Strategic Plan for Global Plastic Waste Reduction: A Comprehensive Data-Driven Approach

Summary

The invention of plastics has brought great convenience to people, but it also causes severe environment problems. Since the lack of effective ways of processing, the single-use and disposable plastic product waste enters the nature and does damage to surface water, soil, the ocean, and the life in the world. It's urgent to develop a plan to reduce plastic waste to an environment-friendly level.

In task 1, Plastic Waste Capacity Model is constructed to assess the maximum amount of waste that can be safely mitigated. First, according to the source and use of plastic waste, plastic waste is classified as non-recyclable, partially recyclable, and widely recyclable plastic waste. Then, we construct a recycling judgment coefficient (RJC) to measure the availability of resources for processing plastic waste. At the same time, in order to measure the degree of damage to the ecological environment, we introduce the ecological environment index of plastic waste (EPWI). In addition, in order to avoid further damage to the ecological environment, a multi-objective planning model based on plastic waste capacity is constructed. Finally, through the optimization of the ant colony algorithm (ACA), we can get the maximum amount of waste that can be safely processed, with a value of 210.85.

In task 2, An optimized model of plastic waste reduction is used to calculate the maximum amount of waste reduction to reach an environmentally safe level. We divide plastic product waste into three categories according to different production uses: residents produce plastic waste, society uses plastic waste, and industry produces plastic waste. Moreover, based on the double difference (DID) model, the degree of influence of policies on various factors can be obtained. Finally, we verified with Chinese data.

In task 3, based on the models in Task 1 and Task 2, we conduct an adjustment analysis of policies. First, by analyzing the mechanism of the environmental protection policy, we construct the idealized state under the best policy. Then, through data prediction, we obtained the approximate value of the relevant factors under the best policy, and the minimum waste amount target value was approximately 346.7. Finally, we comprehensively analyze the impact of achieving this goal on residents, society and industry.

In task 4, the equity issues may be caused is firstly analyzed, through which we find that the plastic waste problem will not be better without a proper rule for all the countries to cooperate. In order to unite the world and solve the equity issues, we propose 4 principles. The principles indicate that every country has its own plastic generation limitation and money to undertake, which are based on plastic waste volume a country does not properly dispose and its GDP.

Finally, we write a memo to ICM, which includes a target level of global single-use or disposable plastic product waste, a timeline to achieve the goal, and some main factors that may influence the timeline.

Key words: Plastic Waste; Plastic Waste Capacity Model ; Ant Colony Algorithm; Double Difference Model;

Contents

1. Introduction

1.1 Background

Plastics is an important basic material invented by human, which has brought great convenience to manufacturing and people's life. Since the 1950s, global plastics production has been rising in a high speed. In 2018, the world plastics production volume reached 359 million tons [11]. After the use of these plastics, especially the single-use and disposable plastic products, since the lack of timely and effective manners to collect and process them, some of them entered the environment. Their natural degradation time is up to decades or hundreds of years, so they kept leaving in the environment, which caused serious environmental pollution to surface water, soil and the ocean [1].

In recent years, this problem has attracted widespread international attention. Since 2011, the United Nations Environment Programme has continued to pay attention to plastic waste in the ocean [1]. Many countries and regions like China, Europe are also aimed at finding solutions to the plastic waste problem.

1.2 Problem Statement

This is a global crisis, so the problem is not easy to solve. The problem can be divided into five parts, and under the certain logic prospect, comprehensively understand and solve the crisis (dilemma).

Estimate the maximum level of single-use or disposable plastic product waste that can safely be mitigated without further environmental damage in connection with variety of relative factors.

To clarity the extent of existing level of plastic waste can be relieved is so as to reach a balance between safe natural environment, which have considered factors among the catalogue of plastic waste, availability of alternatives to plastic, and the impact or effectiveness of different policies in different regions.

To set an aim for the minimum achievable level of single-use or disposable plastic products waste generated by the global population and discuss the impact for achieving such levels

Give some suggestions for ICM to solve the issue of fairness of quotas in global plastic waste processing, especially to discuss the causes and effectiveness of relative measures or policy which is meant for addressing the dilemma.

Describe a realistic global target minimum achievable level of global single-use or disposable plastic product waste, a timeline to reach this level, and any situation that may accelerate or hinder the achievement of different targets and timeline

2. Assumption and Symbol Explanation

2.1 Assumption

- ◆The data source is actual and reliable.
- ◆The government policy in the international setting will not change in the short term.
- ◆Assuming that the proposals from the previous period will come into effect during this period.
- ◆The amount of plastic waste processed minus the wasted amount of plastic product equals the amount of plastic waste reduction.

2.2 Symbol Explanation

For convenience, we use the following symbols in our models .

Table.1 Symbols and its Description

symbol	description
TPW	Total plastic waste
PW^{no}	The non-recyclable plastic waste generation
PW^{Pa}	The volume of partially recycled plastic waste
PW^{ex}	The extensive recycling of plastic waste
RJC	The recovery judgment coefficient
NPC	The natural purification coefficient in year t
RPW	The plastic waste recovery rate
$EPWI$	The ecological index of plastic waste
SPW	The amount of plastic waste that can be safely handled
CBR	Cost Benefit ratio
A	Assumption a=1/2
TR	Incineration rate
CNE	carbon dioxide emissions
FA	forest area
ME	methane emissions

3. Task 1

3.1 Data Preprocessing

3.1.1 Data Collection

Data is the basis for building mathematical models and quantitatively analyzing problems. In order to determine the data required for problem research, we search a large amount of network information and analyze the potential influencing factors. The data we use is mainly from the World Bank [12] and the National Bureau of Statistics of the People's Republic of China [13]. In addition, some of the accepted data we use are mainly from the our world in data [2].

3.1.2 Data Perfection

Since the data we use is derived from historical statistics, some data may be missing**.** To cope with this situation, we need some processing principles to perfect the data. The processing principles we adopted are as follows:

◆If the data is tested for stationarity, we use one of the previous data or the average of the previous data.

◆If the data before and after can be obtained, we use interpolation to predict missing values.

Moving average and exponential averaging are used to predict missing values.

However, complete data is not necessarily accurate, and may sometimes interfere with the establishment of models. Therefore, before using the data, we need to check the validity of the data.

3.2 Source of Plastic Waste

According to different standards, the sources of plastic waste can be divided differently. And there are some differences in the characteristics of plastic waste from different sources, such as the cost of waste treatment, the recyclability of plastics, etc.

By searching the classification criteria of plastic waste in the our world in data, we divided plastic waste into three categories, namely non-recyclable, partially recyclable and widely recyclable plastic waste [2]. Besides, plastic waste of various chemical compositions can be divided into one of these categories.

At the same time, by searching for information, we found that common plastic waste disposal methods include disposal, incineration and recycling. Therefore, comprehensively considering the sources and treatment methods of plastic waste, the classification and treatment diagram of plastic waste is as follows:

As can be seen from Fig.1, Partially recyclable waste mainly contains three specific components, and extensively recyclable waste mainly contains two types. Meanwhile, non-recyclable plastic waste contains Low-density polyethylene, Polystyrene, Polyurethanes, and other polymer types. [3]

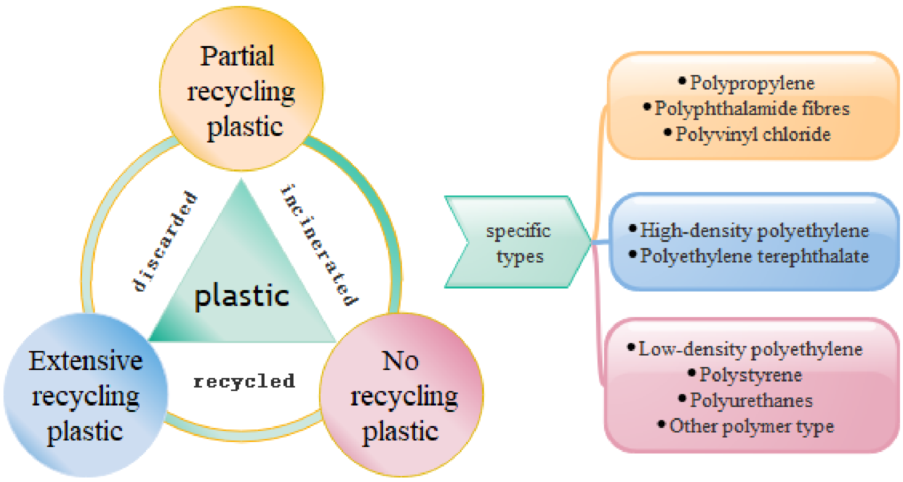


Fig.1 Classification and treatment of plastic waste sources

3.3 Resource Availability for Waste Disposal

Plastic waste treatment can directly reduce the cumulative waste of plastic products. However, the disposal of plastic waste requires certain resources. At the same time, we can know that the chemical composition and treatment of plastic waste will affect the availability of resources. Therefore, before processing plastic waste, we should first measure the availability of processing resources.

We use a cost-benefit function to measure the availability of resources for processing plastic waste. According to the cost-benefit function, we can get the cost-benefit ratio (CBI) of the corresponding resources, and the function expression of CBI is as follows:

$$CBI_t = f(benefit_t, \cos t_t) \tag{1}$$

where the subscript *t* indicates that the time is in year t. The variable *benefit* is the benefit of resources used to process waste, and *cost* is the cost of consuming resources.

In fact, the benefits of waste disposal (*benefit*) mainly include the value of recycled plastic (*Vec*) and the contribution of reducing waste to the environment (*Vrp*). Therefore, we can get the function expression of *benefit*:

$$benefit_t = B(Vec_{t-1}, Vrp_{t-1}) \tag{2}$$

where the subscript *t* indicates that the time is in year t. Time t-1 indicates that the benefits have a certain lag, and the benefits of this period come from the previous period.

Similarly, the cost of treating waste (*cost*) is primarily the value of the resources used (*Vresource*), and it is also affected by technical factors (*tech*). Therefore, we can get the function expression of *cost*:

$$\cos t_t = C(Vresource_t, tech_t) \tag{3}$$

where the subscript *t* indicates that the time is in year t.

In addition, because the availability assessment of resources affects the decision-making of waste disposal, we convert the cost-benefit ratio into the recovery judgment coefficient (RJC). And the function expression of *RJC* is as follows:

$$RJC_t = \begin{cases} 1 & CBI_t > a \\ 0 & CBI_t < a \end{cases} \tag{4}$$

Where the subscript *t* indicates that the time is in year t, and the constant a is a threshold value used to adjust the decision value for recycling waste.

Based on the above analysis, we can get the related equations of the recovery decision coefficients *RJC*:

$$\begin{cases} RJC_t = \begin{cases} 1 & CBI_t > a \\ 0 & CBI_t < a \end{cases} \\ CBI_t = f(benefit_t, \cos t_t) \\ benefit_t = B(Vec_{t-1}, Vrp_{t-1}) \\ \cos t_t = C(Vresource_t, tech_t) \end{cases} \tag{5}$$

3.4 Ecological Index of Plastic Waste

The current severity of plastic waste can change people's environmental awareness to a certain extent, and then affect the waste of single-use or disposable plastic products. Therefore, we constructed the ecological index of plastic waste (EPWI).

The ecological index of plastic waste (EPWI) can be set through multiple environment-related indicators. The ecological and environmental indicators we selected include carbon dioxide emissions (CDE), forest area (FA), methane emissions (ME), and the amount of marine floating microplastics. In addition, microplastics are divided into two categories based on whether the diameter is greater than 0.5 cm. Among them, MP1 indicates the amount of microplastics with a diameter greater than 0.5 cm, and MP2 indicates the amount of microplastics with a diameter less than 0.5 cm.

After obtaining each specific indicator, according to the standardized method of the ecological environment indicator, we first convert the indicator value to the standard value. Then, we calculate the ecological index (EPWI) of plastic waste by weighted average method. The function expression of EPWI is as follows:

$$\begin{cases} EPWI_t = \sum_{i=1}^{5} (\alpha_i \times index_{it}) \\ index_t = \left\{ I_t^{CDE}, I_t^{FA}, I_t^{ME}, I_t^{MP1}, I_t^{MP2} \right\} \end{cases} \tag{6}$$

where the subscript t indicates that the time is in year t. $index_{it}$ represents the standard value of the i-th index in year t, and I_t^{CDE} is the standard value of the indicator CDE in year t. α_i represents the weight of the i-th index.

In order to avoid the error caused by subjectivity, we use the entropy weight method (EWM) to determine the weight of each index. The processing steps of the entropy weight method are

Step 1: Standardize each index value.

Step 2: Calculate the entropy of each indicator.

Step 3: Calculate the utility value of the indicator.

Step 4: Determine the weight of the indicator.

According to the standardization process of the ecological environment index, the higher this index, the better the ecological environment. To avoid unnecessary ambiguity, we make the eco-environment index of plastic waste follow the same standardization process. Therefore, in order to minimize the damage to the environment, we can get an objective function:

$$\max EPWI_t = \sum_{i=1}^{5} (\alpha_i \times index_{it}) \tag{7}$$

where the subscript t indicates that the time is in year t, and the meaning of the variables is consistent with equation (6).

3.5 Plastic Waste Capacity Model

According to the source of plastic waste, plastic waste can be divided into non-recyclable, partially recyclable and extensively recyclable plastic waste. Differences in the characteristics of each plastic waste also make its capacity different.

In general, the factors affecting the capacity of plastic waste include incineration rate (*IR*), recovery rate (*R*) and natural purification rate (*NPC*), and the factors will vary with the type of waste. However, for non-recyclable plastic waste, there is no recovery rate. Although recyclable waste may have high recoverable rate, it is also limited by the resources required for waste disposal.

Based on the above analysis ideas, we can get the flowchart of the overall analysis of task 1:

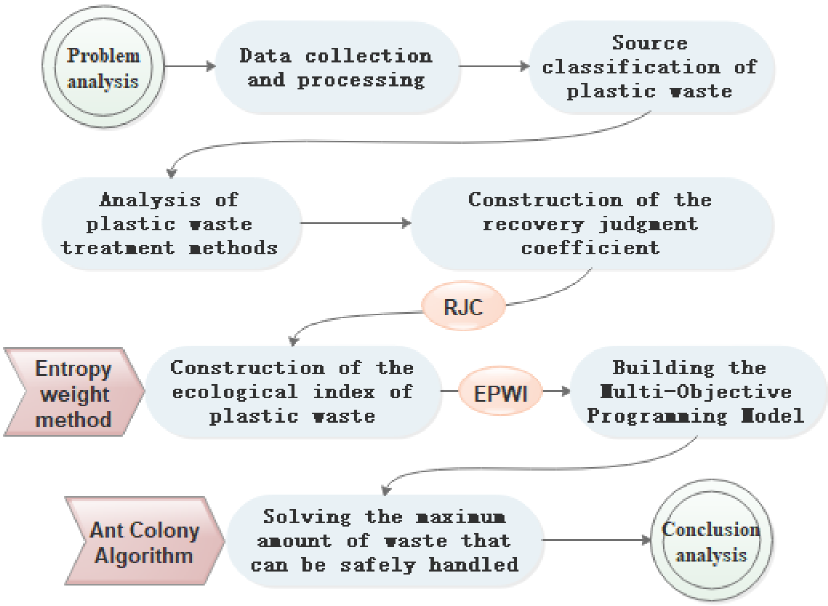


Fig.2 The flow chart of overall analysis for task 1

3.5.1 Sub-capacity of Plastic Waste

◆Non-recyclable plastic waste

Non-recyclable plastic waste is no recycling rate, so only the incineration rate and natural purification rate need to be considered. On the one hand, the amount of waste contained in plastic waste is positively related to the amount of waste generated (*PW*). On the other hand, the amount of waste contained in plastic waste will also decrease as the incineration rate (*IR*) and natural purification rate (*NPC*) increase. Therefore, the capacity of non-recyclable plastic waste PW_1 is as follows:

$$PW_{1t} = PW_t^{no}(1 - IR_t^{no} - NPC_{i-1}^{no}) \tag{8}$$

where the subscript *t* indicates that the time is in year t, and superscripts 1 and *no* indicate non-recyclable plastic waste. The subscript *i*-1 indicates that the indicator is lagging.

◆Partially recyclable plastic waste

Unlike non-recyclable plastic waste, partially recyclable plastic waste has the recyclable rate (*R*), and the actual recovery rate is also affected by the availability of waste resources for processing. Therefore, by introducing the recycling judgment coefficient, we can construct the capacity of plastic waste that can be partially recycled PW_2. Only recyclable plastic waste that passes the recycling discrimination coefficient test will be actually recycled. The function expression of PW_2 is as follows:

$$PW_{2t} = PW_t^{pa}(1 - R_t^{pa} \times RJC_{1t}^{pa} - IR_t^{pa} - NPC_{i-1}^{pa}) \tag{9}$$

where the subscript t indicates that the time is in year t, and the subscript i-1 indicates that the indicator is lagging. RJC_{1t}^{pa} is the recovery judgment coefficient corresponding to the partially recyclable plastic waste. The superscript pa indicates partially recyclable plastic waste.

◆Extensively recyclable plastic waste

Similarly, we can construct the function expression for the capacity of the extensively recyclable plastic waste PW_3:

$$PW_{3t} = PW_t^{ex}(1 - R_t^{ex} \times RJC_{2t}^{ex} - IR_t^{ex} - NPC_{i-1}^{ex}) \tag{10}$$

where the subscript t indicates that the time is in year t, and the subscript i-1 indicates that the indicator is lagging. RJC_{2t}^{ex} is the recovery judgment coefficient corresponding to the extensively recyclable plastic waste. The superscript ex indicates extensively recyclable plastic waste.

3.5.2 Total Capacity of Plastic Waste

According to the previous analysis, plastic waste is divided into non-recyclable, partially recyclable and widely recyclable plastic waste. Therefore, the total capacity of plastic waste (TPW) is the sum of the capacities of the three types of plastic waste:

$$TPW_t = PW_{1t} + PW_{2t} + PW_{3t} \tag{11}$$

where the subscript t indicates that the time is in year t. The subscripts 1, 2, and 3 indicate the capacity of three types of plastic waste.

In order to maximize the amount of plastic waste that the ecological environment can hold, we can obtain an objective function:

$$\max TPW_t \tag{12}$$

where the subscript t indicates that the time is in year t.

3.5.3 Multi-objective Programming Model

According to equations (1) to (12), we can get a multi-objective programming model:

$$\begin{aligned}
&\max \eta_1 \times TPW_t + \eta_2 \times EPWI_t \\
&s.t.\ \ \eta_1 + \eta_2 = 1 \\
&\left\{\begin{aligned}
TPW_t &= PW_{1t} + PW_{2t} + PW_{3t} \\
PW_{1t} &= PW_t^{no} \times (1 - IR_t^{no} - NPC_{t-1}^{no}) \\
PW_{2t} &= PW_t^{pa} \times (1 - R_t^{pa} \times RJC_{1t}^{pa} - IR_t^{pa} - NPC_{t-1}^{pa}) \\
PW_{3t} &= PW_t^{ex} \times (1 - R_t^{ex} \times RJC_{2t}^{ex} - IR_t^{ex} - NPC_{t-1}^{ex}) \\
EWPI_t &= \sum_{i=1}^{5} (\alpha_i \times index_{it}) \\
index_t &= \left\{ I_t^{CDE}, I_t^{FA}, I_t^{ME}, I_t^{MP1}, I_t^{MP2} \right\} \\
RJC_t &= \begin{cases} 1 & CBI_t \geq a \\ 0 & CBI_t < a \end{cases} \\
CBI_t &= f(benefit_t, \cos t_t) \\
benefit_t &= B(Vec_{t-1}, Vrp_{t-1}) \\
\cos t_t &= C(Vresource_t, tech_t)
\end{aligned}\right.
\end{aligned} \tag{13}$$

where the subscript t indicates that the time is in year t. Parameter η is the weight of multiple targets.

3.6 Model Solving and Analysis

3.6.1 Model Transformation Processing

Since the data we have collected is incomplete, some implicit functional relationships in the multi-objective programming model cannot be accurately fitted. Therefore, for this case, we simplify and specify the model.

◆Cost-profit function

As previously analyzed, cost profit rate (*CBI*) is positively correlated with profit (*benefit*) and negatively correlated with cost (*cost*). Therefore, the cost margin is expressed as the ratio of profit to cost, and the specific expression of the cost-profit function is

$$CBI_t = \frac{benefit_t}{\cos t_t} \tag{14}$$

where the subscript t indicates that the time is in year t.

◆Profit function

Similarly, we represent the profit (*benefit*) from waste disposal as the sum of the value of the contribution to the ecological environment (*Vec*) and the value of recycled plastic waste (*Vrp*). Therefore, the specific expression of the profit function is

$$benefit_t = Vec_{t-1} + Vrp_{t-1} \tag{15}$$

where the subscript t indicates that the time is in year t.

◆Cost function

The higher the level of technology, the lower the cost of processing unit waste. Therefore, we represent the cost of processing waste as the ratio of the value of the resources consumed to the level of technology, and the specific expression of the cost function is

$$\cos t_t = \frac{Vresource_t}{tech_t} \tag{16}$$

where the subscript t indicates that the time is in year t.

3.6.2 Conclusion Analysis

First, we assume that both the eco-environment index of plastic waste and the total capacity of plastic waste have a weight of 0.5. Then, by integrating equations (13) to (16), we can obtain a solvable multi-objective programming model. In addition, in order to ensure the reliability of the model solution, we use ant colony algorithm (ACA) to optimize the solution.

Through the above analysis and treatment, we can calculate the maximum total capacity of plastic waste and the maximum capacity of three types of plastic waste, respectively. The end result is as follows:

According to Table. 2, the maximum capacity of plastic waste that can be partially recovered is 82.86, which is the largest among the three types. This is followed by the non-recyclable plastic waste, which has a maximum capacity of 74.72. Finally, there is the extensively recyclable plastic waste with a maximum capacity of 53.27.

Table.2 The maximum capacity of plastic waste

Types of plastic waste	Maximum disposal
Resident	153.8
Social	77.6
Industrial	115.3
Total	346.7

This shows that the current level of plastic waste that can be partially recycled in the world is maintained at a high level, and there is a trend of further promotion. However, for the widely recyclable plastic waste, due to the influence of other factors such as cost and technical difficulty, the amount currently put into use is relatively small.

In addition, we can get the total capacity of plastic waste from Tab.1 is 210.85.

4 Task 2

4.1 Data Preprocessing

As the first part, Data which we searched is used for building mathematical models and quantitatively analyzing problems. And before recalculating, the researched data is sorted and filled. Since the process similar to the first part, this section will not repeat it. Then let us build and solve the models.

4.2 Analysis of Total Plastic Waste Reduction (TD)

According to the understanding of the achievable extent of plastic waste reduction (PWR), it means that to calculate the maximum of PWR is so as to reach the environmental safe level.

Obviously, plastics used for different purposes are different in terms of processing and industry policy. Therefore, plastic waste needs to be divided into different categories. In this section, the seven types of plastic are divided into three categories for subsequent calculation and analysis. They are resident plastic waste(PWR_1), social plastic waste (PWR_2) and industrial plastic waste (PWR_3). Details are as shown in the following figure 4-1

4.2.1 The Catalogue of Source of Plastic Waste

Based on different plastic waste for different purposes, there are mainly 7 types, namely, Packaging, Consumer and Institutional Products, textiles, electrical (or electronic), industrial machinery, transportation and other sectors. Then, they are divided into three catalogues, namely, PWR_1, PWR_2 and PWR_3. And then, we can research their impact factors to further calculate the value TD.

4.2.2 The Analysis of Factors to TD

Undeniably, the reduction of plastic waste (PWR) is related to the generation of plastic waste (PWG), which is the commonality of all catalogues to plastic waste. In fact, PWG is the basis of PWR. But we cannot simply equate PWG with PWR, the Plastic waste treatment can directly reduce the cumulative waste of plastic products waste in connection with those three types. Furthermore, the market of alternative, the feature of plastic (lifespan in use is few overweight than that in treatment), the environmental-protection awareness and the development of economy have impact on PWR.

Apparently, the greater the value the availability of alternative is, the greater the value of PWR, so is the degree of environment protection, but neither is the level of economy. At the same time, these factors are also effected by the policies with various extent, and we will study it in latter. Therefore, though there are the commonality among them, but the difference lead to the different specific function to all kinds of plastic waste.

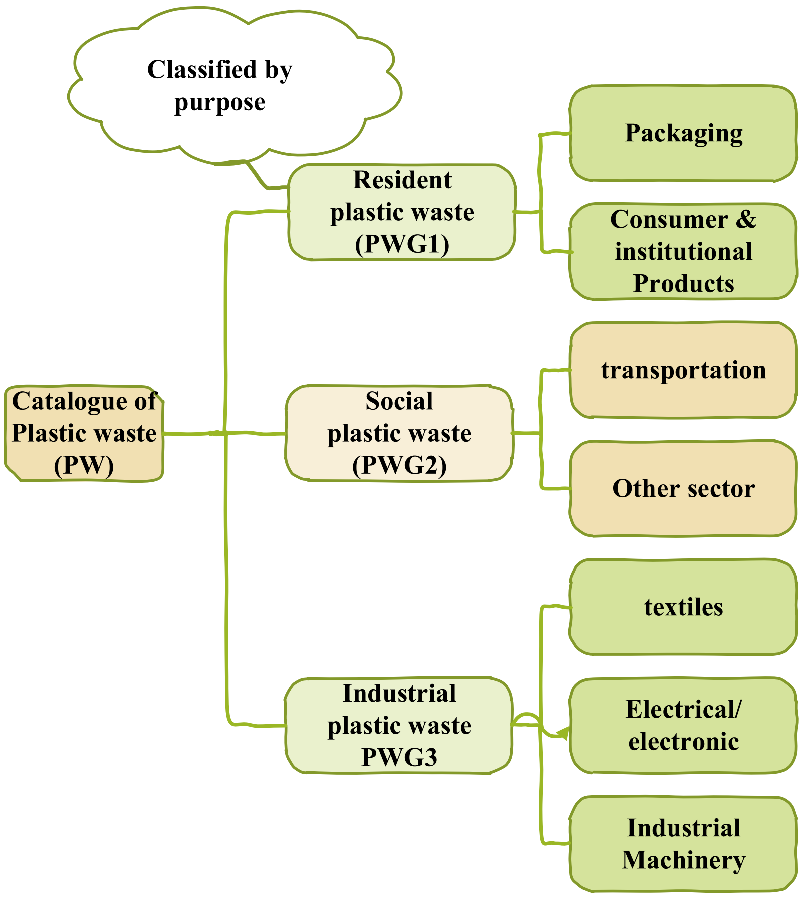


Fig. 3 the catalogue of Source of Plastic Waste.

4.2.3 The Establishment of the TD Solution Model

◆Step 1 define the Reduction of plastic waste

In order to obtain the TD Solution Model, it is necessary to determine the reduction of various types of plastic waste, that is, $PWR_j, j=1,2,3$. Based on the above analysis, the functional relationship of PER initially can be constructed, as shown in (4.1) below.

$$PWR_{jt} = PWG_{jt}(AC_{jt} + \mathrm{EF}_{jt} - EC_{jt} + 1), j=1,2,3 \tag{17}$$

Where AC_{jt} is the Alternative Coefficient of type j PW in year t in connection with availability of alternative, EF_{jt} is environment-protection awareness of type j plastic waste in year t, and EC_{jt} is economic coefficient in year t.

◆Step 2 Define Various Coefficients

As analysis saying above, every factor is relative with some variable. The specific function expression is as follows

$$AC_{jt} = AP_{jt}\cos t_{jt}^{a} / AP_{jt}\cos t_{jt}^{a}, j = 1,2,3 \tag{18}$$

$$\mathrm{EF}_{jt} = 1 / EPMI_{t} \tag{19}$$

$$EC_{jt} = \tau\Delta GDP_{t} / GDP_{t-1}, \tau\text{为常数} \tag{20}$$

◆Step3 construct the TD Solution Model

Obviously, based on the analysis to the relation of factors, the TD solution Model can easily be constructed, as followings.

$$\max \quad TD = \sum_{j=1}^{3} PWR_{jt} \; j = 1,2,3 \tag{21}$$

Where PWR_{jt} represents the resident plastic waste, social plastic waste, and industrial plastic waste in year t, namely, PWR_1, PWR_2 and PWR_2. And when the reduction of the three types of waste reaches equilibrium, it is the TD we required

4.3 The Calculation of TD

Substituting data into the above model and using the optimization algorithm, the final result is shown in the following table. 3, and TD is 287 million tons.

Table. 3 the Calculation result table of TD.

variable	$j=1$	$j=2$	$j=3$	Total
PWG_j	178	59	65	302
PWR_j	124.6	64.9	97.5	287(TD)

4.4 The Effectiveness of Policies to different factors

However, these factors above vary between regions because of different policies and policies whether or not be implemented. At this situation, it is necessary to study the effectiveness in various factors above.

4.4.1 Establishment of Double Difference (DID) Model

In order to better explore the impact of policies on various factors and the degree of influence, we refer to the double difference model, use the parameter estimates of the cross-terms of the two variables in the econometric model, and judge the impact direction based on the positive and negative parameter estimates.

◆Step1 Defining Policy Variables (0-1)

$$NPI_{\mathrm{it}} = \begin{cases} 1 & implemented \\ 0 & no-implemented \end{cases}, i = American, China, Europe, \cdots \tag{22}$$

Where implemented mean policy is implemented in country i in the year t, and the NPI_{it} is 1, or NPI_{it} is 0.

◆Constructed DID Model

Three regression models were established for each of the three variables.

$$PWR_{jt}=\beta_{0jt}+\beta_{1jt}AC_{jt}NPI_{ijt}+\beta_{2jt}NPI_{ijt}+\beta_{3jt}AC_{jt}+\sum controls+\varepsilon_{1j} \tag{23}$$

$$PWR_{jt}=\gamma_{0jt}+\gamma_{1jt}EF_{jt}NPI_{ijt}+\gamma_{2jt}NPI_{ijt}+\gamma_{3jt}EF_{jt}+\sum controls+\varepsilon_{2j} \tag{24}$$

$$PWD_{jt}=\lambda_{0jt}+\lambda_{1jt}EC_{jt}NPI_{ijt}+\lambda_{2jt}NPI_{ijt}+\lambda_{3jt}EC_{jt}+\sum controls+\varepsilon_{2j} \tag{25}$$

Where $\varepsilon_{ij}(,i=1,2,3)$ is the random error term, $\sum controls$ is the control variable.

◆Make a Return

In order to simplify the difficulty of regression, the regression model is simplified, as can be seen below.

$$PWR_{jt}=\beta_{0jt}+\beta_{1jt}AC_{jt}NPI_{ijt}+\beta_{2jt}NPI_{ijt}+\beta_{3jt}AC_{jt}+\varepsilon_{1j} \tag{26}$$

$$PWR_{jt}=\gamma_{0jt}+\gamma_{1jt}EF_{jt}NPI_{ijt}+\gamma_{2jt}NPI_{ijt}+\gamma_{3jt}EF_{jt}+\varepsilon_{2j} \tag{27}$$

$$PWD_{jt}=\lambda_{0jt}+\lambda_{1jt}EC_{jt}NPI_{ijt}+\lambda_{2jt}NPI_{ijt}+\lambda_{3jt}EC_{jt}+\varepsilon_{2j} \tag{28}$$

4.4.2 Parameter Estimation and Impact Analysis of Policies

According to the above did model and data from China, the coefficient estimates and t-statistic of each cross product term are obtained by using the least squares estimation. as shown in the following table. 4.

Table. 4 Parameter Estimation of policy impact to factors

variable	β_{11}	β_{12}	β_{13}
$AC_{jt}NPI_{jt}$	0.049	0.038	0.051
t-statistic	2.205	1.568	2.215
variable	γ_{11}	γ_{12}	γ_{13}
$EF_{jt}NPI_{jt}$	0.093	0.073	0.098
t-statistic	18.73	30.284	34.147
variable	λ_{11}	λ_{12}	λ_{13}
$EC_{jt}NPI_{jt}$	-0.999	-0.692	-1.129
t-statistic	-14.584	-2.807	-7.976

As we can see in table. 4, the coefficient estimates both β_{1i} ,and γ_{1i} ($i=1,2,3$) are positive. The coefficient is a positive value, which means that the policy plays a role in boosting AC and EF , that is, further increasing the plastic waste reduction. However, the estimate of the coefficient b is negative, which indicates that the implementation of policies will inhibit the economic development of industrial enterprises. From the current background, the deterioration of the ecological environment, the state has adopted certain restrictions on various aspects of the sales and production of the plastic production industry. In a way, this is not conducive to the development of enterprises. In other words, after the implementation of the policy, there is a significant negative correlation between the reduction in the amount of plastic waste handled by enterprises. We therefore say that there is a negative relationship between policy and EC on the dependent variable. Significance is judged by t statistic.

5. Task 3

5.1 Goal Determination

According to the analysis and conclusions of tasks 1 and 2, we can find that the maximum amount of plastic waste treated is less than the current amount of plastic waste generated. At the same time, we also know the impact of environmental protection policies on the factors related to the amount of plastic waste treated. For example, the implementation of environmental protection policies can increase the availability of plastic alternatives and reduce the growth rate of demand for single-use or disposable plastic products. Therefore, we can influence the waste of plastic waste through the implementation of environmental protection policies.

For task 3, our analysis and solution ideas are as follows:

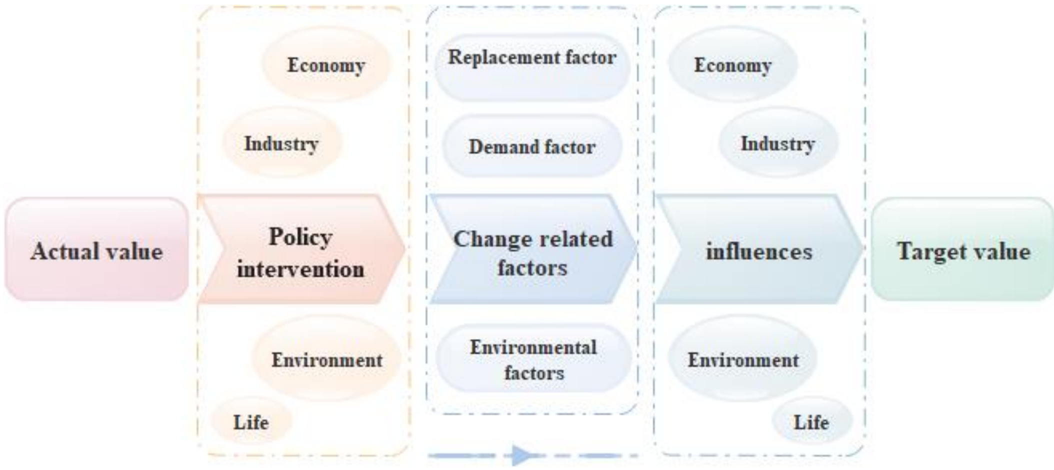


Fig. 4 The analysis flowchart for task 3

5.1.1 Policy Intervention

Through policy intervention, we can adjust the factors related to the amount of plastic waste treated. However, sustainable development can only be achieved when the maximum level of plastic waste disposal is higher than the waste of single-use or disposable plastic products. Therefore, the minimum waste target should be equal to the maximum amount of plastic waste that can be handled globally as far as possible.

Based on the above analysis, policy intervention is the key to exploring the goal of minimum waste. The environmental protection policies we can implement are as follows:

- ◆Limit the use of plastic bags. Minimize the use of non-recyclable plastic. This policy reduces the waste of single-use or disposable plastic products by reducing the demand for single-use or disposable plastic products. (Impact factor: EC, Area of influence: resident)
- ◆Waste sorting and recycling policy. This policy reduces the waste of plastic products by raising residents' environmental awareness. (EF, resident)
- ◆Development of new plastic waste treatment technologies, such as biodegradation and chemical decomposition. This policy reduces the accumulation of plastic waste by increasing the amount of plastic waste processed.

◆Promote the use of plastic alternatives. This policy reduces the waste of single-use or disposable plastic products by increasing the availability of plastic alternatives. (AC, resident)

◆Increase publicity for environmental protection and the dangers of plastic waste. This policy reduces the waste of plastic products by increasing residents' environmental awareness. (EF, resident)

◆Limit the development of companies with high plastic waste emissions. This policy reduces the waste of single-use or disposable plastic products by reducing the amount of plastic waste generated.

◆Encourage the development of companies producing plastic alternatives. This policy reduces the waste of single-use or disposable plastic products by increasing the availability of plastic alternatives. (AC, industrial)

5.1.2 Goal Value Solving

The minimum waste target is equivalent to the maximum threshold for plastic waste treatment. Once the waste of plastic products exceeds the maximum threshold for plastic waste treatment, it will cause further damage to the ecological environment. Therefore, the solution of the target can be transformed into the determination of the critical value.

To determine the critical value of plastic waste treatment, we set the ideal state. The ideal state needs to meet two characteristics. First, development will not cause further damage to the ecological environment. Second, develop as much as possible to reduce waste and increase waste disposal.

The ideal state we set up mainly includes economy, resident life, environment, and industry. The details are as follows:

➢ Economy

For countries with economic conditions, as long as the growth rate of per capita national income is higher than the inflation rate, the maximum amount of plastic waste can be increased.

➢ Resident life

For most residents, when necessary physical, psychological, social, and other needs are met, residents try to reduce the waste of plastic products as much as possible.

➢ Environment

In order to ensure that the environment is not further damaged, the society tries its best to increase the treatment rate of plastic waste.

➢ Industry

For companies with good development status, when ensuring that the rate of expansion and reproduction of the company is higher than the safe level, the company will minimize the waste of plastic products as much as possible.

The ideal state is difficult to appear in the natural state, and only by using incentive policies can we approach the ideal state. In order to simulate the maximum amount of plastic waste treated under the optimal policy, we use the ideal state approximation to calculate the maximum amount of plastic waste.

Through factor analysis, we use actual data to fit and predict the environment factor (EF), the alternative coefficient (AC) and the economy coefficient (EC) under ideal conditions. According to the prediction results, compared with the actual state, the EF, AC, and EC have increased by approximately 15%, 8%, and 27%, respectively. Then, using the model in task 2, we can calculate the maximum disposal amount of plastic waste. The specific results are as follows:

Tab.5 the maximum amount of plastic waste disposal

Types of plastic waste	Maximum disposal
Resident	153.8
Social	77.6
Industrial	115.3
Total	346.7

According to Tab.5, the minimum amount of waste that can be achieved in plastic products worldwide is 346.7. In addition, the minimum achievable waste for residents, society, and industry is 153.8, 77.6, and 115.3 respectively.

5.2 Impact of Goal

5.2.1 Impact on Resident Life

➢ Living standard

On the one hand, as the consumption of plastic products is restricted, the improvement of residents' living standards will be hindered. On the other hand, the high price of alternatives to plastic products will also affect the lives of residents.

➢ Convenience of life

Due to the convenience of disposable plastic products, restricting disposable plastic products will reduce the convenience of residents' lives.

➢ Environmental awareness

With the popularity of the hazards of plastic waste, residents' environmental awareness will also increase.

➢ Health index

After the waste of plastic products is controlled, the ecological environment will be improved. Livable ecological environment is good for residents' physical and mental health.

5.2.2 Impact on the Social Environment

➢ Economic development

The government strengthens the protection of the ecological environment and invests a lot of money in the treatment of plastic waste, which will slow down the social and economic development.

➢ Natural environment

On the one hand, the multi-channel treatment of plastic waste can speed up the restoration of the ecological environment. On the other hand, restrictions on the amount of waste of plastic products can reduce the generation of waste. Therefore, the natural environment will be improved.

5.2.3 Impact on the Plastic Industry

➢ Expansion of reproduction

Policy restrictions on the plastics industry and support for the alternatives industry will slow down the expansion of the plastics industry.

➢ Waste discharge rate

In response to national policies, the plastics industry will improve waste disposal processes and reduce waste discharge rates.

➢ Waste treatment technology

In order to reduce production costs and enhance market competitiveness, the plastics industry will improve production technology and waste treatment technology.

6. Task 4

6.1 The equity issues and solutions

Researches indicates that plastic waste generation and inadequately managed waste vary greatly in different regions all over the world. In fig. n, countries like China, United States, Germany and Brazil generate much plastic waste over the world. In fig. m, countries like India, Tanzania, Madagascar, Mauritania and China have high share of plastic waste that is inadequately managed over the world.

Because of different waste generation and management, as well as different levels of economic development, if all countries are required to put in the same effort and money to solve the problem, or simply distribute the effort according to the area of country, it will cause some sever problems:

- ◆Some policies like reduce the production of plastic will hit the plastics industry. It may be a piece of cake for developed countries, but may cause many economic problems for some developing countries. What's more, the same number of money has totally different meaning for countries with different economic level.
- ◆The more plastic a country generates, the better this rule is for it, because other countries are paying for the plastic waste it produces. As a result, no country is willing to reduce its plastic waste generation, and no country is truly put in effort. There is still more and more plastic waste in the world.
- ◆For the countries who generate approximately the same plastic waste, the disposal of these waste is also very important. Some countries may dispose its waste properly, but some may not care about its waste at all, and let them enter the nature. If the rule doesn't consider the disposal factor, no country will make effort to dispose plastic waste it generates to protect the environment.
- ◆......

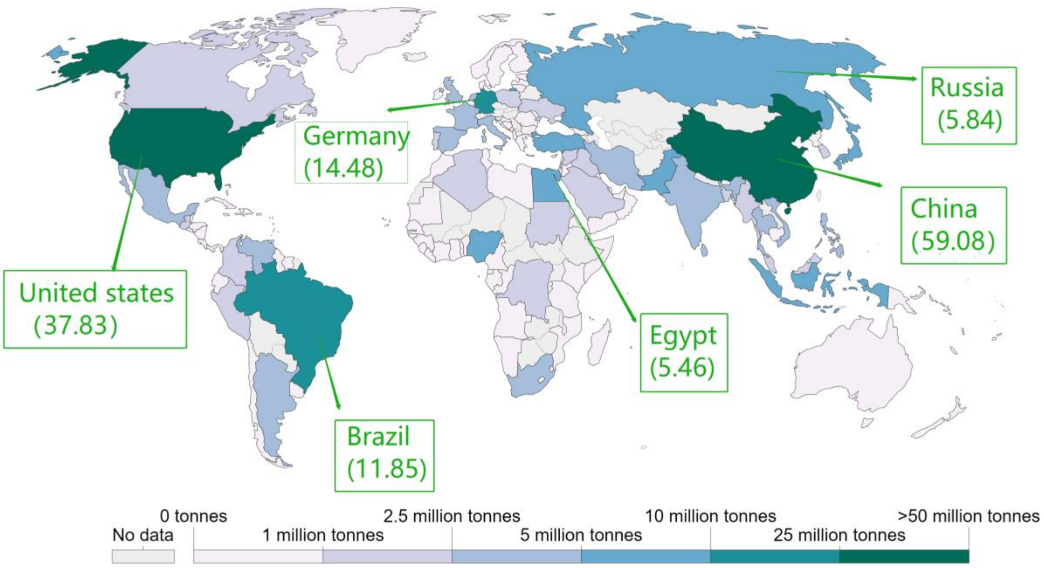


Fig. 4 Plastic waste generation, 2010

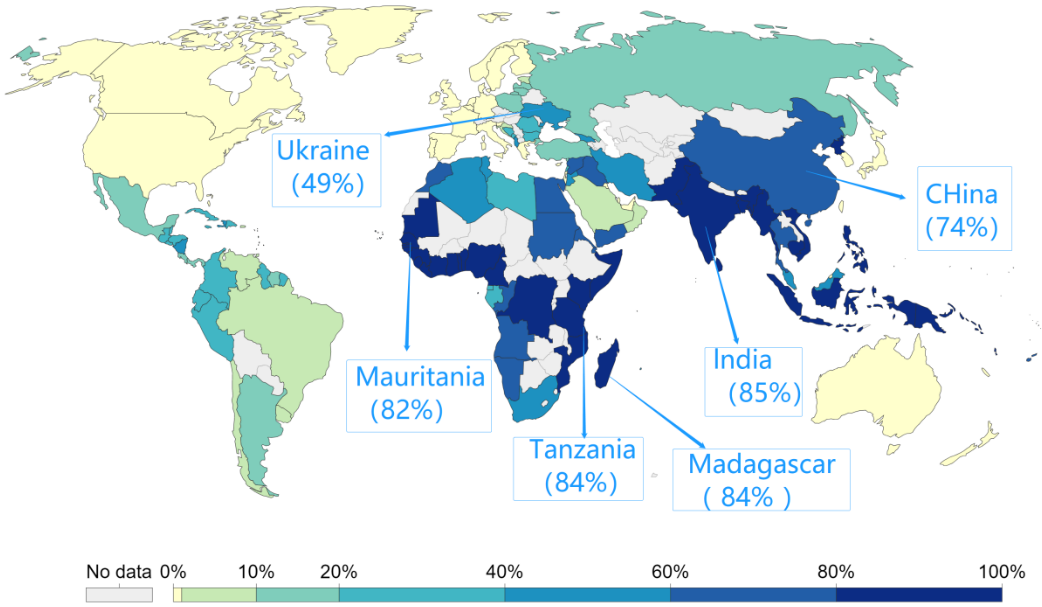


Fig.5 Share of plastic waste that is inadequately managed, 2010

If the rules are not proper enough, it will cause many equity issues. In order to unite the power of the whole world to solve the global plastic waste problem, we propose the following principles, which helps to greatly reduce the equity issues.

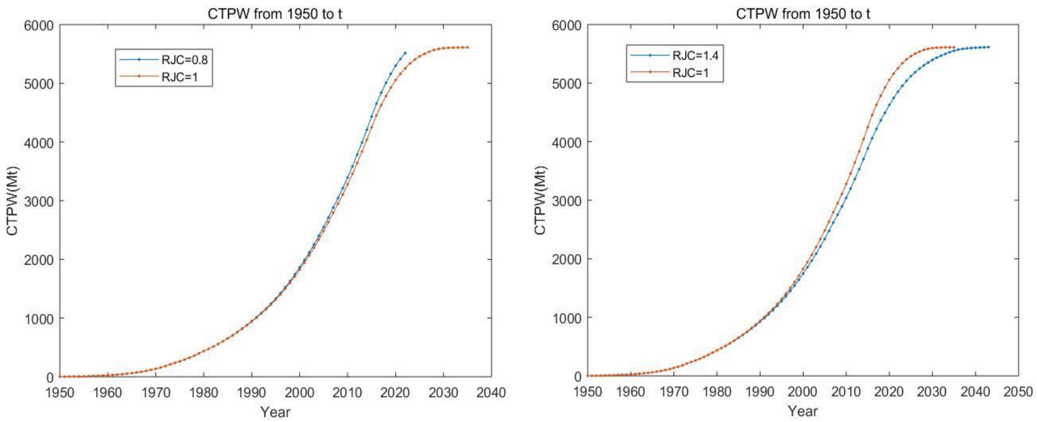
- Every country should obey their part of plastic generation limitation and undertake their part of money to reduce the plastic waste.
- The distribution of the limitation and money is based on the plastic waste volume a country does not properly dispose. The more inadequately disposed plastic waste a country generates, the stricter limitation and more money it should undertake.
- The GDP of the countries will also affect the distribution. If a country's GDP is relatively high (for example, higher than global average level), then the limitation will be stricter and the money will be more, and vice versa.

◆The limitation and money can exchange. For example, if a country wants to generate more plastic waste than the limitation, it can "buy" some limitation from other countries. The whole plastic waste generation will not change during the exchange.

◆The sum of plastic waste generation limitation over the world will decrease every year.

7 Sensitivity Analysis

In this section, we do the sensitivity analysis for the variable RJC and analyze its influence on CTPW. We set the initial value of RJC as 1 and get the figure of CTPW. Then we change the RJC to 0.8 and 1.4 respectively. The results are shown in Fig. 6(a) and Fig. 6(b).



(a) (b)

Fig. 6 CTPW from 1950 to t

From the two figures we can conclude that when RJC changes, the trend of CTPW does not change a lot, keeping rising to a maximum value, which means CTPW is stable. Furthermore, the speed of CTPW to rise to the maximum value is influenced by RJC. When RJC decreases, which indicates that less waste is recycled every year, the time for CTPW to reach the maximum becomes earlier. In Fig. 6(a), the time advances from 2035 to about 2023. In contrast, when RJC increases, which indicates that more waste is recycled annually, the time becomes later. In Fig. 6(b), the time is postponed from 2035 to approximately 2043.

8 Strengths and Weaknesses

8.1 Strengths

- This model include a comprehensive and objective index system. We consider all kinds of aspects which affect the plastic waste level. For each aspect, we choose representative indicators to be included in our model.
- We introduce entropy weight method (EWM) to calculate the weight of some index. The weight is objectively determined. From the model result we can see that the weight is reasonable and precise.

- Since our model consider the regional characteristics, it’s easy to apply to another region and it has good adaptability. It’s also available in different scales, from a city to the whole world.

8.2 Weaknesses

- Some parameters are based on subjective prediction because of the lack of data and time limitation.
- The model is too complicated and sometimes not easy to calculate. Some necessary data is hard to find out.

9. Memo

TO: All managers in the International Council of Plastic Waste Management
FROM: EcoHarmony Team
DATA: February 21, 2020
SUBJECT: Plastic Waste Reduction Plan

The plastic waste is a severe environment problem, which does damage to surface water, soil, the ocean, and the life in the world. In recent years, more and more plastics are generated and enter the environment without proper process. To solve this problem, we write this memo to introduce our plan to reduce single-use and disposable plastic product waste. The plan includes a target level of global single-use or disposable plastic product waste, a timeline to achieve the goal, and some main factors that may influence the timeline. To determine the exact number, we develop a mathematical modal to research and calculate, as well as collect the necessary data to help calculating.

Notes: All generated plastic waste is divided into three categories: recycled, incinerated and discarded. We assume that the recycled and incinerated waste will not affect the environment, so we only pay attention to the discarded waste's influence on the environment.

Target Level

According to our model, the maximum level of global discarded single-use or disposable plastic product waste is 52.25 million tonnes per year, including 18.52 million tonnes no recycling waste, 20.54 million tonnes partial recycling waste and 13.21 million tonnes extensive recycling waste.

In 2015, the global plastic production is 381 million tonnes , the total discarded product waste is 210.85 million tonnes according to our calculation, which means that we should reduce our plastic product waste to 24.79% of current level.

When the maximum level of discarded plastic waste is calculated, factors like source (types) of plastic, ecological influence, resource availability for waste disposal are considered to build the plastic waste capacity model. Large source of no-recycling waste, great ecological damage, poor ability to dispose waste will all cause the reduce of the level.

Timeline

The increment of cumulated Total Plastic Waste (CTPW) is shown in Fig. 1. It can be concluded in the figure that the time to reach the maximum level is approximately 2035. It requires the effort of the whole human and effective policies by the government in different countries. The detailed information is shown in the next section

Influential Factors

The effect of the factors can be considered from three aspects: resident, social and industrial. By analyzing the data under some policies' implementation or some circumstances, three factors that really influence the level of discarded plastic waste on the above aspects are concluded as alternative level, environmental indicator and demand of plastic product (related to economic). They can be called alternative coefficient (AC), environmental factor (EF) and economic coefficient (EC) respectively. The change of these three factors and discarded plastic waste level will affect the timeline. Here we list some policies and circumstances that influence the timeline. The content in the brackets indicates the influence factors and aspects.

Policies and circumstances that postpone the timeline:

- ◆The quick growth of social economy. (EC, social, industrial)
- ◆The growth of online shopping and takeaway. (AC, EC, resident)
- ◆The high price of the plastic alternative materials. (AC, industrial)
- ◆The investment to plastic industry. (EC, industrial)

Policies and circumstances that advance the timeline:

- ◆Limit the use of plastic bags. Courage people to use eco bags in their daily lives. (AC, resident)
- ◆The waste classifying and recycling policy. (EF, resident)
- ◆More and more waste incineration plants are built. (EF, resident, social, industrial)
- ◆Develop new technologies to process plastic waste, such as conversion of plastics waste into liquid fuel. (EF, industrial)
- ◆Replace the single-use or disposable plastic product with degradable plastic product. (AC, resident)

Thank you for reading our plan! Any comments and suggestions will be appreciated. We are glad to discuss the topic with you.

Attachment:

Fig. 1. The increment of CTPW.

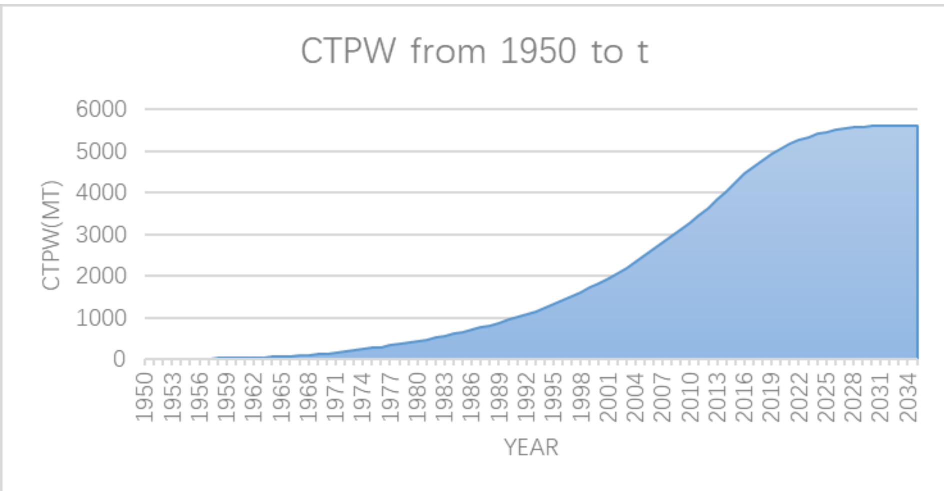


Fig. 7 $CTPW_t$

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