Should plastic waste trade be banned?

An analysis of misguided regulatory actions and argument for expanding Scandinavian-like plastic waste trade markets

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Abstract

The current implementation of the Basel Convention undermines its stated goals by forcefully redirecting plastic waste exports to countries with higher levels of waste mismanagement. To establish a more efficient global market for plastic waste trade, we recommend a gradual introduction of trade restrictions based on plastic waste subcategories. Drawing insights from Scandinavian plastic waste trade markets, we conclude that specialization in different types of waste treatment would have a substantive impact on the world's ability to counter the global pollution crisis.

Contents

1 Introduction

1.1 Background

Recent policy developments aimed at reducing plastic pollution worldwide have dramatically reshaped the flow of international waste. While the effects of these policy developments are largely unknown, the United States is considering joining 180 U.N. Member States in signing the Basel Convention and thereby committing to rapidly throttle down domestic participation in international plastic waste trade.

Perhaps the most dramatic recent example of such regulation is China's 2017 decision to ban imports of a broad swath of solid waste products with the aim of eliminating all waste imports by 2020. Previously the world's largest importer of waste plastic, China played a crucial role in recycling plastics for many Western countries. In the wake of this decision, Chinese recycling firms fled regulatory extinction by relocating throughout Southeast Asia, notably in Malaysia, Thailand, and Vietnam - often without proper permitting [12]. Host countries, however, faced swift backlash in the form of domestic unrest [1]. In response, a second wave of import restrictions emerged including a ban on the import of most plastics to India in 2019 with similar bans implemented subsequently in Malaysia, Thailand, and Vietnam [12].

These tensions came to a head in 2019 as the Basel Convention was amended to include regulations on the global trade of non-recyclable plastic waste. Because contaminated plastics cannot be recycled, imports of such plastics may instead be dumped illegally in rivers and the ocean [1]. Indeed, it is estimated that since its commercial introduction in the early twentieth century, only 9% of plastic waste has been recycled, with the vast majority resulting in environmental contamination [2]. The 2019 amendment to the Basel Convention aims explicitly to curb this practice by banning global trade in contaminated plastics. Yet, illegal trade of contaminated plastic waste persists [12]. Contaminated rubbish that cannot be recycled is often exported illegally in falsely labelled containers. While Basel signatories such as Malaysia have sent back thousands of ships full of illegal rubbish back to their country of origin, in many other cases non-recyclable contaminated plastics are simply dumped much as they were prior to the agreement [1].

In contrast to these conspicuous examples of illegal trade post-Basel Convention, the volume of documented global plastic trade has in fact plummeted in recent years, with total imports and exports falling 90% and 85% respectively from 2017 to 2019 [13]. Simultaneously the center of plastic waste trade has shifted from China to Southeast Asia, where there is less capacity [13]. Since the global outbreak of COVID-19 in early 2020, demand for single-use plastic products has surged as consumers seek to limit their exposure to the virus. The resultant increase in waste, coincident with a pattern of global supply chain disruptions, has placed additional strain on the rapidly shifting plastic waste industry.

While the recent restrictions on international waste trade are motivated by concern over environmental contamination by plastics, some researchers conclude that because of the complexities of global plastic trade, "the consequences of such policies on the management of waste — whether domestically or when exported — and their related environmental impacts are unknown" [8]. Of particular concern is the shift in this market's center of gravity from high capability, traditional plastic importers to new entrants with lower historical presence in the market and higher potential for mismanagement.

1.2 Contributions to current literature

There are very few sources of direct, quantitative information about the amount of plastic waste pollution generated by the global plastic waste trade. Much more often, data describing volumes of plastic waste imports and exports are reported. Therefore, when determining the amount of plastic pollution to attribute to each country, an essential first step is to determine the proportion of plastic waste which will be mismanaged (i.e., become pollution) in each country. Previous research in the area has exhibited two major flaws. Firstly, when waste mismanagement proportions are reported by countries, the estimates are treated as if they were exact values, sweeping the obvious practical challenges of such estimates under the rug. Secondly, in addressing countries which do not report waste mismanagement proportions, researchers have invoked simple descriptive statistics, like conditional means, to infer missing data, again precluding any hope for principled uncertainty quantification. We have attempted to address the problem statistically, modeling the reported values as samples from a distribution which depends on socioeconomic and geopolitical characteristics of each country. This affords us a means for uncertainty quantification for both countries which do and do not report mismanagement proportions.

Prior research has also been performed under the assumption that trade is solely first-order; that is, if country A ships plastic waste to country B, the waste remains in country B. Rather than operating under that assumption, we instead determine second-order trade effects by following the amount and location of plastic waste *re*-exports [2] [8] [9]. Contemporary literature also aggregates different types of plastic waste into a single plastic waste commodity, which may misrepresent actual trade flow and mismanagement[8]. Our analysis breaks plastic waste into the three subcategories: vinyl chloride polymers, styrene polymers, and ethlylene polymers.

The segregation of plastic waste flow by polymer type particularly helps to reveal the complex multi-step trade flows characteristic of the industry. From 2017 - 2019, Russia demonstrated 30-40% annual growth in imports of plastic waste. During this period, 100% of imported plastic waste was recycled [11], while 94% of domestic waste went to landfills for the simple reason that the construction of recycling facilities outpaced recycling collection. This strange fact is apparent *only when one separates imports and exports by plastic waste subcategory.* Thereby, one may observe that Russia exports different plastic waste subcategories than they import to meet the demand of their recycling plants. Hence, any approach that extrapolates domestic waste mismanagement onto the imported waste without any regard for the type of material being treated would considerably overestimate the amount of pollution that Russia's trade partners generated.

As we have discussed above, the current literature evaluating global waste trade regulations often employs slack methodology. In addition, they almost ubiquitously analyze the consequences of a single regulatory event – China's 2018 plastic waste imports ban. Such articles invariably reach their a priori expected conclusion that waste trade regulation has a salutary effect in resolving the crisis of plastic pollution. However, by evaluating a larger collection of regulatory events and employing more rigorous methodology we find evidence that strong trade regulations may not induce a uniform improvement across countries in their responsibility for pollution, at least in the short term.

Utilizing the mismanagement predictions and proper trade flow, we estimate each country's responsibility for global plastic waste mismanagement. By reconstructing more contemporary time series data, we are able to analyze country and global responses to several recent policy events in order to gain a deeper understanding of policy impacts.

In summary, we address the shortcomings of previous models by using a three-step methodology: (i) utilizing socioeconomic and geographical covariates to provide enhanced estimation and uncertainty propagation of the prevalence of waste mismanagement in countries where direct data is and is not available, (ii) developing a model for the ultimate destination of plastic waste exports which considers second-order trade effects and plastic subcategories, and (iii) embedding the above two models in a time series framework which permits more flexible analysis of systemic shocks such as that posed by the Chinese waste import ban and the Basel Convention.

2 Materials and Methods

2.1 Estimating plastic waste mismanagement

In order to assess the effects of waste trade flows from high to low income nations, it is crucial to obtain reliable estimates of waste mismanagement in importer nations. Law et al. (2020) demonstrate that including indirect pollution via mismanagement of US recycling exports in destination nations amplifies the amount of plastic pollution attributable to the United States by a factor of five [8].

While this analysis highlights the importance of considering waste management practices in importing nations, it suffers from a key limitation of its material flow methodology: a reliance on accurate and complete reporting of waste management practices. In fact, 43 countries do not report waste treatment data to the World Bank, forcing their omission from Law (2020). Additionally, for countries that do report waste management data, other missing data are imputed as a simple regional-income conditional mean. These methods present two threats to the internal validity of the analysis. First if the propensity to report waste management data is related to waste management capacity (i.e., informative missingness), this method will systematically underestimate the indirect plastic pollution of waste exporters. Second, utilizing a simple region-income-group imputation is inflexible and accommodate unique properties of the observed distribution of reported rates of waste mismanagement 1. We propose the use of a beta regression model, with simultaneous variance regression, to obviate these pitfalls.

To motivate our regression model, we leverage previously unutilized data to construct an enhanced feature set. Crucially, our method includes the following geographic features: group indicators for small island nations and small wealthy nations (i.e., islands with area under 10,000 km^2, and states with area under

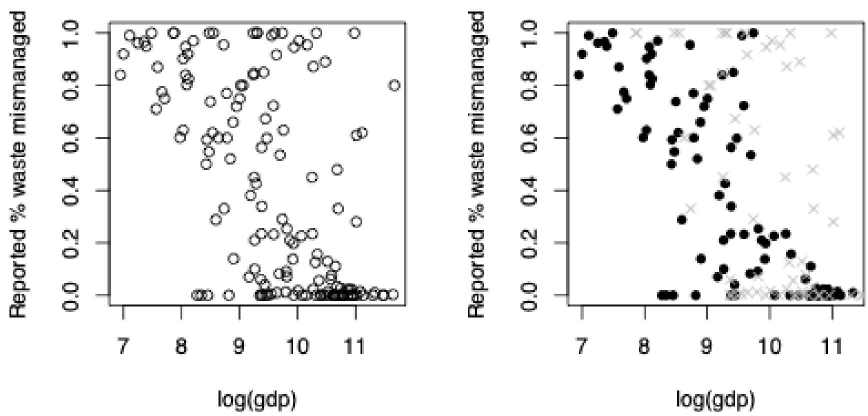


Figure 1: While waste mismanagement is often assumed to be explained well by differences in per-capita GDP, the left plot above highlights that the association is much stronger for countries with GDPs below the first quartile, whereas dependence seems to evaporate for higher GDP countries. This would at first seem to suggest we employ quantile regression or a robust regression method to minimize the influence of observations in the upper tail on our fitted `log(gdp)` coefficient. However, after inspecting which countrys' reports populated the upper tail, we discovered that nearly all of them fell into one of three categories: (1) Small island countries; (2) Small-area, high-income countries (likely to manage/mismanage only a small portion of the waste they generate, leading to unreliable estimates); (3) Heterodox countries (oil-rich middle-eastern countries and former Warsaw Pact countries). In our plot on the right, those countries are de-emphasized, revealing a strong, linear association between mismanagement and log per-capita GDP among the remaining reporting countries. This realization motivated the precision model we adopted in our beta regression - that is, we afford separate precision (*equiv.* separate variance) terms to the "pathological" and "non-pathological" reporting countries.

10,000 km^2 and PPP adjusted GDP per capita above \$30,000 USD respectively) and sub-regional indicators to allow distinctions between more practically significant regions than those defined by continent. Finally, where previous analyses took for granted reported estimates of waste management, we instead use estimates from our model's predictive distribution, permitting uncertainty propagation.

To improve upon the above methods with the aim of more fully utilizing all available data, we estimate the proportion of mismanaged plastic waste at the country level using a beta regression on economic and geographical indicators. Ferrari and Cribari-Neto (2004) propose a highly flexible regression model for a response restricted to the standard unit interval and assumed to follow a beta distribution whose mean and precision are modeled separately via logistic regression and log-linear regression [5]. Following this work, we model the proportion P of waste expected to be mismanaged by country i in region j as:

$$\begin{aligned} P_{ij} &\sim \text{Beta}(\mu_{ij}, \phi), \text{ where} \\ \mu_{ij} &= \text{logit}^{-1}(\alpha_j + X_{ij}\beta) \\ \beta_j &= \alpha + v_j \\ \log\phi &= -Z\delta, \end{aligned}$$

where in the above we use the convenient mean-precision parameterization of the beta distribution. The country-level mean is modeled via an intercept α and fixed effects β corresponding to the effect of country level covariates X. Crucially, this formulation also permits us to specify a model for the precision using a subset Z of the country-level covariates accommodating the apparent heteroskedasticity of the data. The model is fit via maximum likelihood estimation using the highly efficient quasi-Newton method of Broyden-Fletcher-Goldfarb-Shanno (BFGS) optimization using the `R` package `betareg`.

To see the results of our mean and variance regression, see 1 and 2, respectively. The reliability of our 65% predictive intervals is illustrated in 2.

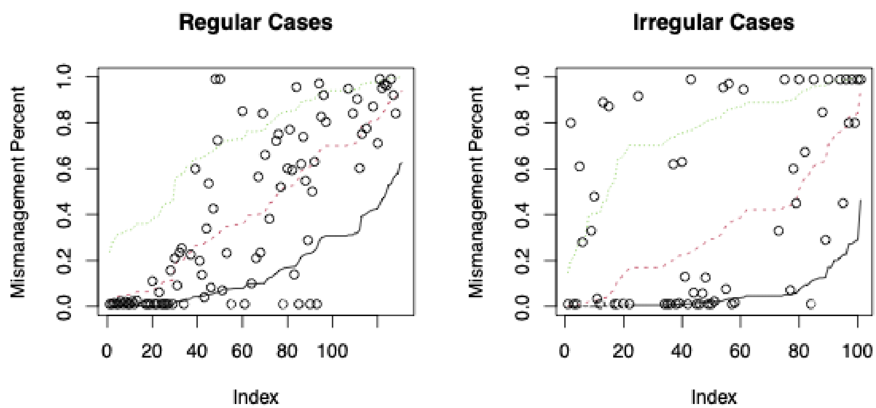


Figure 2: Plots illustrating the responsiveness of our beta regression prediction intervals to the differential variances exhibited by the non-pathological and pathological waste mismanagement reports (labeled "regular" and "irregular" above). The fitted predictive median for each country is plotted against its ranked index, and 65% predictive intervals are indicated with green and black lines above and below the dotted median line. Those countries for which waste treatment information is provided in the World Bank data are superimposed as points.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	6.63	1.15	5.77	0.00
log(GDP)	-0.75	0.12	-6.20	0.00
Africa	0.00	0.35	0.00	1.00
Australia and Pacific	-0.27	0.44	-0.63	0.53
Carribbean	-0.25	0.36	-0.69	0.49
Continental Americas	0.10	0.39	0.26	0.79
Eastern Europe and Central Asia	0.57	0.37	1.57	0.12
Europe	-0.21	0.37	-0.56	0.57
Middle East	0.95	0.41	2.30	0.02

Table 1: Coefficient estimates for the expected value in our beta regression model. Our model described the logit of the expected value of reported mismanagement in terms of log GDP per capita and regional effects. Asia is absorbed as a baseline category, to preserve identifiability. The coefficient associated with GDP is highly significant (p-value less than 0.01), and suggests that countries with higher GDP tend to mismanage a smaller portion of waste. Among the various regions, only the Middle East demonstrates a clear significant difference relative to Asia. In particular, countries in the Middle East tend to report elevated rates of waste mismanagement.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.03	0.15	0.21	0.83
Non-"Pathological" Case	0.60	0.19	3.16	0.00

Table 2: Coefficient estimates for the precision term in our beta regression model. Note that the non-pathological countries exhibited significantly lower variance (higher precision by a factor of $e^{0.6} \approx 1.8$) with p-value less than 0.01. Note that this significance value is likely overstated given our *a posteriori* strategy for constructing the "pathological case" covariate.

2.2 Accounting for second-order trade effects

To derive a quantitative estimate of a country's contribution to global plastic pollution it is critical to determine where their waste is ultimately disposed of. Most of the plastic waste trade literature is restricted to the consideration first-order exports (see Brooks et al. (2018), Law et al. (2020), Pekow (2021)). The validity of this analysis rests entirely on the tenuous assumption that if plastic waste is shipped from country A to country B, then that plastic waste subsequently remains in country B. As we demonstrate below, this assumption is untenable.

Our key contribution is to extend traditional plastic waste trade accounting by considering the second-order effects. Towards this end, we utilize additional

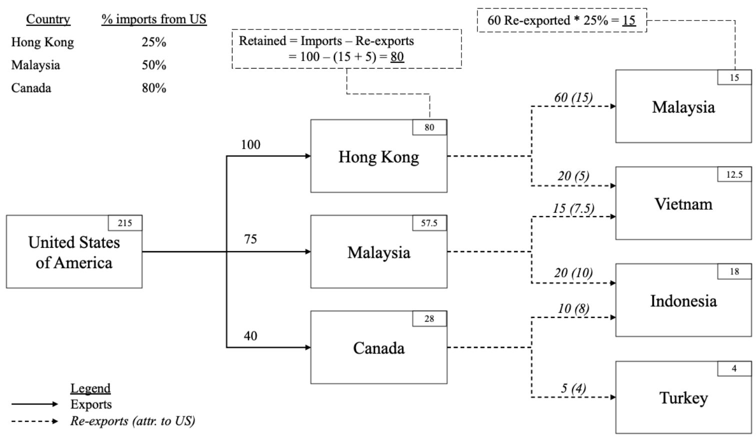


Figure 3: First and second-order plastic waste destinations

re-exports (i.e.,plastic waste originally imported from another country that is now being exported), which are reported in the UN Comtrade Database but have been neglected in previous research on the topic [4].

Additionally, we perform our analyses using plastic waste sub-categories (ethylene polymers, styrene polymers, and vinyl chloride polymers) rather than treating all plastic waste as homogeneous. Given the different environmental concerns associated with each type of plastic, this analysis leads to a finer understanding of the consequences of mismanagement within the plastic waste trade. Further, this yields a greater ability to detect secondary trade flows.

In order to estimate where a country's plastic waste exports reside, we distinguish between two forms of plastic exports: (1) plastic waste that is sent from an origin country to a direct trade partner and then re-exported to a second-order trade partner, and (2) plastic waste imports that are not re-exported. Figure 3 illustrates this with a trade flow diagram. In this fictional illustration, the United States exports 100 units of plastic waste to Hong Kong, 75 units of plastic waste to Malaysia, and 40 units of plastic waste to Canada, for a total of 215 units of plastic waste. Hong Kong then *re-exports* 60 units of plastic waste to Malaysia and 20 units of plastic waste to Vietnam. Note that these re-exports are totals by destination, so the 60 units of plastic waste re-exported from Hong Kong to Malaysia could originate from any of Hong Kong's trade partners. We make the assumption that each country is indifferent as to where their re-exported plastic waste originates from, which we justify by performing our analysis at the most granular plastic waste sub-category level and treat each sub-category of plastic waste as fungible.

The re-exports attributable to the country of origin are simply the re-exports multiplied by the proportion of imports from the country of origin. In the illustrated example, Hong Kong imports 25% of their plastic waste from the US. Thus, of the 60 units re-exported from Hong Kong to Malaysia, $60 * 25\% = 15$ is attributable to the US. Finally, the amount of plastic waste retained by the first-order trade partner is the amount imported from the country of origin less the total re-exports attributable to the country of origin.

We find that this second-order measure is more accurate when exporting plastic waste to countries that re-export much of their imported waste. For example, Estonia, Hong Kong, the United Arab Emirates, and Bahrain all re-export more than 10% of their imported plastic waste, on average. Using the simpler first-order method would overstate the plastic waste that ends up in these countries.

The result of this analysis is a multivariate time series for each high income country representing the ultimate allocation of its total plastic waste among the countries of the world, and by plastic waste sub-category. Hence, for each high income country $i = 1, \cdots n$ and each plastic type $j = 1, \cdots 3$, we obtain a time series whose realization at time t is the vector

$$\mathbf{w}_{ij}^T(t) = (w_{ij1}(t), w_{ij2}(t), \cdots, w_{ijm}(t))$$

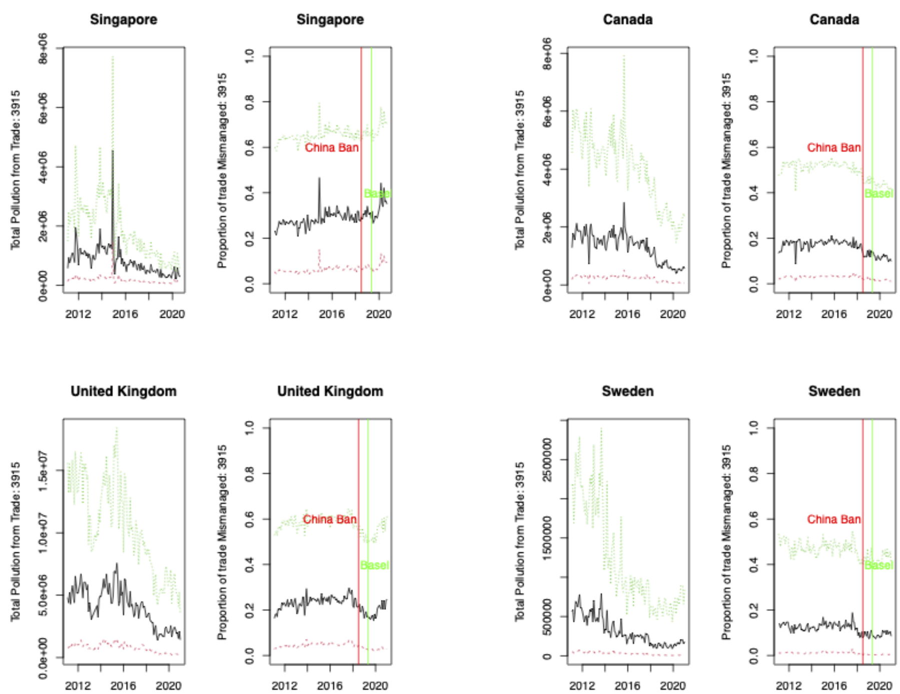
with components indicating the value in USD of plastic waste exports to countries $k = 1, \cdots, m$. We then use these results, in conjunction with the mismanagement rates estimated via beta regression as described in the section, to estimate an analogous multivariate time series whose components detail each country's contribution to global plastic pollution.

3 Conclusions

3.1 Basel Convention effectiveness

After estimating both where a country's plastic waste resides post-trade and how effective each destination country is at properly managing their plastic waste, we have a framework to analyze policy events and speculate on potential future action.

We find that the Basel Convention plastic waste amendment, signed May 10^{th}, 2019, has varying effects on countries and does not consistently achieve its aim of minimizing mismanaged plastic waste. Rather, in some cases the Basel Convention has increased global waste mismanagement. Figure 4a and 4b show two plots per country, one for total volume of exported plastic waste, and one for the percentage of waste mismanaged at destination countries.



(a) Affected by Basel

(b) Unaffected by Basel

Figure 4: Total export volume percentage mismanaged. Blank lines represent predictions; green and red lines indicate 95% confidence intervals around the prediction.

Singapore and the United Kingdom both exhibit negative responses to the Basel Convention. While the countries exported less plastic waste, the destinations of their plastic waste mismanaged a higher proportion than pre-Basel Convention. This presumably occurs because Singapore and the United Kingdom are restricted in who they can export plastic waste to; rather than opting for their usual trade partners, they instead must find countries who are still permitted to import plastic waste.

On the other hand, Canada and Sweden both exhibit positive responses to the Basel Convention. While volume of plastic waste exports are increasing for both Canada and Sweden, the waste mismanagement rate of their plastic waste decreases or remains the same.

In summary, we observe that the Basel Convention plastic waste amendment reallocates the burden of plastic waste imports. As demonstrated by the examples above, the Basel Convention can have a net-negative impact on certain countries global plastic waste pollution.

3.2 Policy recommendations

The goal of the Basel Convention's plastic waste amendment is to minimize the amount of plastic waste trade; rather than trading, the Basel Convention envisions each country managing its own waste. Having studied intra-Scandinavian waste trade, we believe that an effective way for to minimize global waste pollution is for each country to specialize in a particular form of waste treatment.

Contrasting Figure 5 and Figure 6, we can see that even for a relatively broadly defined Scandinavia, the total proportion of the mismanaged plastic waste is only 20% compared to 41% mismanaged for the world's largest exporters. Figure 4a and 4b further illustrate this point: since the China ban and the Basel Convention, the UK was effectively forced to export less but the waste that they did export was mismanaged at a higher rate due to their choice of destination; meanwhile, Sweden's metrics were not affected because of its involvement in the relatively closed Scandinavian ecosystem of plastic recycling.

The Scandinavian region's plastic waste trade achieved such success because of its plastic waste trade regulation strategy. Landfills in both Finland and Norway were only outlawed when it was well-established that Sweden had extra capacity to dispose of waste; waste that would previously be managed in Finnish and Norwegian landfills could thus be redirected to Sweden's incinerators [10]. Sweden has become highly specialized in waste recycling through their incineration plants and utilize the steam created from incineration as an energy source. Sweden's capacity to incinerate waste currently exceeds their natural waste production, so they rely on imports from surrounding countries for waste fuel. The efficiencies in this micro-economy are the results of carefully planned specialization, treatment facility production, and waste trade management.

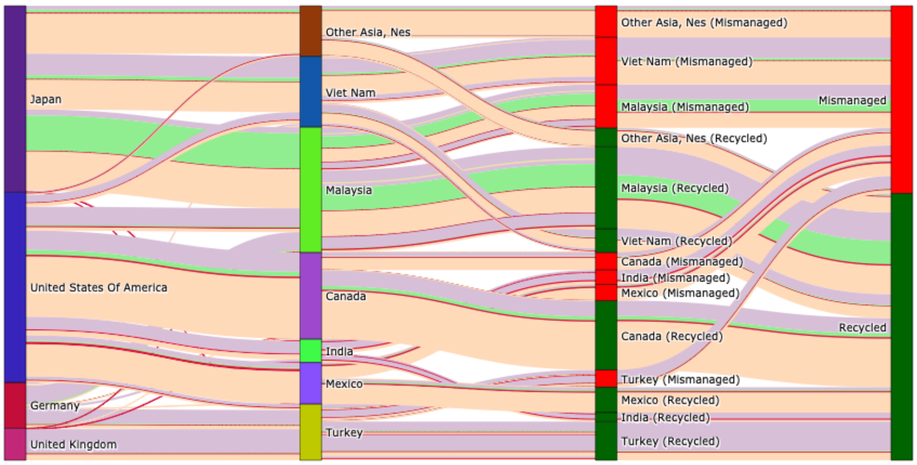


Figure 5: Top plastic waste trade exporters, 2021

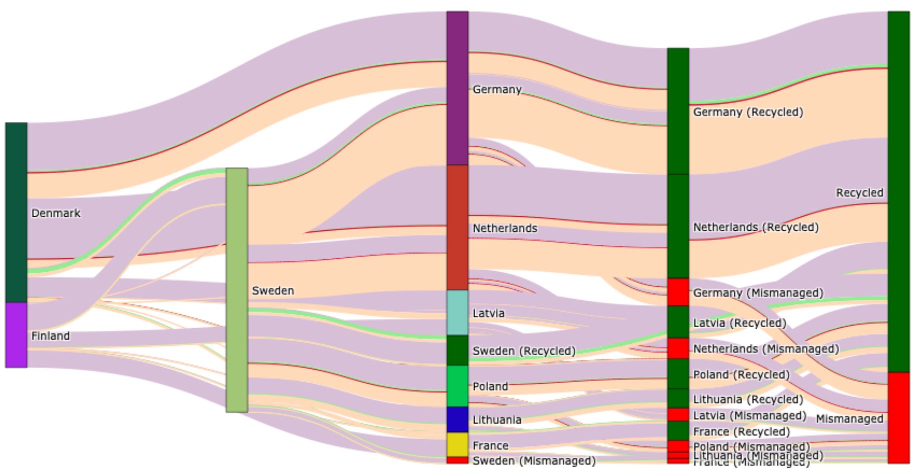


Figure 6: Scandinavian plastic waste trade market, 2021. Each connection width indicates the volume of plastic waste flow. Different colored connections indicate a different type of plastic. The right half of the chart summarizes the flow first by country and proper/improper waste management, and then aggregates all flow from the origin countries into proper/improper waste management.

In our view, this represents a compelling example of a regional trade network where each agent was able to progressively phase out landfills while others could build significant capabilities in recycling and waste-to-energy incineration, allowing each country to minimize its pollution footprint.

With extant infrastructure and the current implementation of the Basel Convention plastic waste amendment, we conclude that the Basel Convention appears rushed and will exacerbate global plastic pollution. Under the convention, countries are forced to export their plastic waste to destinations with poor plastic waste management capabilities, or retain plastic waste in-country where there may not be sufficient infrastructure. The United States' entry into the Basel Convention would create additional pressure on the global plastic waste trade economy without proper infrastructure to manage plastic waste. Instead, we recommend the introduction of policies that encourage specialization and sustainable waste management facilities to shift the global waste trade market towards the Scandinavian waste trade market.

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