Trading Responsibility: navigating national burdens in a globalized world

Navarre, N.H.

Chapter 6

General Discussion

6.1 Introduction

The objective of this thesis is to answer the following research question:

> *How is trade affecting the environmental impacts of the food and plastic waste systems?*

As indicated in the introduction, to this end the following sub-Research Questions will be answered by exploring multiple dimensions of the food system before tackling the plastic waste system:

> RQ1: How would global agricultural land-use change if countries could reduce their dependence on food trade?
>
> RQ2: How does food consumption in the Netherlands contribute to domestic and international plastic pollution?
>
> RQ3: How does international trade contribute to global plastic pollution?
>
> RQ4: How are international trade policies affecting the contribution of trade to global plastic leakage?

Section 6.2 builds on the results compiled in chapters 2-5 to offer a more general and holistic discussion that addresses this main research in the context of societal implications and future research avenues to further refine the insights offered in this dissertation. After this, section 6.3 discusses the limitations of the dissertation while offering future research lines to refine current work. Finally, section 6.4 offers final remarks and additional insights drawn from the entirety of the research presented.

6.2: Synthesis of research questions

6.2.1. RQ1: How would global agricultural land-use change if countries could reduce their dependence on food trade?

In chapter 2 we explore the feasibility of shifting to a food system which couples national food production to national food consumption. We use the EAT-Lancet diet as a foundation of our assessment to ensure that our conclusions would be based on food production that would not only be feasible within national agricultural land areas but also provide a nutritious diet. Our findings reveal that while many countries are heavily dependent on global food trade, 51% of the global population lives in countries that have sufficient agricultural land and production diversity to theoretically supply their populations with an EAT-Lancet diet. The EAT-Lancet diet we modeled indicates that food consumption could be nearly halved, largely by reducing a currently excessive consumption of roots and tubers and sugar. However, our analysis reveals that decentralizing the food system such that all nations produce what they require, would lead to efficiency losses in feed production and waste, each increasing relative to the food consumption of our modeled EAT-Lancet diets. In particular, an increase in food production would be required in sub-Saharan Africa and Southeast Asia, where supply chain inefficiencies would limit the agricultural land-use savings from shifting to an EAT-Lancet diet consumed in appropriate quantities. The findings emerge despite the EAT-Lancet diet's reduction in consumption of meat compared to current food consumption patterns.

Overall global agricultural land-use would decrease, but only due to the dietary changes modeled. The land-use efficiency of the global food system would decrease with the fraction of food waste increasing and average yields decreasing.

We then turn our attention to the countries that host the remaining 49% of the global population that would not have sufficient agricultural land to incorporate an EAT-Lancet diet through national food supply chains. Via a combination of food-system interventions further shifting food consumption patterns away from meat consumption, improving local crop and livestock yields, and optimizing supply chains to reduce food loss and waste, we find two globally important outcomes. First, 95% of the global population lives in a country that has a pathway to source a nutritious diet within the agricultural land resources, and second, universally implementing these interventions could reduce global agricultural land use by 71%.

Analyzing these interventions at a national level and identifying solutions for each country individually helps us progress towards a more robust global food system. The interventions we've put forward provide pathways and flexibility for nations across all income groups, creating a global food system that can allow for more local food production, shorter supply chains, and reduce the current overdependence on trade of certain countries. Such changes can improve local food resiliency and reduce the vulnerability of these trade-dependent countries that have repeatedly faced food crises due to international supply chain shocks caused by global economic conditions or sanitary conditions outside of their control.

6.2.2 RQ2: How does food consumption in the Netherlands contribute to domestic and international plastic pollution?

In chapter 3 we explore another important dimension of the food system: plastic waste generation. In this chapter, we establish a plastic intensity for the current Dutch diet, by collecting data from various literature sources. We estimate the plastic waste generated from food consumption in the Netherlands in 2019 by connecting our plastic intensity to Dutch dietary surveys, before connecting the plastic waste to the Dutch post-consumer plastic waste network.

We find that on average 2 grams of plastic waste was generated for every 100 grams of food consumed in the Netherlands (including beverage consumption). This generated a total of 279 kilotons of plastic waste in 2019. By tracking this waste through the Dutch post-consumer plastic waste network, we find that over 37 kilotons were exported, largely to South and Southeast Asia and West and Central Asia where plastic waste infrastructure is more susceptible to mismanagement.

In total, 6.1 kilotons of Dutch plastic food packaging were lost to aquatic environments in 2019, primarily in Turkey and Malaysia which accounted for 2.4 kilotons. Only 1.3 kilotons of the 6.1 kilotons are the result of littering within the Netherlands. The remaining 4.8 kilotons were the result of leakage points

international, highlighting the spatial disconnect between plastic waste generation in the Netherlands and its global impacts on the environment.

6.2.3 RQ3: How does international trade contribute to global plastic pollution?

In chapter 4, we further explore the role of international trade on plastic pollution. We expand our scope from chapter 3, by incorporating all plastic waste traded from all countries. We developed an innovative model that spatially connects mismanaged plastic waste from both domestic and imported sources to perennial aquatic environments. We then model which fraction is likely to reach marine environments, either directly, or from rivers, to further compartmentalize the sinks of aquatic plastic debris.

This work was the first to calculate the effect of trade on global plastic pollution to the aquatic environment (both freshwater and marine), improving our understanding of which countries most drastically shift their burden of waste management and underestimate plastic pollution caused by the generation of their plastic waste.

We estimate that plastic waste exports generated an additional 1.5 Mt of plastic debris in 2019, of which 0.17 Mt reached the oceans. Although 1.5 Mt of aquatic plastic debris resulting from international trade is comparatively small in relation to the 92 Mt of aquatic plastic debris, the traded fraction still represents a critical source of marine plastic debris. Traded plastic waste was found to be the third largest source of marine plastic, only behind Indonesia (0.7 Mt) and China (0.3 Mt), uncovering an important, and previously unconsidered, source of marine plastic debris.

Japan, Germany, the United States, and the United Kingdom were found to be the most influential stakeholders (by total volume) to the phenomena, though countries such as Australia, Norway, and Denmark, are expected to underestimate their contribution to plastic pollution in aquatic environments by a factor of 5. In total, we expect high-income countries to be responsible for 51% more freshwater plastic pollution than previously expected, and for twice as much marine plastic pollution.

These findings reveal the breadth of critical stakeholders contributing to plastic debris reaching freshwater and marine environments and reveal some critical flaws in the plastic waste management policies of many high-income countries. These policies have largely been guided by conclusions from life cycle impact assessments, which has pushed forward a narrative of recycling plastic waste at all costs. However, these policies have failed to properly measure recycling metrics, partly due to allowing countries to incorporate exports in these statistics, resulting in overestimated recycling rates. Particularly in Europe, we find that over one third of plastic waste collected for recycling is instead exported, largely to low- and middle-income countries with high rates of mismanagement raising concerns regarding recycling metrics and recycling policies in these countries.

6.2.4 RQ4: How are international trade policies affecting the contribution of trade to global plastic leakage?

Finally, after contextualizing the influence of international trade with respect to global plastic pollution in chapter 4, we explore the influence of ongoing policy changes surrounding the international plastic waste trade network in chapter 5. From 1992 to 2016, the plastic waste trade network was relatively stable, with China operating as the largest importer (45% of total imports) during that period. However, in 2017 China announced it would ban the import of plastic waste in 2018 due to repeated concerns regarding the quality and recyclability of the plastic waste exported to them. Indeed, the country had ambitions of utilizing these waste streams to stimulate its secondary plastics market, but instead, the waste began to damage and pollute local ecosystems. After implementing softer policy changes such as the 'Green Fence' geared towards improving the quality of the waste imported, Chinese authorities acknowledged they could not prevent the issue of international plastic waste polluting their environment.

China's ban drastically altered the global plastic waste network, and we find increased aquatic plastic debris from traded waste increased from 1.6 Mt/yr between 2012 and 2016 to 2.1 Mt in 2018. In 2019, economic conditions led to a reduction in plastic waste

generation, while in 2020 and 2021 the Covid pandemic halted many international supply chains. As a result, plastic pollution from trade decreased every year since 2019, falling to 0.7 Mt in 2021. Nevertheless, China's import ban has nearly doubled the fraction of traded plastic waste reaching aquatic environments, from 11% between 2012 and 2016 to 18% between 2018 and 2021.

Although official statistics indicate a net decrease in the volume of trade plastic waste reaching the aquatic environment, international authorities have reported a dramatic increase in illegal plastic waste trade activities since China's import ban. Authorities expect that official trade statistics may underestimate the plastic waste trade by over 40%, making these hidden flows more difficult to track and address moving forward. The countries most affected by this, including Malaysia, Vietnam, India, and Turkey, have attempted to emulate China's example and implemented import bans with varying degrees of success. Authorities from these countries have reported a growing number of illegal recycling facilities and illegal dump sites since China's ban, however, corruption and lack of resources to enforce trade barriers have limited the effectiveness of such policies. As such, estimates derived from official trade statistics of traded plastic waste reaching aquatic environments are now more likely to underestimate actual leakage quantities.

6.2.5 Discussion on the overall RQ: How is trade affecting the environmental impacts of the food and plastic waste systems?

From the previous research questions, it is clear that international trade has led to unwelcomed tradeoffs for both the food and plastic waste systems. Within the food system, in the form of consumption patterns that have shifted towards more land intensive diets which would not be feasible under autarkic conditions. In the plastic waste system, international trade has led to additional plastic waste leaking to the aquatic environment.

However, this dissertation puts forth the idea that international trade causes a knowledge imbalance among all countries involved. The food sector policies of the 1970s and 1980s, which enabled the expansion of food trade and the consolidation of food production to rich industrialized countries, have had lasting impacts seen in the 2015-2019 analysis carried out in chapter 2. While rich industrialized countries continued to develop farming techniques, improved food system efficiencies, and more generally innovated within the food system, many low- and middle-income countries were forced to rescind their food self-sufficiency policies and adopt lopsided food import policies (Clapp & Moseley, 2020). The result of this has created a drastic knowledge imbalance seen in the low yields and high rates of loss and waste in many low- and middle-income countries. This fundamental imbalance in knowledge has prevented more modern initiatives, such as the New Green Revolution for Africa, from successfully restoring food sufficiency in many African countries despite their ability to do so in the 20th century (Fischer, 2022).

Similarly, the plastic waste trade has created a knowledge imbalance between major exporters and importers. Most major exporting countries have strong rates of plastic collection and separation. Most of the plastic waste these countries export is typically either too difficult to recycle affordably or exceeds local recycling capacity. On the other hand, major plastic waste importers tend to have low rates of plastic waste collection and separation from municipal solid waste. Although there is conflicting literature on the subject, the plastic waste network in major importing countries has shifted to only focusing on developing recycling facilities, choosing to rely on already collected and separated imports, rather than investing in more expensive systems that also focus on domestic collection and separation. Since the plastic waste trade network fragments the power of major importers, each needing to be a more attractive destination than other importers, the result has been plastic waste systems that have stunted any innovation in domestic plastic waste management.

In short, international trade not only plays a major role in disconnecting environmental and social costs from consumption, it also creates knowledge imbalances which, over time, contribute to institutional and infrastructural lock-ins, preventing a transition away from trade-centric systems. Therefore, any future food policies must put a strong emphasis on international exchange of knowledge, in addition to material and economic flows, to reduce the overdependence of many countries on imports and aid.

6.3 Limitations and future research

6.3.1 Modeling the food system

In terms of the global food system, there are many important economic risks associated with removing global food trade. The 2008 economic crisis and inflation of 2022 are recent examples of financial shocks placed on the food system, increasing the price of major commodities. Removing trade could threaten efficiency gains that helped stabilize the price of food commodities. Therefore, financial accessibility to food commodities under nationally sourced diets may be extremely volatile, or entirely inaccessible to lower-income groups within certain countries. A detailed economic analysis of such a food system would be essential to further evaluating the feasibility of such scenarios.

In addition to the economic considerations of international trade and the food system, other dimensions of the food system must be considered. The influence of international trade on ongoing water crises in different regions of the world highlights the importance of gaining a deeper understanding of how new approaches to a global food system would affect the water consumption of countries. The nutrient dimension of the food system is also critical, with Nitrogen and Phosphorus playing a crucial role in driving sustainability issues caused by the food system. Currently, the global trade system shifts vast quantities of nutrients between major exporters and importers. Understanding the impacts of halting this global exchange of nutrients, plastic, and water is critical to avoid simply shifting major sustainability issues from one region of the world to another. Furthermore, improving the resolution of the analysis to a sub-national scale is crucial, as certain countries span many different biomes. This could alter the production potential of certain commodities, reveal important considerations surrounding water availability, alienate regions based on regional income variations, accentuate nutrient concerns, and more.

The analysis also does not account for the seasonality of production. Although the production data accounts for the yearly potential of production, this would have serious repercussions on a country's food losses and waste depending on their capability to properly store their production until it is needed for consumption. Considering this analysis is global, many countries that currently lack the infrastructure to store large amounts of food for a long period of time would be impacted by the omission of this consideration, thus potentially affecting the conclusions drawn within chapter 2. Furthermore, FAOSTAT production data can also be an inaccurate representation of actual food production. The data is collected via questionnaires which may be prone to misrepresentation. Researchers compared FAOSTAT production data to ESA Climate Change Initiative Land-cover (ESA-CCI LC) maps and found that only 8% of countries, largely OECD countries, reported FAOSTAT data that matched ESA-CCI LC map data. ESA-CCI LC maps estimate that up to 66% of countries may underestimate their production compared to FAOSTAT data, highlighting the uncertainty surrounding FAOSTAT (Liu et al., 2018). Nevertheless, ESA-CCI LC maps are not a perfect representation of production either, and the variations in production estimates based on which data source is used highlight the continued need for improved data surrounding the food system, particularly in middle- and low-income countries.

From a societal perspective choosing between plastic leakage or increasing the environmental burdens of the food system seems like an impossible choice. This conundrum is frequently alluded to in this dissertation. A key conclusion of chapter 3 is that plastic food packaging policies could be adapted to optimize the reduction of plastic waste generation while minimizing the risk of food waste. Future research exploring the trade-offs of reducing plastic food packaging and food waste would add invaluable context in balancing plastic leakage and food waste ensuring that future policy decisions do not mitigate one option while exacerbating the other.

6.3.2 Modeling plastic waste generation and disposal

From a plastic waste system perspective, global plastic waste trade accounts assign a positive financial value to the traded plastic waste. The only way to recover such payments for waste imports is by producing products with a positive value via recycling. Such waste is also exported in rather concentrated and homogenous flows to recyclers in importing countries. This would imply imported waste is much less likely to be mismanaged as domestically generated waste, which first must be collected and sorted before a similar concentrated waste stream for recycling is available, while particularly the collection step is prone to waste leakage. Chapter 4 acknowledges this potential within the sensitivity analysis. Many governments however, including China, Malaysia, and Turkey openly stated that imported plastic waste is largely or partly mismanaged and leaked within their borders (Gündoğdu & Walker, 2021; Khan, 2020; Sarpong, 2020; Tan et al., 2018). This issue is not exclusive to plastic waste, textiles and e-waste are other major waste sectors that are mismanaged in importing countries despite being assigned a positive economic value within international trade accounts. Nevertheless, exploring the global plastic waste trade from an economic lens and trying to assess real recycling rates after exports would provide valuable considerations, particularly because the recyclability of plastic waste export flows is likely to vary from country to country and even sub-nationally.

Finally, when considering the works analyzing the international plastic waste trade, data sources estimating plastic waste generation and plastic waste mismanagement are generally only available at national scales. This resolution is very low as the collection rate of plastic waste typically varies sub-nationally, particularly in urban and rural areas of low- and middle-income countries. Furthermore, estimates of national plastic waste mismanagement sometimes vary due to methodological and temporal differences between sources. Certain countries only report the plastic mismanagement of collected waste, while others report the mismanagement rate of the waste in its totality, leading to large ranges in estimates. For instance, Russia is estimated to mismanage 18% in Kaza et al.'s dataset, while Lebreton and Andrady's dataset estimated 96% (Kaza et al., 2018; Lebreton & Andrady, 2019b). The two main sources of national plastic mismanagement used in this dissertation also vary temporally with Kaza et al.'s dataset being developed using data primarily collected between 2011 to 2017 while Lebreton and Andrady's dataset was largely collected from data recorded between 2009 and 2013 (Edelson et al., 2021; Kaza et al., 2018; Lebreton & Andrady, 2019b).

The scientific literature also applies additional definitions of mismanagement that vary between studies. For instance, Borrelle et al. assumed certain waste sent to unspecified landfills should be considered mismanaged in low-income countries, while that same management pathway was considered properly managed in high-income countries (Borrelle et al., 2020). This combination of uncertainty at the level of baseline data, as well as methodological decisions within the scientific community, has led to wide ranges in plastic leakage estimates; particularly in low- and middle-income countries which are expected to be the largest generators of plastic debris in aquatic environments. Therefore, harmonizing such datasets should be a critical priority to further refine future global studies of plastic leakage to the environment.

In addition to unclear disposal pathways, the mass of plastic waste generated by the sources used in such modeling exercises could significantly underestimate the actual quantities of plastic waste generated annually. For the most part, datasets from The World Bank or The Waste Atlas are derived from post-consumer plastic waste, however, preliminary results of a global plastic footprint indicate that up to 40% of total plastic waste generation may occur at pre-consumer supply chain stages and would therefore be unaccounted for in such datasets. Although this packaging is not seen by consumers, it plays an important role in ensuring efficient pre-consumer food supply chains and should therefore be considered when estimating the plastic intensity of food items, if possible. Similarly, estimates of national-scale littering remain virtually nonexistent, implying that current plastic waste estimates only account for the fraction which reaches the post-consumer supply chain. We relied on simple assumptions despite littering varying significantly from country to country, and even sub-nationally, however, it is important to note that significant fractions of plastic, both in the form of pre-consumer packaging, and littered plastics are not encompassed in most traditional plastic waste generation data estimates.

Furthermore, finding consolidated plastic food packaging data for all items consumed in the proved challenging. Collaborations with food distribution companies could alleviate both these issues and allow for much more refined research to be conducted regarding the plastic footprint of food systems. Improving this aspect of our models could influence our estimate of plastic waste debris, particularly in countries with low rates of mismanagement once the waste enters the post-consumer plastic waste network.

This thesis uses population density as a proxy to estimate the location at which plastic waste is leaked to the environment, however, this is at best a general approximation. These studies could be improved by leveraging high-resolution satellite data available to researchers. Satellite data can be coupled to artificial intelligence tools such as machine learning, deep learning, and neural networks to generate geospatial estimates of mismanaged plastic waste. Coupling locally or remotely observed data to global plastic leakage models could significantly improve estimates of where plastic waste is lost to the environment. With current models, the location at which plastic is originally leaked to the environment is critical to understanding the movement of plastic waste through the different environmental compartments (terrestrial, aquatic, marine), therefore relying on observational data, rather than proxies, to initiate such global calculations could significantly improve our mass estimates of plastic waste leakage which are currently diverging within the scientific community.

6.4 Policy Implications

Leakage of plastic waste to aquatic environments has largely been framed as a consumer habit issue in high-income countries (González-Fernández et al., 2021). Due to the high rates of waste management, the primary leakage point of plastic waste from the economy to the environment is often considered to be littering. While littering is an important source of local aquatic plastic debris, we find that national policy decisions that encourage the export of plastic waste are a far greater source of global plastic debris generated by the Dutch economy, making plastic pollution as much of a governance issue as it is a behavioral issue in the Netherlands.

Specifically, we find that soft drinks, grocery products (e.g. pasta, rice), and dairy are the largest contributors to exported plastic waste due to both the quantity of plastic waste they generate, being the three largest generators, but also due to their use of PE and PET plastics. These two plastic types have higher recycling potentials, making them more frequently sorted waste streams that can be exported from EU countries. The quality of these waste streams remains very contentious however, as the recyclability of such export streams was heavily contested by China in the 2010s.

In terms of plastic waste policy, the U.N. has made its ambitions of a global plastic waste treaty clear in recent years. This dissertation brings forward a novel perspective by quantifying the role of international trade on global plastic pollution. Many policies defer addressing plastic waste trade to the Basel Convention, and though the amendments of 2018 were a step forward, those amendments are still limited by certain major traders refusing to ratify them, a lack of enforcement mechanisms, and unclear definitions (Khan, 2020; Wen et al., 2021). As it stands plastic waste trade policy remains fragmented, and still places the onus of action on importers, which are frequently held back by corruption and lack of resources (Barrowclough & Birkbeck, 2022; Wen et al., 2021). For instance, the Basel Convention ensures that the costs of returning plastic waste deemed unfit for trade are paid by the exporter, however, the importing country must still carry out legal investigations with multiple international parties to prove where the unfit waste initially came from. It must also stock the waste, blocking ports, and limiting the flow of other goods. Future policies must ensure stricter oversight and quality control occur at the point of exit. Doing so will ensure low- and middle-income destinations do not become overwhelmed by international bureaucracy which regularly prevents the expedient return of illegal waste.

I also recommend any future policy regarding the recycling of plastic waste strictly disconnect recycling metrics from international trade. Including exports as part of recycling has allowed countries to continuously increase their recycling rates annually, despite very limited increases in plastic collection, separation, and recycling capacity. This recommendation is further amplified by the China import ban. With illegal trade activities reaching new heights since 2018, validating the fate of exported plastic waste as recycled has become nearly impossible (INTERPOL, 2020a). Therefore, future plastic waste policies should discourage exports, regardless of the impact this may have on reported recycling rates