Problem Chosen	2020	Team Control Number
E	MCM/ICM	2022174
	Summary Sheet	

As tasked by the International Council of Waste Management, we developed an ambitious plan to nearly eliminate plastic waste globally. This plan occurs within the scope of a decade, the expected time before emissions increase warming to 2° Celsius.

In order to create a plan to reduce plastic waste, we must consider the world's capability to mitigate this waste. Our model analyzes three mitigation mechanisms: pyrolysis, incineration, and ocean plastic removal. The estimations for pyrolysis and incineration rely on a scaling equation, derived using plastic production, nominal GDP, and land area, which scales the United States' capabilities to different regions of the world. Meanwhile, the estimation for ocean plastic mitigation relies on data and projections from The Ocean Cleanup. Overall, our model calculates a maximum mitigation of 165,372,675 tons of plastic waste.

We propose policies to curtail the production of plastic as well as improve plastic waste collection measures in order to mitigate environmental harm. In addition to education campaigns dedicated to shifting consumer behavior, policies including taxes, bans, and other incentives will be necessary to reduce supply and demand of plastic in such a short time frame. With simultaneous improvements in infrastructure and waste collection frameworks, we project that only 368,600 tons of plastic will go mismanaged or uncollected in the environment in a single year.

Since the plastic waste problem has varying implications from country to country, we examine the equity issues associated with this global crisis. We implement a stratification procedure in which we sample nations representing a certain strata and apply a plastic waste debilitation index to model equity differences between countries. Our model displays an insignificant difference in equity between coastal and land-dense populations but showcases higher levels of plastic debilitation in middle income nations. The unequal distribution of plastic waste in world nations is vital to understanding its impact on different population dynamics.

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1 Memo

Memorandum

To:	International Council of Plastic Waste Management
From:	Team #2022174
Subject:	Plastic Waste Management Crisis Proposal
Date:	Feb 17, 2020

The purpose of this memo is to propose an ambitious plan to combat the global plastic crisis within a decade, the mark at which warming reaches 2° Celsius and catastrophic events will occur.

We are pleased to find and report that the minimum achievable global plastic waste target level is 373,600 tons of plastic waste in a single year. This number includes mismanaged waste that is not collected and excludes all landfill waste and to-be incinerated waste due to projected future technologies that will handle those forms of plastic waste.

This finding is supported on a timeline of roughly a decade of policy implementation, research and development, and behavior shifts. We propose a range of policies to combat the plastic waste epidemic: Taxes, Bans, Education campaigns, Infrastructure upgrades, and incentives towards research and development. While not every policy is recommended to be implemented in any singular country, many of these policies are best implemented together. With respect to advancements in technology, many of the technologies necessary for a greener future are already in existence. The goal of some of the policies is to commercialize and expand the presence of these technologies in order to help the transition away from plastic.

Several obstacles stand in the way of enacting these proposed actions. First and foremost is the lobbying conducted by the plastic industry. They have successfully lobbied local governments previously in the US and pose a significant threat to dismantling plastic waste. Past this obstacle is the greenwashing of products in order to fool and trick consumers into believing their mass consumerism is acceptable due to "eco-friendly sourced materials." Education campaigns will prove crucial in dismantling many myths about plastic and industry greenwashing and accelerating the timeline for this proposal. Having a wave of grassroots movements across the globe will certainly help expedite the process of overcoming lobbyists and corporate interests, forcing governments to be beholden to the citizens of the world. These obstacles are intrinsically tied to the profitability of plastic; once alternatives become more profitable than plastic, through government subsidies or advancements in technology, then capitalist markets will regulate themselves and naturally switch away from plastic at rapid rates. Thus, capitalism acts as both an obstacle and accelerating force in our model. Another indirect accelerating force would be the momentous policy change enacted by China, and other Southeast Asian countries, that banned further imports of plastic waste. Although chaotic and damaging in the short-term, this action has made many developed countries reconsider their infrastructure with dealing and handling plastic waste. This will optimally speed up the process of passing legislation to upgrade recycling infrastructure. Although tackling climate change isn't mutually exclusive with tackling plastic waste, there will be a challenge of distributing funding towards plastic waste policies and climate change policies. This competition of resources for 2 different, yet very intertwined, causes may pose as an obstacle as well.

Achieving such ambitious goals in incredibly dire situations requires radical changes to society in both daily behavior as well as entire plastic waste management infrastructures. This is no easy feat to achieve for such a complex and long overdue solution, but this proposal outlines the necessary steps for a solution to occur within the decade timeframe we have as a society before the Earth warms 2^{o} Celsius.

We recommend swift and decisive action with respect to implementing changes as soon as possible. Aside from the proposed policies, we recommend removing money from politics as well as starting a grassroots movement to begin any sort of momentous change.

For further questions and comments, please contact Team #2022174.

2 Introduction

The case of plastic waste is a well-documented and complex issue that will have no easy solution with challenges both technologically and policy-wise. First to map out the life of plastic:

At no point in the life cycle of plastic is it ever innocuous to the environment, whether through resource usage or mismanagement of the final product. Manufacturing plastic emits CO_2; chemicals added to plastics are absorbed by human bodies[1]; plastic discarded either ends up in the wild where it harms wildlife and can make its way up the food chain to humans or gets incinerated, releasing emissions. In the event of being recycled, the process still releases emissions and once the structure becomes too weak to be recycled again, it is incinerated or sent to landfills, where it slowly rots away for centuries while affecting the soil, air quality, and the environment surrounding it. Furthermore, the myth of recycling being the great redeeming quality of plastic is a charade that covers the shipment of plastics to China to be “recycled” which were mostly incinerated[2]. In fact, only 9% of all plastics are recycled, showing how much of a facade recycling truly is; furthermore, traditional plastics can only be recycled several times before being rendered obsolete and discarded[3]. Thus, at no point in the life of plastic is the oil derived material not harming the environment or living creatures. Furthermore, the harmful effects of plastics are spread across to affect virtually everyone in society as weathering, rainfall, and floods spread plastic across vast distances where it ends up in fish-farms, agriculture, and other food sources which all affect human health negatively.

3 Models

3.1 Maximum Mitigation Level Estimate

The mitigation of single use and disposable plastic product waste is severely lacking all over the world. However, there do exist potential mitigation mechanisms, and in order to determine the maximum level of mitigation, we will attempt to analyze the world’s capability to prevent further environmental damage through looking at these potential mechanisms.

3.1.1 Framing of the Estimate

Our approach will define "further environmental damage" as causing more harm to the environment than is currently being done. As all plastic waste that is in oceans, landfills, or natural environments is environmentally harmful, methods that remove plastic from these areas and in the process don't do significant environmental damage through their processes will be taken as mitigating the waste and lowering environmental harm. The final answer will be the total amount of plastic waste that these methods can account for, as that would mean that if the actual amount of waste met this level, the mitigation mechanisms would result in the total amount of added waste being zero.

3.1.2 Mitigation Mechanisms

In order to calculate an estimation for the amount of plastic waste that can be mitigated, we will divide the problem into cases by looking at different mitigation mechanisms and adding up our results from each case. These methods are as follows: extracting plastic from the oceans, waste-to-energy incineration, and waste-to-oil pyrolysis. We choose these methods because they are some of the more effective methods that are either widespread or project to be widespread even before scaling and do not cause environmental harm that exceeds that of the plastic waste itself. Thus, we believe that after scaling, they will serve as a reasonable frame for the world's capabilities, even though there are obviously more methods available.

3.1.2.1 The Scaling Equation

For two of the mitigation mechanisms, waste-to-oil pyrolysis and waste-to-energy incineration, we weren't able to find direct data on the world's capabilities. Thus, we will create a scaling equation and apply it to data and evidence that we do possess, which is the United States' capabilities in these areas. The scaling equation will examine a region's plastic production, economic capabilities, and land area compared to the United States in order to produce an estimate for their pyrolysis and incineration capabilities.

Let P = a region's % of world plastic production

GDP = a region's GDP in trillions

A be a region's land area, in square miles

We provide the following scaling equation and its justification:

$$Capability\ Multiplier\ =\ \sqrt{\left(\frac{P}{10.12}\right)\ *\left(\frac{GDP}{21.44}\right)}\ *\sqrt{\frac{A}{3{,}797{,}000}}$$

We multiply the factors together to obtain a multiplier that awe will multiply the United States capability by for each region. We will justify each of the three pieces of the equation individually.

Justification for $\sqrt{(\frac{P}{10.12})}$

The $\sqrt{(\frac{P}{10.12})}$ represents the scaling factor for a region's plastic production compared to the United States, which comprises 10.12% of world plastic production. The 10.12% is calculated from the fact that the plastic production per capita in the United States is 106.2 kg per year[4] and there are 329,294,337 people in the United States. Multiplying these and then converting to tons gives us 38,548,947.6 tons of plastic per year, which is 10.12% of the 381 million that is produced worldwide[2]. Thus, by dividing P by 10.12, it gives us the ratio of a country's plastic production to the United States. We believe that this should be part of the equation because it takes into the account the source of plastic waste. For example, even if a country has high economic capabilities and a lot of land area, if they don't produce much plastic, then there wouldn't be much reason nor would they agree to harbor a huge amount of plastic mitigation plants. We take the square root of $\frac{P}{10.12}$ because we believe that compared to economic capability, plastic production should influence the capabilities less, as it relates more to keeping the estimates reasonable as opposed to directly influencing the amount of plants a country could build.

Justification for $(\frac{GDP}{21.44})$

As the United States' nominal GDP is 21.44 trillion USD, we divide a region's nominal GDP by 21.44 to find the ratio of that region's economic capabilities to the United States. For the sake of this model, we make the assumption that the ratio of nominal GDP represents the ratio of their economic capabilities. Although nominal GDP is not a perfect representation of the resources that a country could spend on waste mitigation, we believe that there is no perfect representation and that GDP roughly correlates with a country's ability to dedicate resources to a cause. Furthermore, as we are looking to create an estimate, there will be no exact scaling mechanism. The reason why we include the ratio of economic capability to the United States is because resources and money are needed to build and maintain these various plants. By taking the United States economic level and associating that with the number of plants that it is able to maintain, we can produce an estimate of the number of plants that an arbitrary region could maintain. We do not take the square root of this value because we believe that economic capability is the most important factor and most directly impacts how much waste can be mitigated of the three pieces to the equation.

Justification for $\sqrt{\frac{A}{3{,}797{,}000}}$

The final part of the equation is the land area. The 3,797,000 figure comes from the fact that the United States' land area in square miles is 3,797,000[5]. A large area is required for pyrolysis or incineration plants because it is not desirable for them to be close to areas of high population or critical natural resources. However, we believe that area is less direct than economic capability because the amount of area for a plant isn't high enough to the point where it's a major detriment to most regions, especially considering the fact that there aren't too many plants being built per region, as we will see in the specific mitigation mechanism calculations. For this reason, we have also taken the square root of the ratio of land area to the United States.

3.1.2.2 Mechanism #1: Waste-To-Oil Pyrolysis

The first method we will analyze is converting waste to oil which is done through pyrolysis. According to an estimation by the American Chemistry Council, the United States could feasibly have 600 pyrolysis units that handle 30 tons of plastic per day[26]. This comes out to a capability of 6,570,000 tons per year for the United States. We will now use our scaling equation to estimate the capability of the world in pyrolysis. The regions we will be looking at are Asia (not including the Middle East), Europe, NAFTA countries, the Middle East and Africa, and Latin America. We can conjure a reasonable estimation based on these regions because they make up nearly all of the plastic production, so they'd be the ones who are using these plants to mitigate plastic waste.

Asia (not including the Middle East)

We examine the three factors that are used in the scaling equation.

% of Plastic Produced: 50%[6]

GDP (in trillions of USD): 23.31 (East Asia) + 3.95 (South Asia) + 3.32 (Southeast Asia) + 1.24 (Central Asia) = 31.82[7]

Land Area (in square miles): 17,212,000 (Asia) - 3,500,000 (Middle East) = 13,712,000[8][10]

Plugging these values into our scaling equation, we end up with:

$$\sqrt{\left(\frac{50}{10.12}\right) * \left(\frac{31.82}{21.44}\right) * \sqrt{\frac{13{,}712{,}000}{3{,}797{,}000}}} = 6.27$$

Thus, our multiplier for Asia is 6.27. The United States can mitigate 6,570,000 tons, so Asia can mitigate 41,193,900 tons.

Europe

% of Plastic Production: 19%[6]

GDP (in trillions of USD): 21.96[7]

Land Area: 3,837,000[8]

Plugging these values into our scaling equation, we end up with:

$$\sqrt{\left(\frac{19}{10.12}\right) * \left(\frac{21.96}{21.44}\right)} * \sqrt{\frac{3,837,000}{3,797,000}} = 1.93$$

$6,570,000 * 1.93 = 12,680,100$, so we estimate that Europe can mitigate 12,680,100 tons of plastic through pyrolysis.

NAFTA:

% of Plastic Production: 18[6]

GDP (in trillions of USD): 24.44[7]

Land Area (square miles): 8,413,600[8]

$$\sqrt{\left(\frac{18}{10.12}\right) * \left(\frac{24.44}{21.44}\right)} * \sqrt{\frac{8,314,600}{3,797,000}} = 2.26$$

$6,570,000 * 2.26 = 14,848,200$, so we estimate that NAFTA can mitigate 14,848,200 tons of plastic.

Middle East / Africa:

% of Plastic Production: 7%[6]

GDP (in trillions of USD): 2.89 (Middle East) + 2.58 (Africa) = 5.47 [7]

Land Area (in square miles) : 3,500,000 (Middle East) + 11,608,000 (Africa) = 15,108,000[8]

$$\sqrt{\left(\frac{7}{10.12}\right) * \left(\frac{5.47}{21.44}\right)} * \sqrt{\frac{11,608,000}{3,797,000}} = .42$$

$6,570,000 * .42 = 2,759,400$, so we estimate that the Middle East and Africa can mitigate 2,759,400 tons of plastic.

Latin America:

% of Plastic Production: 7%[6]

GDP (in trillions of USD): 3.56 (South America) + .29258 (Central America) = 3.85258 [7]

Land Area (in square miles): 6,880,000 (South America) + 202,230 (Central America) = 7,082,230[8][9]

$$\sqrt{\left(\frac{7}{10.12}\right) * \left(\frac{3.85258}{21.44}\right)} * \sqrt{\frac{7,082,230}{3,797,000}} = .204$$

$6,570,000 * .204 = 1,340,280$, so we estimate that Latin America can mitigate 1,340,280 tons of plastic.

Adding up the mitigation capabilities of all of the regions, we get that the world has the pyrolysis capability to mitigate 72,821,880 tons of plastic.

3.1.2.3 Mechanism #2: Waste-To-Energy Incineration

The next mitigation mechanism is through incineration plants. The calculations for this section will use the same scaling equation as derived in 3.1.2.1 and used in 3.1.2.2, which means we can use the same scaling factors for the different regions. In order to calculate the amount of plastic that the United States is able to mitigate through incineration, we use the fact that the United States incinerated 29.5 million tons of municipal solid waste, combined with the fact that 16% of municipal solid waste that is combusted is plastic.[4][11] We can then calculate that 16% * 29.5 million tons = 4.72 million tons of plastic are incinerated in the United States per year.

Asia

4,720,000 tons * 6.27 = 29,594,400 tons

Europe

4,720,000 tons * 1.93 = 9,109,600 tons

NAFTA

4,720,000 tons * 2.26 = 10,667,200 tons

Middle East / Africa

4,720,000 tons * .42 = 1,982,400 tons

Latin America

4,720,000 tons * .204 = 962,880 tons

In total, this amounts to 52,316,480 tons.

3.1.2.4 Mechanism #3 Ocean Plastic Extraction

Cleansing the oceans of plastic is crucial, as 8 million tons of plastic waste go into the oceans every year, which harms marine life, the overall health of the hydrosphere and its ecosystem, and coastal land areas[12]. The most capable and effective tool developed to handle this waste that operates on a significant enough scale is The Ocean Clean Up's Interceptor, so we will evaluate this mechanism through Interceptors[13]. As per their official website, under optimal conditions the Interceptor can extract up to 100,000 kg of plastic per day, and their goal is to have Interceptors in 1,000 rivers[13]. Given that we are looking at the maximum amount of mitigation that is possible, we can use these figures to calculate the amount of tons of plastic per year that can be extracted.

$$1,000\ (units) * 100,000\ (kg/unit/day) * 365\ (days) * .00110231\ (kg/ton) = 40,234,315\ tons$$

3.1.3 Overall Results

In the end, adding up the 3 different mechanisms gives us 72,821,880 + 52,316,480 + 40,234,315 = 165,372,675 tons. Thus, we estimate that 165,372,675 tons can be safely mitigated without further environmental damage, as we have determined through our research, calculations, and scaling to worldwide capabilities that this amount of plastic waste can be handled with methods that are not as environmentally damaging as the plastic waste that they are addressing.

3.1.4 Strengths and Weaknesses

Strengths

- The model attempts to scale the United States' capabilities to the world using three distinct and relevant factors that account for characteristics such as the source of waste, technological capabilities, reasonability, and resources, giving the model the full scope of the world even though the pure data wasn't available.
- The mitigation mechanisms examined are all relatively popular, so we aren't scaling up extremely obscure methods that would never be implemented on a large scale.
- The mitigation mechanisms account for plastic flowing out to the ocean, plastic in landfills, and plastic elsewhere on land. It doesn't gloss over and ignore major sources of environmental harm from plastic waste.

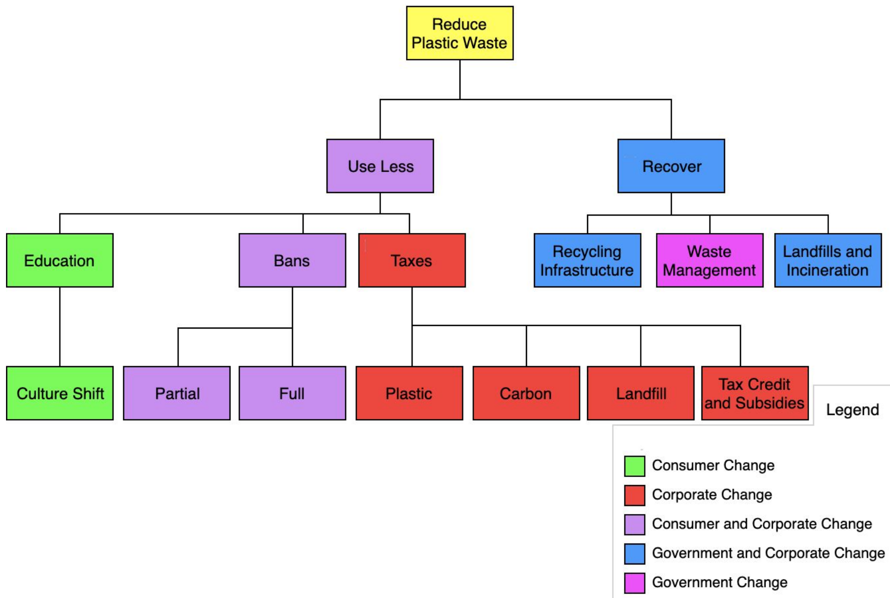
Weaknesses

- The model only takes into account three mitigation mechanisms, but there are several mechanisms in use. In general, they are less relevant and widespread than the examined methods, but they still increase the world's capabilities.
- We partly rely on goals and proposed targets instead of current data. For example, we used the fact that The Ocean Clean Up's goal is to have 1,000 Interceptors by 2025 and used 1,000 as our calculation figure.
- The scaling equation arbitrarily decides to take the square root for land area and plastic production but not for GDP.
- The scaling equation variables don't nearly account for all of the various factors that go into a country or region's capabilities, such as politics, government, or public support.

3.2 Plastic Reduction Policy Analysis

As this is a policy proposal, we will not dive into the feasibility of certain policies passing legislation; however, we recognize the wide-reaching influence of lobbying by the multi-trillion dollar plastic industry, thus we strongly advise countries to remove money from politics in order to achieve any quick and meaningful change.

Figure 1: Policy Outline



There are three main actors in the models: the consumer, corporations and organizations, and the government. In Figure 1 above, the outline of the plastic waste proposal is depicted with which of the three actors' behavior the policies will attempt to change.

3.2.1 Assumptions

1. We assume that in the definition of plastic waste: "plastic objects that...cannot be recycled" refers to traditional plastic materials and methods of recycling.
2. These policies outlined below, unless otherwise mentioned, do not consider underdeveloped countries due to their relatively minimal plastic waste output[2] and lack of basic infrastructure in all areas of life to be able to have the capital and capacity to implement these policies.
3. The Plastic Recovery Model assumes two main points:

a. Recovering plastic waste from the environment is in of itself a reduction of plastic waste since at least 20% of plastic waste not recovered is of value to be recycled[14].
b. New technologies will be developed and implemented over the time frame of the model's implementation, only increasing the 20% figure stated in assumption 3a.

3.2.2 Plastic Production Reduction Model

By reducing the demand and costs of the supply chain, the production of plastic will naturally decline through forces in capitalism and consumerism. To change consumer behaviors, we propose several policies to better educate the populus and change societal norms, while different forms of bans and taxation measures will attempt to change corporate business models and consumer consumption.

3.2.2.1 Education

Local programs and even national anti-plastic and anti-littering education campaigns can be helpful for setting up future generations to really begin a cultural shift in the way we handle plastic as society. Issues such as biomagnification, fast fashion, cosmetic, soft drinks, and other industries' usage of plastic, and the reality of the current recycling situation has shown to start grassroots movements of eco-friendly consumerism. Bringing awareness to the attempt of many fast fashion (and other industries) companies like Zara and H&M to greenwash and cover bad environmental practices with misleading claims of eco-friendliness is crucial[15]. Furthermore, dispelling the myth of recycling being a savior through telling the realities of improper recycling that lead to only 9% of global plastic even being recycled[16] can shift guilty consumer behaviors. These education campaigns can be implemented in regions across the globe from developed and developing countries to coastal and landlocked states.

3.2.2.2 Plastic Bans

- **Limited Bans:** Cities and countries like San Francisco and China have banned single-use plastic bags, resulting in 72% drops in the presence of those plastic wastes[17]. A direct result of this is that both companies and consumers will need to rethink their plastic production and consumption levels. Such bans would be able to be implemented across multiple forms of single-use plastics (i.e. under 1 liter water bottles) and all stages of development in countries, with underdeveloped countries banning whatever they deem as unnecessary forms of plastic items (i.e. styrofoam cups)[18].

- **Complete Bans:** The end goal is to eventually stop producing plastic. This policy will be more of a target rather than a policy that countries implement on its own. At the point of this policy's implementation, safer alternatives will be more prevalent to ensure a smoother transition.

3.2.2.3 Taxation

- **Plastic Tax:** this would tax stores that distribute single-use plastics (i.e. Ireland has implemented this at a 15 euro cent level and it has reduced the use of single-plastics by 90%)[19]. Even a modest tax of 1 penny for any plastic good, for example, would generate a sum of roughly $1 billion for the state of California. These taxes would incentivize research and development into discovering and lowering the cost of alternatives[18].
- **Carbon Tax:** the process of creating plastic from shipping it to generating the energy to transform oil into plastic, releases CO_2 emissions. Thus, taxing companies for their carbon emissions would not only generate funds for countries to funnel into other plastic waste reduction policies, but also incentivize organizations to develop lesser polluting methods to create plastic alternatives.
- **Landfill Tax:** to stop the accumulation of plastic waste on landfills where plastic degrades and continues to emit carbon emissions[20]. This could be implemented through utility fees or other fees to disincentivize build up of plastic and incentivize further development into ways to safely process plastic.
- **Tax Credit and Subsidies:** by offering tax credit and subsidies to companies and nonprofits that center around plastic alternatives or other green solutions to plastic waste, a more economical and safer alternative will rise sooner[18]. In a primarily capitalist global market where plastic is very cheap, there is often little incentive for companies to try and curb the harm caused by plastic waste, thus government action is suggested to incentivize innovative solutions like plastic blockchain to promote grassroots plastic waste cleanup in exchange for decentralized, peer-to-peer currency[21].

3.2.3 Plastic Recovery Model

The crux of this model aims to improve current infrastructure within countries and reduce the leakage of plastic waste into the environment. In conjunction with the development of new technologies to safely handle plastic waste, this model aims to reduce the plastic waste that currently exists and will inevitably be produced.

3.2.3.1 Recycling Infrastructure

Infrastructure across the globe is insufficient to deal with the current situation, let alone the increasing plastic production[22]. This infrastructure doesn't even need to be adopted on national levels, making it easier to achieve in local municipalities. This implementation would vary in urban vs. rural areas. Urban centers could implement a range of programs from street workers picking up plastic litter to water dispensers, reducing plastic bottles[18][4]. Rural areas could implement recycling centers that accept deposits of plastic waste in exchange for money[23]. For the most part, governments will have to take charge in revamping infrastructure due to minimal profits, especially in rural towns after China single-handedly changed the recycling market[24].

3.2.3.2 Waste Management Infrastructure

In coastal areas or areas with large amounts of rainfall and flooding, microplastics and other plastic waste debris can travel across land and through inadequate stormwater and rainfall management systems to end up in marine environments[18]. Plastic leakage reduction solutions need to be implemented and developed in order to improve plastic collection rates and reduce plastic leakage rates into the ocean[16].

3.2.3.3 Landfills and Incinerated Plastic

The existing plastic in landfills and plastic that would normally end up incinerated can be recycled or safely mitigated with new recycling technologies that are on the rise. Improvements in pyrolysis, use of PDK plastics, and other advancements would reduce the amount of plastic waste from these existing sources[25][26].

3.2.4 Strengths and Weaknesses

Strengths

- The models account for a variety of policies that pair well together by establishing sources of funding and revenue.
- The models provide for different options of policies that accomplish the same effect through different means; this gives different countries different options depending on which policy complements their economic system the best.

Weaknesses

- The models lack understanding in how policies interact with each other and how unintended consequences could arise.

3.3 Achieving A Goal

3.3.1 Assumptions

1. We will conduct a two worlds experiment where one world, world 1, is the world as we know it where the present year is 2015. The other world, world 2, is a world in which the policies outlined in 3.2 were enacted in 2005 (with today's technology) and it has been 10 years since then.
2. Assume different types of plastic and different usages of plastic play no role in affecting the likelihood of whether that plastic waste will be collected or not.
3. Assume underdeveloped countries' plastic production is negligible.
4. Assume that the highest previously shown efficacy rates can be applied across the globe since the process of modeling multiple policy implementation efficacy rates would be too extreme of a task. Furthermore, the task as interpreted is to determine the minimal achievable amount, thus we will assume the best case scenarios for these policies.

3.3.2 Modeling the Target

Given that 381 million tons of plastic were produced in 2015 with 68.6% of it being discarded, left in landfills, or incinerated, then the baseline for how much waste is produced is 261.65 million tons of plastic waste in world 1. We will model the minimum amount of plastic waste produced in world 2 in two steps: policy analysis and mitigation capability.

3.3.2.1 Quantifying Policy Impact

Policies were enacted in two fronts: Production Reduction and Recovery. In enacting the previously aforementioned policies in section 2.2, demand and supply in plastic production will have reduced.

With so many different policies outlined, compounding effects, as well as hard isolation, modeling the varying implementation of these policies across the globe is an extremely challenging task. We can however presume best-case scenarios for our policies since the task is to determine the minimal achievable target. Assuming the plastic tax achieves it's high efficacy globally as it does in Ireland[19], then 90% reduction in single-use plastic (46.19% of all primary plastic production) will occur, resulting in 17.6 million tons of single-use plastic being produced[2]. Given the larger incentive to develop greener plastics, alternatives, and methods, we can also expect other disposable plastic productions to slow similarly at a 90% rate. The implementations of other forms of taxes and bans will not be considered due to assumption 4. This will result in overall production dipping to 38.1 million tons of plastic produced in 2015.

We can measure improvements to infrastructures in the Recovery model by examining proposed solutions and extending their effects across the globe to produce the minimal theoretical achievable amount of plastic waste produced. With respect to land collection schemes, the best countries have upwards of 99% plastic waste collection, an 18% increase from the 81% global average[14]. Increasing collection rates across the globe by 18% results in 22.22% increase in waste collection capabilities which leads to 37.72 million tons of plastic waste collected instead of the 30.861 million that would have originally been collected. This brings the waste produced in 2015 to be 0.38 rather than 7.24 million tons. As given in section 3.1, Pyrolysis capabilities will have expanded past what is necessary in world 2, thus we can conclude the plastic waste collected will either be converted to oil through pyrolysis or other green alternatives to incineration and landfills that will have developed. Thus plastic waste numbers that belong to those categories are not considered as plastic waste. Proposed solutions estimate a 65% reduction in plastic leakage from land-sources within 10 years[14], such as poor waste management systems, which constitute 80% of all 3% of plastic leaked into the ocean[28]. This leads to a reduced level of 5,000 tons of plastics leaked into the ocean in world 2. This totals to 373,600 tons of plastic waste discarded and mismanaged.

However, as mentioned in section 3.1, an innovative technology, the Interceptor, is projected to have over 1000 units within a 10 year time frame. This fleet will be able to operate at an ocean plastic waste cleaning rate of 40.23 million tons of plastic waste a year. Not only does this reduce the 373,600 tons of plastic waste figure to 0, but it also represents the technology cleaning up plastic waste build-up from previous years. This results in a total of 368,600 tons of plastic waste produced in 2015.

3.3.2.2 Changing Lifestyles

Given these policy changes, society will have major changes including shifts in the packaging, textile, and other major plastic intense industries. The once trillion dollar plastic industry will have all but collapsed or pivoted their business operations towards green solutions. Human life will have either adapted to the less convenient alternatives or the alternatives will have been developed to the point of rivaling plastic's versatility and convenience. While carbon emissions, ecosystem damage, air and soil degradation, and other consequences of plastic may not have been reversed, the environment will be set on a course of self-correction, now that plastic is being removed and reduced at a groundbreaking pace.

3.3.3 Strength and Weaknesses

Strengths

- Provides an optimistic model from which to work with in incentivizing major policy change.
- Illustrates the gravitas of the problem and how much structural change is necessary to accomplish environmentally safe conditions.

Weaknesses

- The model ignores the complexities of underdeveloped nations and the dumping of plastic waste in those countries.
- The model doesn't factor a probabilistic model in likelihood of different types of plastic waste being collected (i.e. shirts would almost always be picked up whereas scraps or smaller plastic items would go unnoticed).

3.4 Equity

Given the global nature of the plastic pollution issue, we examine the differing implications it poses upon world nations, inherently unique in geographical location and economics. In this section, countries are stratified through certain categories in order to yield sets of data groups, likely to experience diverging plastic waste impacts. A *plastic waste debilitation index* developed as a model for comparison is then applied to each of these groups in order to quantify differences in equity that currently result from plastic waste output, followed by a discussion on the resulting effects of our solutions on such equity issues.

3.4.1 Stratification

To effectively categorize countries into groups based on how plastic waste may impact countries with certain characteristics, we selected these criteria[1], each with a rationale:

- **Coastal population density:** Countries are categorized in the stratification based on whether they are considered to be *coastal-dense* or *land-dense*. Coastal population data was sourced from the study conducted by Jambeck *et al.* (2014),

[1] The list of countries considered in this plastic waste impact equity analysis is sourced from Jambeck *et al.*, which considers a subset (yet still a majority) of the nations that the World Bank indexes for its statistics.

in which a 50 kilometer coastal buffer was created in the GIS geographic mapping system to gather coastal populations[27]. This data was selected as a defining step in the stratification as plastic waste debilitation as coastal nations are more susceptible to the harms of plastic pollution in oceans and beaches, and contribute heavily to plastic waste mismanagement in the oceans, amounting to about 8 million tons a year[28].

We further refined this data to yield a coastal population density (measured in % of total population), by comparing the coastal population values with population figures from the World Bank in 2014[29]. The two group distinction was as follows:

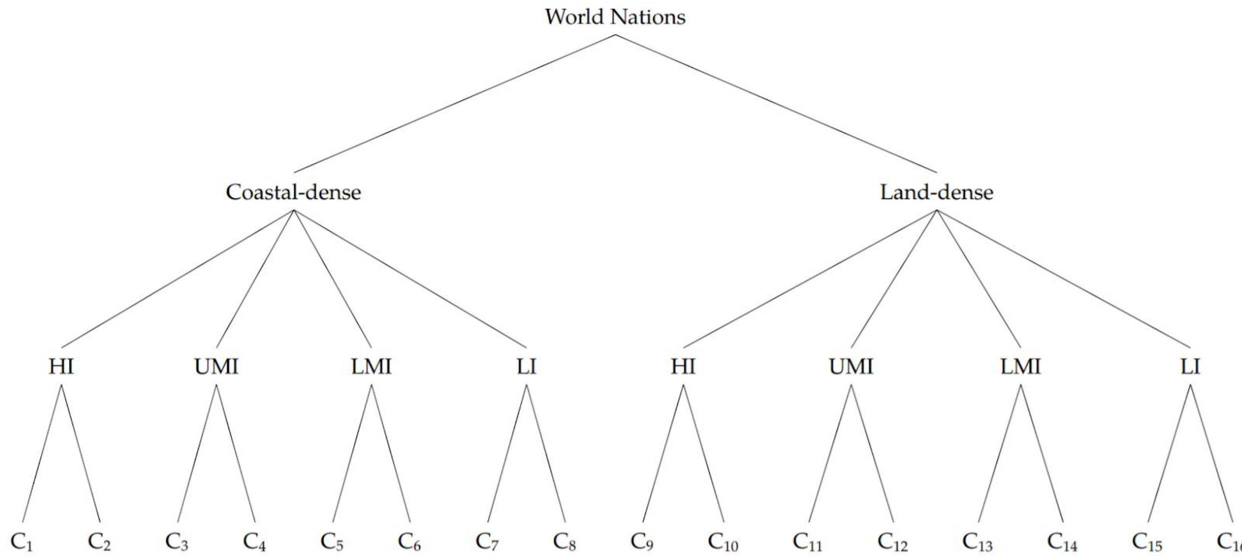
- If the coastal percentage exceeds 62% (median percentage of coastal pop. density), classify the country as *coastal-dense.*
- Otherwise, classify the country as *land-dense*.

- **Income indices:** The World Bank classifies world nations in its list as one of four income groups, a classification calculated using their Atlas method, which evaluates countries based on their GNI (gross national income) per capita[30]. We chose to stratify based on this metric as countries with different economic standings may have different levels of consumerism, especially pertaining to single-use plastics, as developing nations toward the lower side of the income indices may not have the necessary infrastructure to support proper handling of the waste[31]. The classification of country incomes is as follows:
    - *High-income economies (HI)* have a GNI/capita of $12,376 or more.
    - *Upper middle-income economies (UMI)* have a GNI/capita between $3,996 and $12,375.
    - *Lower middle-income economies (LMI)* have a GNI/capita between $1,026 and $3,995.
    - *Low-income economies (LI)* have a GNI/capita below $1025.

We first stratify countries into two groups based on coastal/land density, then each of those groups is further sectioned into their income indices. Then, two arbitrary nations from these groups were chosen (with the restriction that each would have to be from a different continent to combat bias) for calculation of the plastic waste debilitation index to be done in the next section.

The stratification procedure is pictured in the figure below (where C_x represents a country in the group of two under each income index)

Figure 2: World nation stratification for plastic waste equity[2]



The results of the stratification procedure are given in the following table; each entry is in the format of a 2-tuple as follows: `country_name, coastal_density_percentage`

Table 1. Resulting Groups of Stratification Procedure

Coastal-dense				Land-dense			
HI	UMI	LMI	LI	HI	UMI	LMI	LI
Norway, 80.426%	Jamaica, 98.102%	Tunisia, 65.758%	Guinea-Bissau 71.383%	Poland, 8.610%	China, 19.270%	Myanmar, 36.320%	Yemen, 23.424%
Japan, 90.535%	Malaysia, 76.642%	Indonesia, 73.384%	Haiti, 86.792%	Canada, 33.430%	Ecuador, 40.121%	Angola, 14.068%	Guinea, 17.904%

3.4.2 Quantifying the Plastic Waste Problem

Our stratification of countries into groups provides us the foundation on which we will apply our calculations to quantify the impact of plastic waste on each group, and ultimately compare groups with one another. In order to do so, we develop a statistic in which increasing values correspond to increased debilitation resulting from plastic

[2] "World Nations" refers to the nations enumerated in the periodical by Jambeck *et al.*

waste: the plastic waste debilitation index. This model will factor in major researched inputs in which countries would be more impaired by abundant plastic waste, while commingling data from international sources. We discuss the factors and rationales behind such factors and then compile the findings into an equation below.

- **Mismanaged plastic waste (kg/capita/day):** Mismanaged plastic waste, rather than simply plastic waste, is used in the calculation of the index, as this factor directly contributes to major harms such as pollution of the oceans; the data by country is sourced from Jambeck et al. and is defined as "[plastic] that is either littered or inadequately disposed", from 2010[27].
- **Seafood consumption (fish/capita/year):** Fish consumption is a considerable metric due to the process of biomagnification, in which increasing concentrations of a certain substance are located when going up the food chain. A study by Mizukawa et al. purports that certain types of molecules present in plastic, known as PCBs and PBDE congeners are biomagnified in organisms of the food chain in Japan, while other compounds present in plastic are possibly metabolized by the bloodstream[32]. As such, we choose to measure seafood consumption per capita per year as a method of quantifying the effects of biomagnification of plastic waste to certain nations. The data is published by the Food and Agriculture Organization of the United Nations from 2013[33].
- **Water withdrawals (m^3/capita/year):** Groundwater is susceptible to contamination, as explored in a study by Panno et al. in 2019: karst aquifers which constitute about 25% of drinking water sources globally have been shown to harbor microplastic contamination[34]. We consider the volume of water withdrawals per capita as a measure of plastic waste debilitation in our model, using data published by the United Nations Food and Agricultural Organization from 2010[35].
- **Rainfall (mm/year):** Rainfall and extreme weather can exacerbate problems of plastic waste mismanagement by distributing and spreading microplastics/macroplastics around ecological environments[36]. Our model will consider the average precipitation in depth, measured in mm/year by country, through data published by the World Bank in 2014[37].
- **Tourism industry (% of total exports):** Tourism is a major boon to the economies of many nations around the world, yet a prevalence of much plastic waste can deter visitors from possible destinations, especially beaches and coasts. We use

the World Bank's international tourism in 2017 as a percentage of total exports to measure this factor[38].

3.4.3 Plastic Waste Debilitation Index

Based on the factors enumerated above, we develop a plastic waste debilitation index (PWDI) as a model for comparing the stratified countries.

For a certain country,

Let $mpw =$ mismanaged plastic waste (kg/capita/day)

$sea =$ seafood consumption (fish/capita/year)

$wtr =$ water withdrawals (m^3/capita/year)

$rain =$ rainfall depth across country (mm/year)

$tour =$ tourism industry (% of total exports, a number between [0, 1])

$$PWDI = \left(\tfrac{1}{2}log(tour + 0.316228) + 1\right)\left(365mpw + \sqrt{sea + wtr + \tfrac{rain}{100}}\right)$$

Justification for the Index

First, we discuss the second term surrounded by the grouping symbols. We multiply mpw by 365 in order to scale it to a yearly figure as the other factors. The mismanaged plastic waste is a very significant contribution to plastic waste pollution[27], and as such is represented linearly in the equation. We then add a sublinear term, comprised of the square root of the sum of seafood consumption, water withdrawals, and rainfall depth, with rainfall divided by 100 to convert to centimeters, decreasing the relative impact of the factor. Since these can be considered to be factors which exacerbate plastic debilitation and are not as direct in contributing to it, we take a square root of the sum to limit their effect on the size of the resulting statistic. Lastly, we multiply this grouped term by $\tfrac{1}{2}log(tour + 0.316228) + 1$ as $tour$ represents a ratio of tourism comprising the country's exports: if the country is more dependent on tourism, this variable will be higher, making it more susceptible to having a major industry in its economy impacted by plastic waste issues. The rest of the expression, including the logarithmic function and scaling allow for the tourism metric to not be as punishing of countries with low tourism exports, as they could still be strongly affected by plastic waste, and mathematically, presents possible output factors from 0.75 to 1.0597. As such, the entire model should result in increasing magnitude depending on the factors' relation to plastic waste debilitation.

3.4.4 Results and Discussion

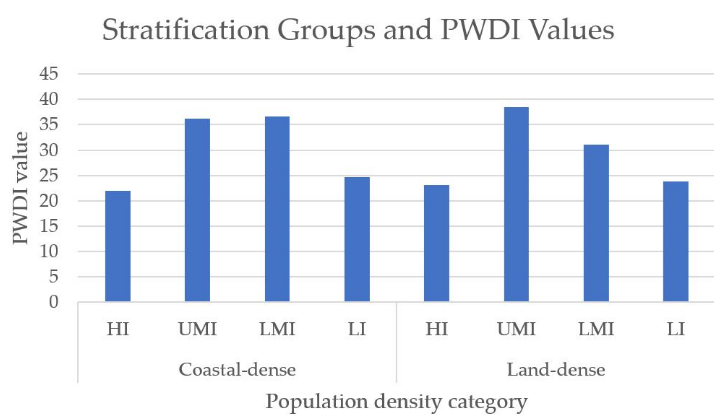
Given the necessary model (our PWDI) and our countries yielded by the stratification, we calculate the PWDI for each pair of countries in each income group, and take the mean of the groups to better compare the differences in the stratified groups.

Table 2. Resulting *PWDI* Data From Stratified Groups

	Coastal-dense				Land-dense			
	HI	UMI	LMI	LI	HI	UMI	LMI	LI
Nation 1	Norway, 22.427	Jamaica, 21.672	Tunisia, 40.502	Guinea-Bissau 23.070	Poland, 17.881	China, 41.83	Myanmar 43.466	Yemen, 33.76
Nation 2	Japan, 21.497	Malaysia, 50.717	Indonesia 32.730	Haiti, 26.143	Canada, 28.334	Ecuador 35.18	Angola, 18.637	Guinea, 13.865
Mean *PWDI*	**21.962**	**36.195**	**36.616**	**24.607**	**23.108**	**38.505**	**31.052**	**23.813**

To visualize trends in this data, we graphed the data in a column chart below:

Figure 3: Column Chart of Stratification Groups and Mean *PWDI* Values



As seen above, a concave-down U shaped chart resulted from the calculated indices for each of the groups, and despite the stratification, a non-significant difference between coastal and land-dense nations was noted through *PWDI* values. The graph shape suggests that plastic waste debilitation increases initially as income goes down, but decreases as income is at its lowest. This may be attributed to consumerism, as the poorest nations may have access to the lowest amount of plastic materials, or perhaps, a decreased overbearance on groundwater.

3.4.5 Equity Effects of Proposed Solutions

The issue of equity of the proposed solutions in 3.3 primarily center around a country's development status. Developed countries will have the capital and technological innovation necessary to deal with such a vast and drastic transition while developing nations will struggle to keep up with such high demands. The case of equity is even worse with underdeveloped countries that are transitioning into developing countries as they will have to make a quick transition as well. The ease of transition definitely impacts non-developed nations harder. The benefits of such solutions will more heavily favor countries with a large tourism industry, and while carbon emission regulations will vary by country, countries with historically high air pollution will see the fruits of their labor much clearer.

3.4.6 Strengths and Weaknesses

Strengths

- This procedure's strengths lie in its stratification by factors that influence plastic pollution effects, and the usage of an index statistic which considers five factors which each contribute to debilitation from plastic waste.
- The *PWDI* weights different factors at an unequal relative scale to better represent the debilitation of a nation resulting from plastic waste.

Weaknesses

- Neither the stratification nor model considers population size, which may also be important towards evaluating equity of the plastic waste problem.
- The analysis does not consider more than two countries in each group, as a more comprehensive analysis could be conducted with every country listed.

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