarized as follows: *How can the environmental impacts of the global plastic waste trade be assessed and mitigated?*

With the identified research gaps in section 1.3, we now can formulate the following sub-questions:

RQ 1: How can plastic waste trade data be reconciled given bilateral trade reporting asymmetries??

RQ 2: What are the recycling rates of imported plastic waste across different countries and waste types?

RQ 3: What are the environmental impacts of plastic waste trade?

RQ 4: How do the Basel Convention Plastic Waste Amendments affect the environmental impacts of the plastic waste trade?

1.5 Overview of the thesis

Chapter 2 addresses RQ1 and investigates three methods for reconciling trade data discrepancies between importing and exporting countries. These methods aim to address the limitations of current reconciled trade data, including systemic reporting errors (consistent over- or under-reporting) and generalised country-specific weighting factors. The reconciled plastic waste trade data will then be used to model its environmental impacts.

Chapter 3 tackles RQ2 by developing the metric of the *Required Recycling Rate* (*RRR*) to evaluate the recycling performance of imported plastic waste. The *RRR*, calculated by country, year, and plastic waste type, is based on the economic break-even point where the costs of imports and recycling align with the value of recycled plastics. This metric reveals the proportions of recycling versus non-recycling, making the foundation for assessing the environmental impacts of plastic waste.

Chapter 4 addresses RQ3 by modelling the environmental impacts of plastic waste trade through both trade and 'non-trade' scenarios. This includes one trade scenario and three 'non-trade' scenarios, representing varied plastic waste treatment structures among the top 18 trading countries in 2022. The model calculates the annual environmental impacts and serves as a foundation for evaluating the effects of international regulations on plastic waste trade.

Chapter 5 focuses on RQ4 by examining changes in trade patterns and environmental impacts among 21 countries before (2019–2020) and after (2021–2022) the Basel Convention Plastic Amendments. This chapter explores further the accelerated shift from global 'North-to-South' to 'North-to-North' trade post-amendments and its potential environmental benefits.

Chapter 6 synthesizes the results from each chapter, highlighting their contributions to addressing each research question. It provides a reflection on the research findings, discusses limitations, and suggests potential avenues for future research.