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# Environmental Threaten of Marine Plastic and its Life Cycle Analysis Solutions

Shunyu Yan

Duke Kunshan University, China

## Abstract

**The objective of this research is to explore new solutions for the increasingly serious problem of marine plastic pollution. This research reviewed the latest situation of annual production and regional distribution of plastics in the world and its harmfulness. Based on the quantitative method, we introduce the Life Cycle Assessment (LCA) evaluation method to explore the measures prolonging the service life of plastic products. And based on the above innovative research methods, this research proposes two solutions of technology and regulation.**

## Keywords

**Plastic Pollution; Marine Environment; Life Cycle Analysis (LCA); Waste Management Hierarchy; Carbon Emission Factor; Policy Solution.**

## 1. INTRODUCTION

### 1.1. Overview of Marine Plastic Production

The world has an exponential growth of plastic production and consumption over the last 7 decades due to the unique idiosyncrasy of plastic, which includes durability, low cost, lightweight, pliability, and versatility. (Pan et al, 2018) Since the 1950s, the growth of global plastics production has outpaced many other materials. Plastics are used worldwide and have replaced such wrappers as glass, metal, paper and jute. From 1950 to 2018, the production of plastics worldwide kept increasing rapidly. The annual global production of plastic increased by 20% from 299 million metric tons in 2013 to 359 million metric tons in 2018. (Figure 1)

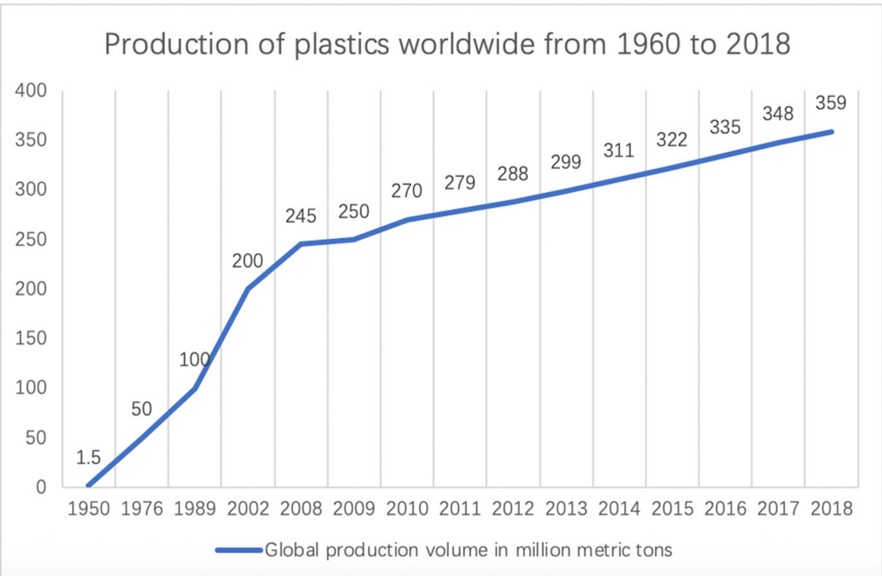


**Figure 1.** Production of plastics worldwide from 1960 to 2018 /in million metric tons. (Garside, 2019)

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The daily consumption of plastic per person is abundant and the difference of daily plastic waste per capita between developed and developing countries is also apparent. In 2010, people who lived in the United States generated 0.34 kg per person per day. This is followed by the United Kingdom (0.21kg per person per day), Brazil (0.17kg per person per day) and China (0.12kg per person per day). (Figure 2) However, daily per capita plastic waste of the highest countries including the United States, the United Kingdom, Brazil and China is 10 times higher than many countries such as India, Tanzania and Mozambique.

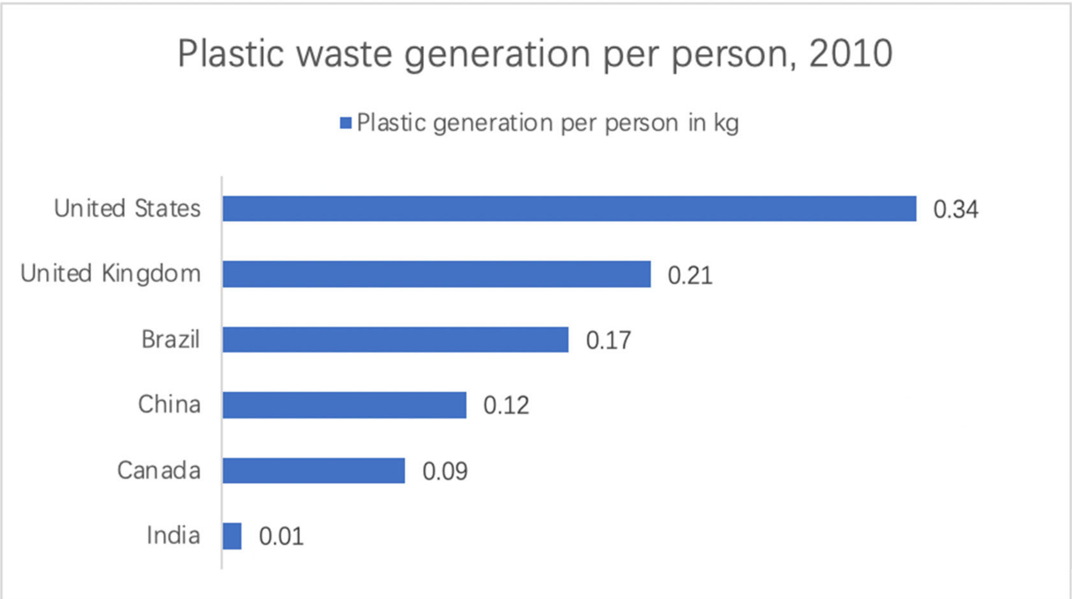


**Figure 2.** Plastic waste generation per person, 2010 (Geyer, R., Jambeck, J. R., & Law, K. L. , 2017)

However, the regional distribution of plastic materials is another story. Although China on average produces less amount of plastic per person per day compared to the United States and the United Kingdom, the massive population of China makes it the country that generates the most plastics waste. In 2018, China was the largest plastic generator in the world, accounting for 30% of plastic production worldwide. And this is followed by NAFTA (United States, Canada, and Mexico), the rest of Asia, Europe, the Middle East, and Africa. (Figure 3)

Plastic production experienced a shift from durable plastics to single-use plastics. Plastic materials are often selected for applications that require toughness and impact resistance. Plastics such as Acrylonitrile Butadiene Styrene (ABS), polycarbonate, Polyphenylsulfone (PPSU), and Ultra-High-Molecular-Weight polyethylene (UHMW) have excellent toughness, but they are exceedingly difficult to degrade in the environment. Therefore, it was of vital importance for industry to manufacture products of single-use plastics to limit the impact on nature. Single-use plastics also refer to disposable plastics, which are used only once before they are thrown away or recycled, including plastic bags, straws, coffee stirrers, soda, water bottles, and most food packaging. In 2015, the packaging industry generated 146 million tons of primary plastic, accounting for nearly 36% of global plastic production. (Figure 4) But plastic waste generation is influenced by not only primary plastic use but also product lifetime. Usually, packaging has a very short lifetime, on average of 6 months or less. On the contrary, the primary plastic used for building and construction has a mean lifetime of about 35 years. Therefore, packaging becomes a dominator in plastic waste generation and accounts for nearly half of the global amount.

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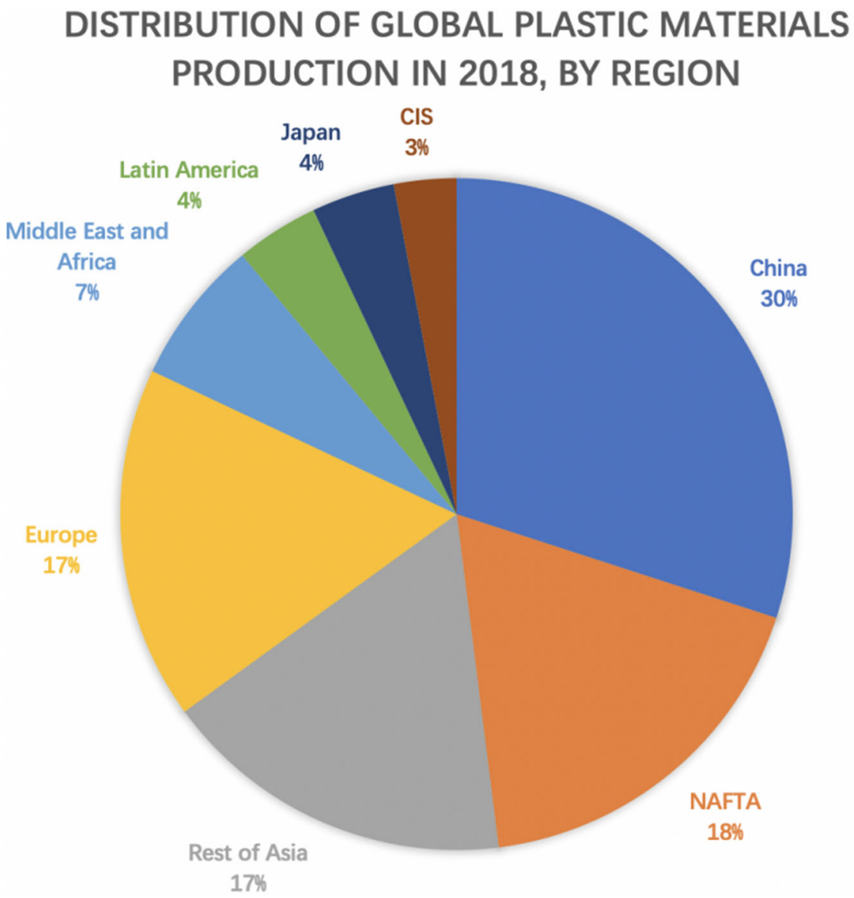


**Figure 3.** Distribution of global plastic materials production in 2018, by region. (Geyer, R., Jambeck, J. R., & Law, K. L. 2017)

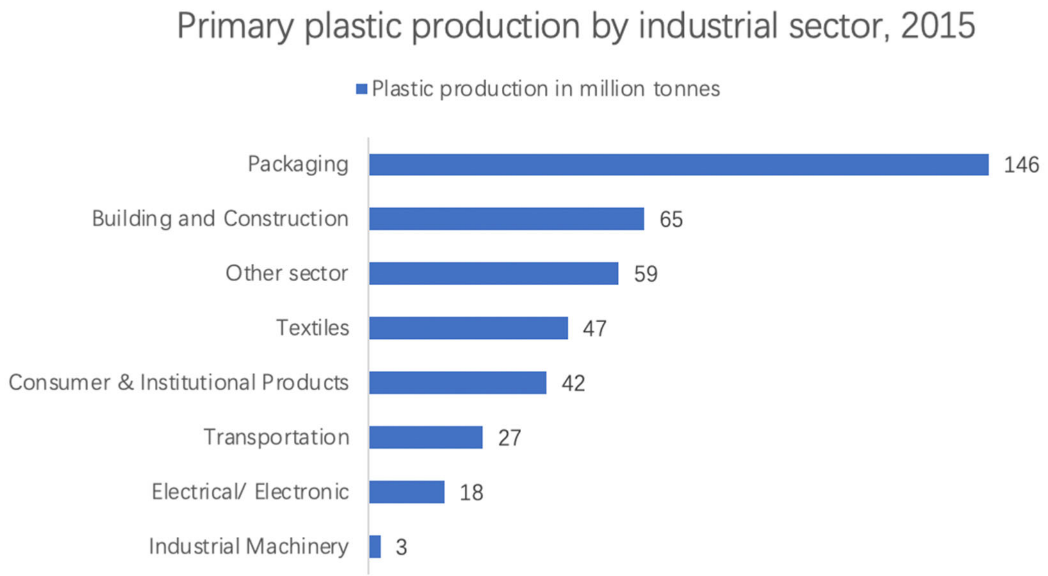


**Figure 4.** Primary plastic production by industrial sector, 2015. (Geyer, R., Jambeck, J. R., & Law, K. L. 2017)

## 1.2. Environmental Threats of Marine Plastic

Over 300 million tons of plastics are produced for various applications every year. However, at least 8 million tons of plastics end up in oceans every year and make up 80% of all marine debris from surface waters to deep-sea sediments. The density of approximately 60% of plastics

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is lower than seawater (UNEP, 2018). When marine plastic waste enter the ocean along the river, some of the floating plastics entered the ocean circulation by the transportation of wind current, which formed the known world's top five vortex plastic garbage gathering areas. Among these areas, there is one famous "Great Pacific garbage patch" located at roughly between 135°W to 155°W and 35°N to 42°N. It is also described as the Pacific trash vortex, a gyre of marine debris particles in the north-central Pacific Ocean. It occupies a relatively sedentary region of the North Pacific Ocean bounded by the North Pacific Gyre in the horse latitudes. The gyre's rotational pattern draws in waste material from across the North Pacific, incorporating coastal waters off North America and Japan. As the waste is captured in the currents, wind-driven surface currents gradually move debris toward the center and trap it. This garbage patch has 0.45 X $10^5$ to 1.29 X $10^5$ tons of plastic floating within the area of 1.6 x $10^6$ square kilometers. Microplastic accounts for 8% of the total mass of flouting plastic material and 94% of the total number of 1.8 X $10^{12}$ to 3.6 X $10^{12}$ plastic material and has an exponential growth tendency (Laurent C. M. Lebreton, et al., 2018).

Marine microplastics are small fragments of plastic debris that are less than five millimeters long. They can be classified into two categories: 1) Primary plastic. These kinds of plastics are "micro" by design, such as microbeads that are tiny plastic spheres added by manufacturers to body washes, toothpaste and other products for extra scrubbing. These primary plastics will enter the surrounding environment with the discharge of sanitary sewage. 2) Secondary plastics. They are fragmented plastic particles of larger plastic debris resulting from physical, chemical, and microbial action, such as water bottles, straws, cups, and car fenders that are exposed to sunlight, temperature, and humidity for a long time. (Figure 5)

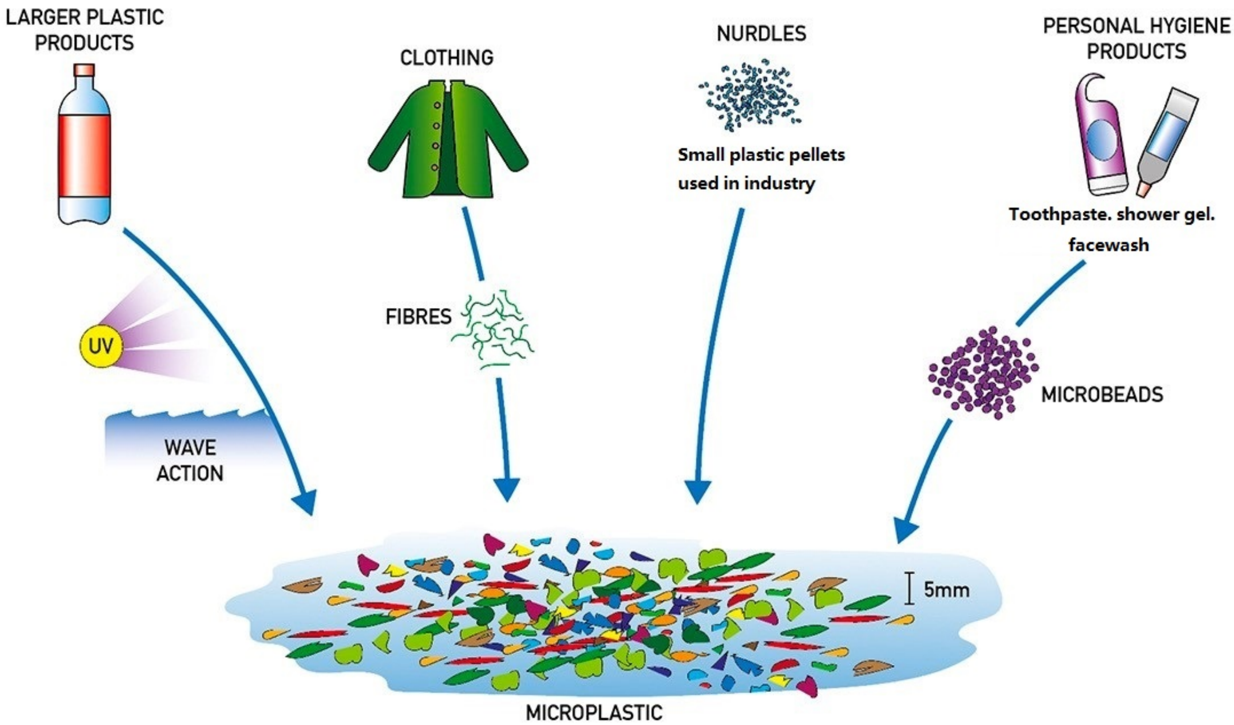


**Figure 5.** Examples of microplastic sources (Retrieved from https://encounteredu.com/multimedia/images/sources-of-microplastics)

Ocean plastic waste is extremely difficult to degrade, which means that it can exist for more than a decade and even hundreds of years. It caused serious effects on the marine ecosystem and the sustainable development of the marine economy, therefore being listed as one of the 10 global environmental problems.

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Scientists have found that there are more than 100 kinds of marine animals threatened by plastic. Large plastic waste can damage natural habitat and lead to illness or death of various kinds of birds, fish, and invertebrate. Many people have seen photos that larger plastics harm the marine life, for example, the sea turtle was snarled in a plastic six-pack ring or a dolphin was entangled in plastic fishing gear. Also, plastic waste can trigger biological invasion brought by chemical pollution and plastic debris, which may destroy the tourism industry and fisheries. What's worse, these large plastics can form microplastic waste by biological or physical activity and present a risk to both marine life and humans since they may contain toxic chemicals like phthalates, bisphenol A and others used in the manufacturing process.

Microplastics can be eaten by marine livings and cause physical damage to them, such as blocking the auxiliary organs and digestive tract, producing a false sense of satiety, consuming stored biological energy, and so on. Various researches show that microplastic can spread to human beings via the food chain including sea products and salt, which might be harmful to marine livings and human health. Microplastic can also bring compound chemical pollution damage to marine life. The toxic monomer, additive, persistent organic pollutants and heavy metals in surrounding environment can accumulate in the body and probably may transmit via food chain, thus leading to detrimental impact on marine life and human body.

## 2. LIFE CYCLE ANALYZE (LCA) OF MARINE PLASTIC

### 2.1. Introduction of LCA Method

Life-cycle assessment (LCA, also known as life-cycle analysis, and cradle-to-grave analysis) is a technique to evaluate environmental impacts associated with all the stages of the life-cycle of commercial products, process, or service. Take a manufactured product as an example, life cycle means from raw material processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave). LCA originated in 1969, when the Coca-Cola company in America began to evaluate the resource consumption and environmental releases of different beverage containers. LCA was largely introduced in the society. The enterprise is the strongest supporter of the early organizers, accounting for 70% of the participants, followed by industry associations (20%) and government (10%). Their research objects constituted packaging (45%), chemical product (9%), construction material (8%), baby diapers (7%) and tableware (3%). LCA has developed promptly since the 1980's and after the 1990s. LCA has been frequently applied in miscellaneous fields globally.

The unique idiosyncrasy of LCA are 1) Whole process evaluation. LCA includes the analytical process of the raw material collection, production, packaging, transportation, consumption, reuse and the final processing of environmental loads related to the life cycle of the entire production system. 2) Systematic and Quantifying. Systematically, LCA studies the consumption of all resources and the generation of wastes in every link of the whole life cycle of the products or behavior and their impact on the environment to evaluate the use of these energy and substances and the impact of released wastes on the environment quantitatively, identify and assess opportunities to minimize the environmental impact. The goal of LCA is to investigate the overall environmental impact assignable to products and services by quantifying all inputs and outputs of material flows and assessing how this material flows influence the environment. 3), and focusing on the environmental impact of the products. LCA emphasizes analyzing the environmental influence of the products or behavior in every phase of the life cycle, including energy consumption, land occupation and pollutant discharge. And in the end, it reflects the environmental impact of the products or behavior in the form of aggregate.

LCA is carried out in four distinct phases, which includes Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation.

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The LCA first explicates the goal and scope of the study, which sets the background of the research and explains how and with whom the results are to be communicated. This step is crucial and the goal and scope of LCA need to be distinctly defined and following the intended application.

Inventory involves inputs of water, raw materials and energy, and outputs to air, land, and water. To develop the inventory, LCA uses the data of inputs and outputs to build a flow model of the technical system.

Details from inventory analysis are used to assess the impact. In the impact assessment stage, all results of impact categories are listed in detail and the importance of each impact category is evaluated by normalization and weighting. This step aims to assess the significance of potential environmental impacts based on the impact flow results.

Life-cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the previous two phases. The outcome of this phase is conclusions and recommendations for the study. One of the most important reasons conducting the life cycle interpretation is to determine the confidence level of the final result. Explaining the result of LCA is not as simple as 2 is better than 1. Interpretation starts from understanding the accuracy of the results and guarantees the results match the goal of the research.

As stated by the National Risk Management Research Laboratory of the United States Environmental Protection Agency (EPA), "LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by 1) Compiling an inventory of relevant energy and material inputs and environmental releases 2) Evaluating the potential environmental impacts associated with identified inputs and releases 3) Interpreting the results to help you make a more informed decision."

## 2.2. Ways to Extend the Life Cycle of Plastic

The plastics waste usually end up with being recycled, incinerated, landfilled or dumped directly in the environment. Before 1980, recycling and incineration of plastic waste are negligible, thus 100% of plastic waste was discarded including landfilled or dumped directly in the environment. Since 1981 for incineration and 1988 for recycling, both of which increased on average approximately 0.7% per year. In 2015, it is estimated that 55% of global plastic waste was discarded, 25% was incinerated and 20% was recycled. We can predict from Figure 6 that by 2050, incineration rates will increase to 50% and recycling to 44%, while discarded waste will decrease to 6%.

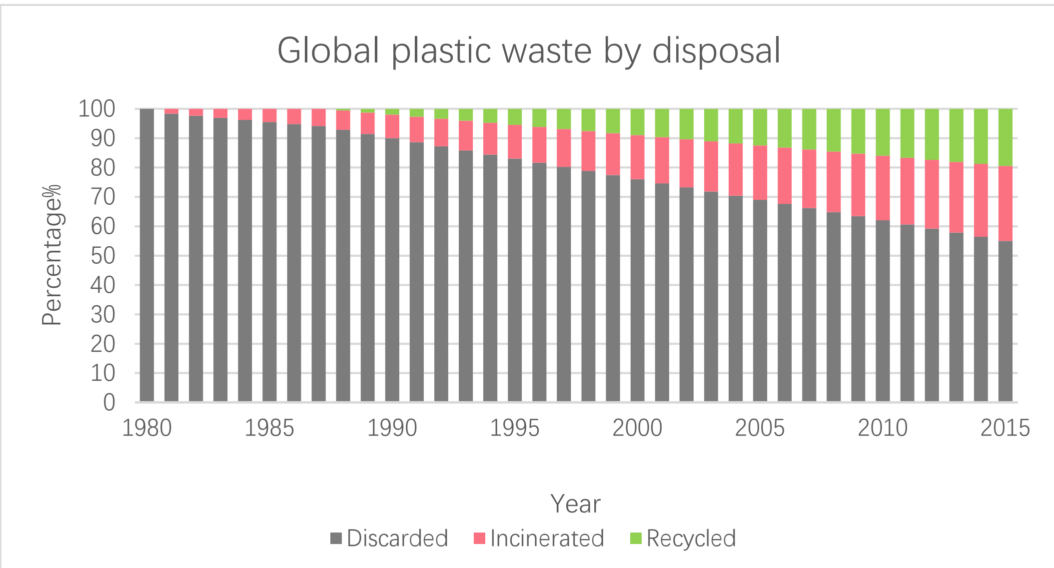


**Figure 6.** Global plastic waste by disposal. (Geyer, Jambeck, & Law, 2017)

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The recycle, landfill and incineration of plastic show different LCA results.

By applying the emission factors, we can determine the environmental impact of the end life of plastics quantitively. Emission factor is a representative value which attempts to associate the quantity of a certain pollutant released to the atmosphere with an activity related with the release of the pollutant. CO2 emission factor, also known as carbon emission intensity, is a key factor to evaluate if a process or material is environmental-friendly. Positive $CO_2$ emission factors mean this product or behavior releases $CO_2$ and thus is detrimental to the environment, while negative $CO_2$ emission factor means this process or product is carbon-negative.

Figure 7 shows the average carbon intensity of different waste treatment routes for each material. (Ref) The average carbon intensities of disposing different categories of plastic waste by recycling are almost negative, though it is positive when dealing with cardboard and paper. When it comes to incineration, it goes without doubt that incinerating PET and HDPE release considerable quantity of carbon dioxide because they contain organic matter including chlorine, which will produce the most poisonous chemical -Dioxin. In the end of treatment, it requires other technique to deal with these toxic chemicals to limit the impact on the environment, which may generate extra carbon dioxide. Interestingly, when incinerating cardboard and paper, the emission factors of these two materials are negative, which means it absorbs carbon dioxide. Although burning them does produce some carbon dioxide since they also contain quantities of organics, it also generates energy, which can substitute coal and petroleum in the context of electricity generation. Since generating electricity in the form of using coal and petroleum releases much more carbon dioxide compared to incineration, incinerating cardboard and paper can lower the carbon dioxide emission in the atmosphere. Landfill is a typical carbon-negative disposal treatment when dealing with solid waste, for the reason that people cannot reverse the impact brought by landfill.

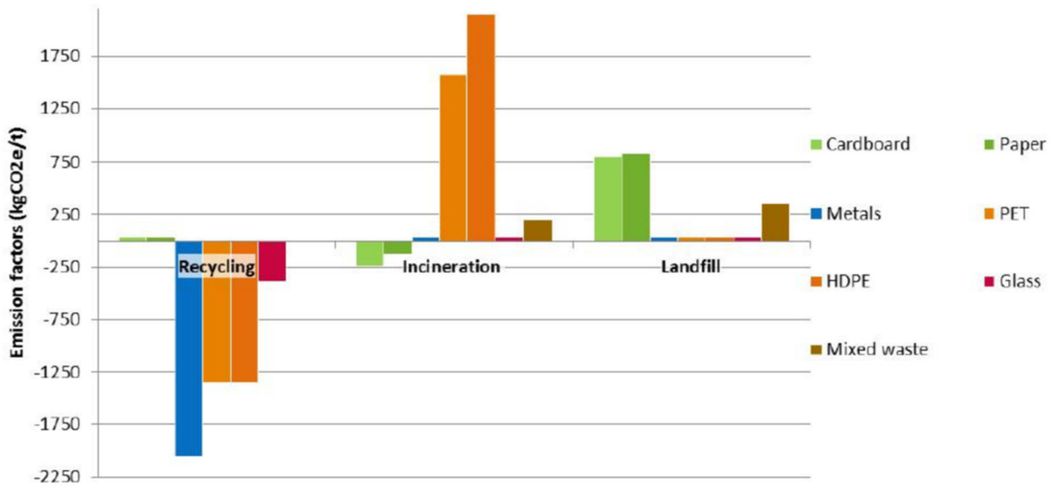


**Figure 7.** Average carbon intensity of different waste treatment routes for each material. (Chen, 2019)

Therefore, prevention and recycling become the primary options for reducing waste-related Green House Gases (GHG) emissions. In 1975, The European Union's Waste Framework Directive introduced the waste hierarchy concept into European waste policy. The waste management hierarchy (Figure 8) indicates an order of preference for action to reduce and conduct waste. The most favored option is prevention, followed by reuse, recycling, energy recovery, and disposal at the last option. Prevention is indisputably the most environment-friendly choice as it prevents and reduces waste generation. Reuse gives the product a second life before they become waste. And recycle can be any recovery operation by which waste materials are reprocessed into products regardless of the original purposes. It includes

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composting other than incineration. Recovery can be some waste incineration based on a political non-scientific formula that upgrades the fewer inefficient incinerators. Disposal, as the least favored treatment, generally means the process to dispose of waste such as landfill, incineration, pyrolysis, gasification and other finalist solutions.

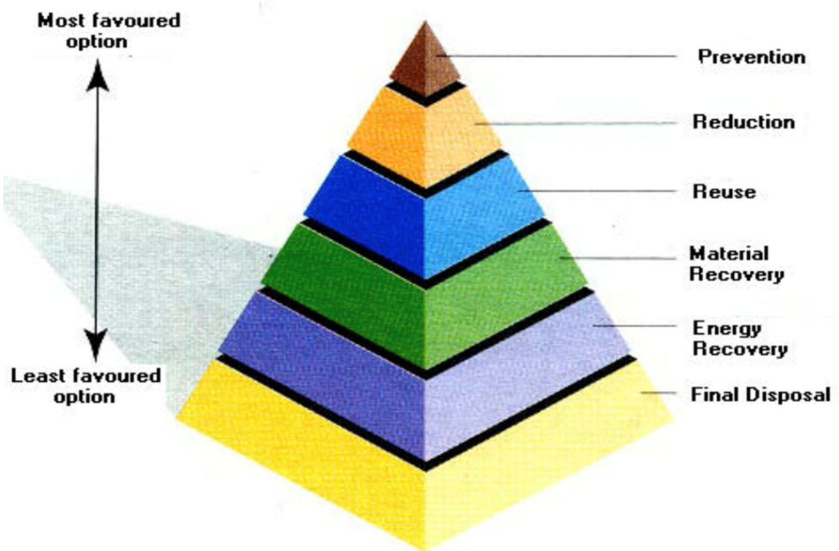


**Figure 8.** Hierarchy of Waste Management (Hansen, Christopher, & Verbuecheln, 2002)

The purpose of the waste hierarchy is to make full use of the maximum practical advantages from wasted products and to generate the minimum amount of waste. The proper application of the waste hierarchy can have many benefits. It helps with preventing emissions of GHG, reducing pollutants, saving energy, conserving resources, creating jobs and stimulating the development of green technologies.

## 3. POLICY AND MOVEMENTS COMBAT PLASTIC POLLUTION

### 3.1. Worldwide Policy Actions

United Nations Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea was adopted at the third United Nations conference on the law of the sea in 1982 and came into force in 1994. Although the convention does not address the issue of marine garbage, it does stipulate the general obligation of states to protect and maintain the ocean environment. It proposes to reduce the possibility of the pollution from land-based sources and vessels to the maximum extent, which serves as a significant guide and review in dealing with marine plastic pollution.

International Convention for the Prevention of Pollution from ships

The MARPOL 73/78 Convention is one of the most important international maritime environmental conventions in the world, to which China acceded in 1983. The MARPOL 73/78 convention aims to minimize the impact of dumping pollutants into the ocean, releasing oil and harmful gases into the marine atmosphere.

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal

The Basel Convention was adopted at the world conference of environmental protection held in Basel, Switzerland in 1989. The purpose of this convention is to curb transboundary transportation of hazardous wastes, particularly exporting and transferring hazardous wastes to developing countries. Nevertheless, this convention only controls hazardous waste from resin production and plastic surface treatment, ignoring plastics, rubber, and synthetic fabrics.

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Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

In 1972, the intergovernmental conference on the convention on dumping wastes at sea was held in London. The conferences passed the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, also known as the London Dumping Convention, which came into force in 1981 and was ratified in 1985 in China. This convention proposed that all the states parties shall "prohibit dumping any waste and substance in any form or condition", including "durable plastics and other durable synthetic materials, such as fishing nets and ropes. However, the reference of the convention to a ban on the dumping of plastic waste is not comprehensive enough, since the point is solely to avoid impeding fishing, navigation and so on.

## 3.2. Regional and Country Policy Actions

A remarkable number of national governments have implemented policies and economic measures to reduce plastic bags and keep Styrofoam products growing. And the number of new regulations on single-use plastics entering into force at the national level has experienced a steep increase since 2015. (Figure 9)

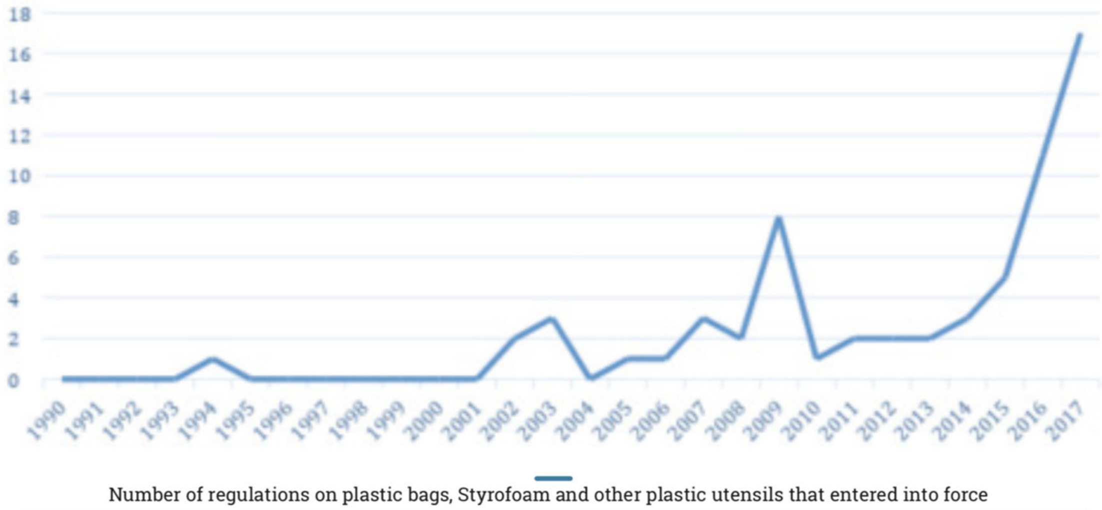


**Figure 9.** Estimated number of new regulations on single-use plastics entering into force at the national level worldwide. (UNEP, 2018)

**Table 1.** China's actions to minimize plastic bags and Styrofoam products (UNEP, 2018)

| Year | Level | Policy | Type | Impact |
|---|---|---|---|---|
| 2008 | National | Ban and levy-entered into force | Ban on non-biodegradable plastic bags < 25u and levy on consumer for thicker and bigger ones. | In Chinese supermarkets, plastic bag use decreased between 60-80%. Ban has been ineffectively enforced in food markets and among small retailers. (Xanthos, 2017) |
| 2009 | Local-Hong Kong | Levy-entered into force | Levy on consumer | Implementation in different phases. Initially limited impact due to implementation only in selected chains and outlets. In 2015, the levy was extended to over 100,000 retailers. 25% fewer bags were disposed in landfills within one year (in 2016 vs. 2015) (Hong Kong Environmental Protection Department; Kao, 2016) |
| 2015 | Local-Jilin province | Ban-entered into force | Ban on production and sale of non-biodegradable plastic bags and tableware in Jilin province. (Sun, 2015) | Limited because of poor enforcement. (Zixiong, 2017) |

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As the producer that generates the most plastic waste in total, China has taken the following actions to combat plastic pollution issue. (Table 1)

As for the United States, the country that generate the most plastic waste per person, also carried out the following policies and actions. (Table 2)

**Table 2.** United States' actions to minimize plastic bags and Styrofoam products (UNEP, 2018)

| Year | Level | Policy | Type | Impact |
|---|---|---|---|---|
| 2010 | Local-Washington DC | Levy-entered into force | Levy on consumer for plastic bags ($0.05) in Washington, DC (Department of Energy & Environment, 2010) | A survey in 2014 revealed that the consumption of plastic bags decreased on average from 10 to 4 plastic bags a week (Department of Energy & Environment, 2014) |
| 2011 | Local-American Samoa | Ban-entered into force | Ban on the sale and use of petroleum-based plastic bags (some exceptions possible for fresh and frozen products and others) (American Samoa Environmental Protection Agency, 2011) | Information not available |
| 2011 | Local-Hawaii | Ban-entered into force | Ban on single-use plastic bags in Hawaii. 2013: Big Island Hawaii, 2018: Honolulu and Pala (S. Walter Packaging, n.d.) | Information not available |
| 2012 | Local-San Francisco, California | Ban and levy-entered into force | Ban on single use checkout plastic bags and levy on consumer on compostable bags, recycled paper bags or reusable (>125 uses) bag of $0.10 in the county and city of San Francisco. (sfenvironment, n.a.) | Information not available |
| 2013 | Local-Austin, Texas | Ban-entered into force | Ban on single-use plastic bags (<101u) in Austin, Texas. (abagatatime, n.d.) | While the consumption of single-use plastic bags decreased, that of reusable, thicker plastic bags increased (Richards, 2015) |
| 2015 | Local-New York City, New York | Ban-entered into force | Ban on single-use Styrofoam containers instituted in New York City. The ban was challenged by coalition of recycling firms and plastics manufactures who claimed the material is recyclable. The ban was lifted in 2015 and reintroduced in 2017 (Alexander, 2017) | Information not available |
| 2016 | Local-California | Ban-entered into force | Ban on single-use plastic bags and levy on thicker reusable ones (US$ 0.10) in California | Plastic bags accounted for about 3% of the litter collected during the 2017 Coastal Cleanup Day, compared to 7.4% in 2010 (Los Angeles Times Editorial Board, 2017) |
| 2017 | Local-Chicago Illinois | Levy-entered into force | Levy on consumer plastic bags in Chicago ($0.07) | The number of plastic bags (and paper bags, as these are also taxed) declined by 42% one month after the introduction of the tax (Cherone and Wetli) |
| 2017 | Local-Seattle | Ban-entered into force | Ban on single-use plastic bags, including bags labelled with biodegradable, degradable, decomposable or similar, and voluntary levy on thicker (>57u) plastic bags in Seattle (Seattle Government, 2017) | Information not available |

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## 3.3. Society and Personal Level Actions

3.3.1 Extended Producer Responsibility (EPR)

This is a strategy to add all of the environmental costs associated with a product throughout the product life cycle to the market price of that product. In Germany, since the adoption of EPR, "between 1991 and 1998, the per capita consumption of packaging was reduced from 94.7 kg to 82 kg, resulting in a reduction of 13.4%".

3.3.2 The Ocean Cleanup

The Ocean Cleanup aims to clean up 90% of ocean plastic pollution. It is developing a passive cleanup method, which uses the natural oceanic force to rapidly and cost-effectively clean up existential plastic in the oceans. It also has developed the first scalable solution to efficiently intercept plastic in rivers before it flows into the oceans.

# 4. CONCLUSIONS AND SUGGESTIONS

This paper analyzes the overall production and environmental threats of marine plastic. Then an LCA method is applied to extend the life cycle of plastic. According to the current policy and solution to combat marine plastic pollution worldwide, a comprehensive solution combing technology innovation and regulation enhancement have been proposed.

## 4.1. Technique

(a) Establish separate collection and sorting systems for different waste streams. Municipal Solid Waste (MSW) consists of various kinds of waste, including glass, metal, plastic, paper, food waste and other wastes. Each category requires different kinds of disposal measure to lower its environmental impact, and therefore MSW should be classified according to its idiosyncrasy.

(b) Apply an LCA strategy to evaluate the environmental impact quantitatively. To implement adequate policy, it is inevitable to obtain data of energy and material consumption in each phase of the waste production.

(c) Conduct further research on the plastic collection and disposal technique. How to deal with those waste remains a dilemma, because there are no effective ways to eliminate the destructive impact brought by current treatment methods, and incineration is now prevalently adopted in many regions.

(d) Carry out further research on substitute of plastics and degradable plastics. It is inevitable for us to use plastics in our daily life because of the unique advantage of being light, portable, and durable. Even though it sometimes costs us a few pennies due to the ban on free plastic bags, people are willing to pay for it. Sometimes it is difficult to prevent people from using plastics, scientists may start to consider new possibilities to replace plastics or renew the technique we previously used to make it degrade easier.

## 4.2. Regulation

(a) Promote the Extended Producer Responsibility (EPR) among enterprises. When faced with either the financial or physical burden of recycling their products after use, they may be intrigued by designing products to last longer that can directly reduce producer’s end-of-life costs.

(b) Establish effective horizontal cooperation between local authorities and municipalities and a vertical co-operation between the different levels of government, from local to regional and even national level when beneficial.

(c) Reinforce administrative capacity at the regional and local levels. The lack of finances, information, and technical expertise must be overcome for effective implementation and success of the waste management policies.

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(d) Establish a comprehensive education system to raise the public's awareness of plastic pollution and intensify the environmental consciousness, which may enable the public to change their consuming behavior and develop the habit of garbage classification consciously.

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