Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
E		2012368

Summary

As disposable plastic products bring great convenience to our life, the exponential increasing plastic waste pollution gradually engulfs our earth. This is a global crisis and how to deal with it is a tough problem, the key of which is to evaluate the current level of plastic waste pollution and put forward reasonable targets correctly. In this paper, we focus on establishing a reasonable assessment model of environmental plastic pollution and setting achievable targets for the control of plastic pollution.

First, we establish an Environmental Plastic Pollution Assessment Model (**EPAM**) to measure the current level of plastic waste pollution, which includes three sub models. In order to evaluate the initial environmental conditions of an area objectively and comprehensively, we introduce Structural Equation Model (**SEM**) and establish **the first sub model,** Initial Environmental Level Model (**IELM**). To measure the ability of plastics waste pollution control in different areas, we use the Interval Scoring Method as well as the Entropy Weight Method (**EWM**) to establish the **second sub model**, Plastic Waste Pollution Improvement Model (**PWIM**). To quantify the pollution severity of disposable plastic products in a region, we set up **the third sub model**, Single-use or Disposable Plastic Product Waste Level Model. **The three sub models are connected by the logistic equation and form the total model EPAM.**

Next, we apply the model to assess the maximum levels of single-use or disposable plastic product waste that can safely be mitigated without further environmental damage to **Turkey**, a country spanning Europe and Asia. Our result demonstrates that the level of plastic pollution in Turkey has exceeded the maximum level. Combining with the actual situation of Turkey, we discuss the specific measures to reduce plastic waste in Turkey, put forward meaningful suggestions to alleviate plastic pollution, and verify the possibility to achieve the level of environmental safety through effective control measures for Turkey.

Then, we apply the model to the world to assess the level of plastic pollution in the world. Our research shows that the level of plastic pollution in the world is under the environmental safety level. We set a **feasible target** for the global use of disposable plastic products and consider the impact of the target from various aspects such as life, environment, and industry. In addition, we also discuss the fairness problems caused by the plastic pollution crisis, and we put forward some creative solutions based on the model: Establish a plastic pollution control community to solve the fairness problems with responsibility system and assistance system.

Finally, we test **the sensitivity of the model**, summarize the model and analyze the strength and weakness. At the end of our paper, we show our achievements to ICM in the form of memorandum, including the time line of target realization, the factors affecting target realization as well as the realistic global target minimum achievable level of global single-use or disposable plastic product waste.

Keywords Plastic Waste; SEM; Logistic Equation; EWM; Microplastics

Contents

I. Introduction

Plastic pollution is becoming more and more serious all over the world. On the one hand, the global plastic products are growing at an ultra-high speed. On the other hand, the global plastic waste recycling rate is less than 30%. Every year, a large amount of plastic waste is buried in the land, or even poured into the sea, causing great ecological pollution. Research has shown[1] that the total weight of plastic waste in the ocean is expected to exceed the total weight of fish in 2050. Plastic pollution not only causes serious damage to the ecosystem, but also causes further problems such as environmental equity, making the world more unstable.

The current problem of plastic pollution is due to the indifference of mankind to the danger of plastic pollution. While plastic products bring great convenience to human life, plastic waste also gradually becomes super garbage, bringing endless troubles to the ecology and human society. At present, some new biodegradable materials have been put into use, some countries have developed plastic pollution control plan. However, plastic pollution problem in many countries is still serious.

Our goal is to establish an evaluation model of environmental plastic pollution to measure the level of plastic waste pollution in a certain area. We try to use this model to measure the environmental safety level of a certain area and the corresponding pollution level of plastic waste. In addition, we set a target for the use of disposable or disposable plastic products in the world and predict the time to achieve the target. Finally, we discuss the equity problems caused by plastic pollution and propose solutions.

In this paper, our total model is Environmental Plastic Pollution Assessment Model (EPAM), which measures the current levels of plastic waste pollution and includes three sub models. The three sub models are Initial Environmental Level Model (IELM), Plastic Waste Pollution Improvement Model (PWIM) and Single-use or Disposable Plastic Product Waste Level Model (PWLM), with which we measure the initial environmental status of the region, the region's waste plastic treatment capacity and the pollution level of disposable plastic products. The three sub models are connected by the logistic equation to form the total model EPAM.

Before applying our model, we put forward the overall hypothesis in part 2, and the specific hypothesis of each model will be introduced in part 3. In part 4, we apply our model to solve practical problems. In task 1 and task 2, we selected Turkey as a case to evaluate the level of plastic waste. We analyze the strengths and weaknesses of Turkey in the fight against plastic pollution and propose plans and suggestions. In task 3 and 4, we assess the global plastic pollution level, set targets for global plastic pollution control and discussed the environmental equity brought by plastic pollution. In prediction part., we predict when the target will be achieved. Finally, we show our achievement to ICM in the form of a memorandum, including the factors that affect the achievement of the targets and the time when the targets are achieved.

II. Assumptions and Notations

2.1 Assumptions

By adequate analysis of the problem, to simplify our model, we make the following well-justified assumptions.

- **The data sources used in the model are real and reliable.** Our conclusions are valid only when the data entered into the model can truly reflect local conditions.
- **Ignore accidental explosive changes.** For example, in this model, we do not consider the huge impact on environmental degradation in such situations: extreme natural disasters, major terrorist attacks, etc.
- Apart from the plastics waste, **the influence on the environment of other forms of pollution is gentle** within the time frame we consider, and would not bring devastating and irreversible effects on the natural environment.
- **We only consider the short-term benefits and natural purification capacity is not effective enough for plastics.** This is because the chemical properties of plastics are relatively stable, and their natural degradation requires more than 100 years[2]. We believe that plastic will not degrade naturally during the time we consider, but the increase of plastic waste will lead to an increasingly harsh environment.
- **In the short-term we considered, the proportion of discarded plastic in solid waste remains the same in the same area.** Due to the limitation of data access, We chose two indicators related to solid waste to evaluate the model. We find that the proportion of waste plastic in solid waste always fluctuates within a small range in many countries and regions[2]. In the United States, plastic products with a service life of less than one year account for about 67%[1]. In China, plastic products account for about 25% of solid waste.

2.2 Notations

Intensity of Value	Interpretation
EPAM	Environmental Plastic Pollution Assessment Model
IELM	Initial Environmental Level Model
PWIM	Plastic Waste Pollution Improvement Model
PWLM	Single-use or Disposable Plastic Product Waste Level Model
ND	Natural Disasters
NR	Natural Resources
EW	The Extent of the Current Waste Problem
AW	The Availability of Resources to Process the Waste
WM	Microplastics Content in Water
SM	Microplastics Content in Soil

III. Model Specification

3.1 Initial Environmental Level Model

There are great differences in different regions in the extent of the current waste problem, the availability of resources to process the waste and the governance capacity of countries, which determines their different tolerances of plastic pollution. Therefore, it is necessary to establish a simple assessment model of the initial environmental level to evaluate the initial environmental level of an area.

3.1.1 Introduction of Structural Equation Model

In order to measure the initial environmental level of an area more objectively and comprehensively, we use structural equation model to construct a simple assessment model of the initial environmental level. Factors such as the extent of the current waste problem and the availability of resources to process the waste are far from enough to evaluate the initial environmental level of an area, because there are many factors influencing the initial environmental level of an area, including material factors, economic factors and human factors. Various factors have different correlations with the initial environmental level, and their interactions directly or indirectly determine the initial environmental level.

Structural Equation Model (SEM) is a statistical method for analyzing the causal relationships between variables that are difficult to observe directly. In the process of establishing the initial environmental level assessment model, the indicators we selected are difficult to observe directly and interact with each other, so it is appropriate for us to use the structural equation model. It includes measurement model and structure model. The measurement model reflects the relationship between potential variables and corresponding observation variables, and the matrix equation of the measurement model is

$$\begin{cases} X = \Lambda_X \xi + \delta \\ Y = \Lambda_Y \eta + \varepsilon \end{cases} \tag{3-1}$$

where, ξ , δ, Λ_X, Λ_Y ,η, ε are matrix.

The structure model reflects the relationship between potential variables. Potential variables are divided into potential cause variables and potential outcome variables. Structural model of the matrix equation is:

$$\eta = B\eta + \Gamma\xi + \zeta \tag{3-2}$$

where, B is m × m matrix, which is the correlation coefficient matrix between potential outcome variables; Γ is m × n matrix, which is a potential results between variables and the potential causes of correlation coefficient matrix; ζ is m x 1 matrix, representing the error of η.

3.1.2 Construction of IELM

From a large number of indicators, we selected five aspects (as shown in *Table 1*) as the assessment criteria for the initial environmental level through the reliability test.

To explore their contribution to the initial environmental level, we proposed the following research hypothesis:

(1) The neglected aspects in the model have minimal impact on the initial environment level and can be ignored. The indicators selected by us can objectively and comprehensively evaluate the initial environmental level of an area.
(2) National capacity has a positive impact on governance input.
(3) Natural disasters, natural resources, man-made pollution and treatment input have a direct impact on the initial environmental level.
(4) National capacity can indirectly affect the initial environmental level.

Table 1. Indicator System of IEL.

A National Capacity	A01	Gross domestic product
	A02	Total import and export of goods
	A03	Number of patents authorized
B Natural Disasters	B01	The drought
	B02	Geological disasters
	B03	Crop damage area
C Natural Resources	C01	Water resources per capita (m3 / person)
	C02	Agricultural land
	C03	Forest area
D The Extent of The Current Waste Problem	D01	Industrial waste production
	D02	Plastic products production
	D03	Plastic products and waste imports
E The Availability of Resources to Process the Waste	E01	Operating costs of waste treatment facilities
	E02	Solid waste treatment facilities operating costs
	E03	pollution-free garbage disposal capacity
F Initial Environmental Level	F01	Nature reserve area
	F02	Urban green space
	F03	Green space coverage

According to the research hypothesis, Amos software was used to establish the structural equation model according to the index system in *Table 1*
(as shown in *Fig 1*).

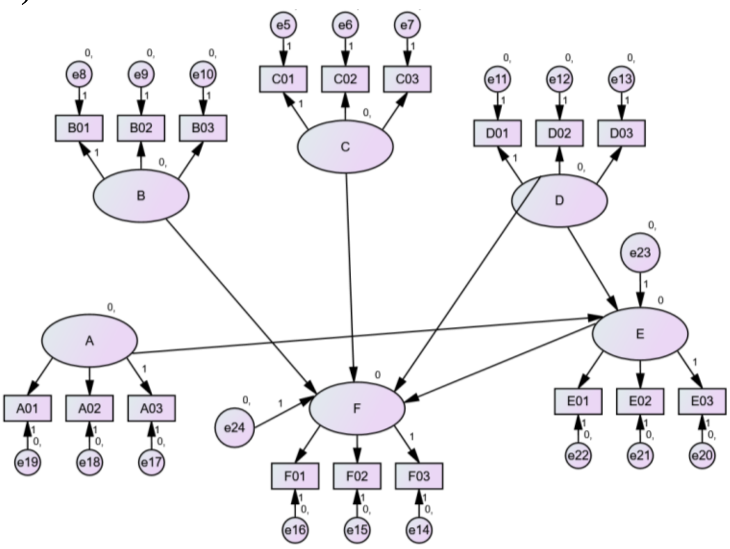


Fig 1. Structural equation model of IELM

3.1.3 Model fitness test

Fitness refers to the degree of consistency between the theoretical model and the actual data. We evaluated from the following three aspects:

Basic fitness test

It can be seen from *Fig A-1* and *Fig A-2* (in Appendix) that all error variances do not have negative values, the load of all standardized factors is between 0.5 and 0.97, and the measurement errors of all observed variables are very small, indicating that the basic fitness test of the model has passed

Global model fitness test

The adaptability index of the whole model is shown in *Table A-1* (in appendix). The significance probability of $\chi 2$ in *Table A-2* (in appendix) was 0.820>0.05, 1<NC=0.792<3, RMSEA=0.003<0.05. All these indicate that the model fits well with the survey data and can be accepted.

Internal adaptability test of the model

As can be seen from *Table A-3* (in appendix), all the estimated parameters reached significant levels, and the internal fitness test of the model passed.

Result Analysis of the Measurement Model

From *Fig A-2* (in appendix), we can obtain the path coefficients corresponding to the four aspects directly acting on the Initial Environmental Level (as shown in *Table 2*), which we standardized in *Table 3*.

Table 2. Path coefficients corresponding to the four aspects.

F	<---	B	-0.38
F	<---	C	0.79
F	<---	D	-0.78
F	<---	E	0.89

Table 3. Normalization of path coefficients.

Variable symbols	full names	weights
B	Natural Disasters	$\omega_B = \frac{-0.38}{-0.38+0.79-0.78+0.89} = -0.731$
C	Natural Resources	$\omega_C = 1.52$
D	The Extent of The Current Waste Problem	$\omega_D = -1.5$
E	The Availability of Resources to Process the Waste	$\omega_E = 1.711$

In order to improve the practicability of the model, we assign different weights according to the load factor relationship in *Fig A-2* (in appendix) to make the indicators more representative. Finally, we get the specific expressions of the four indexes in *Table 4*. These indicators represent the specific capability or defect of an area respectively, which can objectively measure the initial environmental level of an area.

Table 4. Selection and definition of the most representative indicators.

Indicator	Definition
ND	$ND = \frac{0.40\text{Crop disaster area} + 0.32\text{Geological disasters} + 0.28\text{Drought area}}{\text{Agricultural land area}}$
NR	$NR = 0.25\frac{\text{per capita available water resources}}{3000} + 0.75\frac{\text{Agricultural land+Forest area}}{\text{Total land area}}$ (water resources unit: cubic meters/person, 3000 is internationally recognized level of mild water scarcity)
EW	$EW = \frac{0.4\text{Industrial waste production} + 0.4\text{Plastic products and waste imports} + 0.2\text{Plastic products production}}{\text{total industrial production}}$
AP	$AP = 0.2\frac{\text{pollution-free garbage disposal volume}}{\text{Solid waste treatment facilities capacity}} + 0.8\frac{\text{Operating costs of waste treatment facilities}}{\text{cost of production}}$

Using the indicators and the weights obtained, we score IEL on a 10-point scale

$$IEL = 10(\omega_B ND + \omega_C NR + \omega_D EW + \omega_E AP) \tag{3-3}$$

3.2 Plastic Waste Pollution Improvement Model (PWIM)

The ability of a region's waste plastics management has a significant effect on the maximum levels of single-use or disposable plastic product waste allowed in the region. In this section, we will use the interval scoring method and the entropy weight method[3] to establish the Plastic Waste Pollution Improvement Model (PWIM).

3.2.1 Interval Scoring Method

There are many important reflections of waste plastics management capabilities, such as good policies, active processing facilities investment, etc. Therefore, we choose four indicators that are closely related to the management of waste plastics in our model. These indicators can reflect the role how local policies and project implementations can impact the role in improving the waste plastic pollution at different levels. In order to expand the applicable scope of the model, we adopt the interval scoring method with range from 0 to 5 in order to score each indicator. The specific scoring indicators are as follows:

Table 5. Scoring Criteria

Intensity of Value	Annual solid waste construction projects per unit area (pcs / 10,000 km^2) X_1	Waste plastic recycling rate X_2	Per capita investment in solid waste treatment projects (yuan / person) X_3	Number of harmless treatment plants per capita (million people / seat) X_4
1	<0.3	<10%	<1	<0.2
2	0.3~0.6	10%~20%	1~2	0.2~0.4
3	0.6~0.8	20%~40%	2~4	0.4~0.8
4	0.8~1.2	40%~60%	4~6	0.8~1.2
5	>1.2	>60%	>86	>1.2

3.2.2 The Application of the Entropy Weight Method (EWM)

We choose four evaluation indexes in the model, and we collect data from 31 provinces in China[6]. According to the characteristics of these data, we decide to use EWM to determine their weight. EWM is a method for determining weights by calculating the information entropy of various indicators, and is widely used in multi-index comprehensive evaluation. Since the data we find are mostly parallel data of various provinces of China, it is proper to select EWM to analyze the information entropy of each indicator and determine the weights.

(1) The Application of EWM

Step 1: Calculate the probability of the i-th plan under the j-th index

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3-4}$$

Step 2: Calculate the entropy value e of the j-th index

$$e_j = -\frac{1}{\ln n} \sum_{j=1}^{n} p_{ij} \ln p_{ij} \tag{3-5}$$

Step 3: The calculation of weights

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n} (1-e_j)} \tag{3-6}$$

(2) The Weight Distribution of Each Indicator

We substitute the data of 31 provinces in China into the formulas above to calculate the weight distribution of the four indicators, as shown in the following table:

Table 6. EWM-derived weights.

Factor	**w_1**	**w_2**	**w_3**	**w_4**
Weight	0.2514	0.1833	0.4247	0.1405

We find that the weights of the indicators meet our expectations, and also conform to objective facts, which can well reflect the role of local human interference in the treatment of waste plastic pollution. For example, the per capita investment weight of solid waste treatment projects has reached 0.4247, which indicates that the government's investment in solid waste treatment projects will account for a large proportion of the entire pollution improvement model.

So we get the formula of this model:

$$PWI = \sum_{i=1}^{n} X_i w_i \tag{3-7}$$

where

- PWI is the plastic waste pollution improvement level.
- X_i is the score determined by the interval scoring method for the four indicators we select.
- ω_i is the weight ratio corresponding to the four indicators.

3.3 Single-Use or Disposable Plastic Product Waste Level Model

Plastic is difficult to degrade in the environment, so we use the residual amount of plastic in the environment to evaluate the levels of single-use or disposable plastic product waste (PWL). The concept of microplastics refers to small plastic particles with a diameter of less than 5mm[7]. Owing to their small particles, microplastics are easy to be ingested by animals and eventually transmitted to humans along with the food chain, thus affecting the environment and the health of a variety of organisms. As plastic products become useless, part of the waste plastic is discharged directly into the environment and transformed to fragments. These fragments will break down into tiny particles under physical and chemical effects[7]. Others is disposed of as waste and get handled, but common methods such as incineration or landfilling do not break down the plastic effectively, while plastic waste is also broken down into microplastics. Therefore, it can be considered that the amount of residual plastic largely depends on the content of microplastics. Since the majority of microplastics are distributed in water and soil, we use two indicators to evaluate PWL. One is Microplastics Content in Water (WM) and the other is Microplastics Content in Soil (SM).

- Microplastics Content in Water

Plastics are distributed in various water bodies, such as rivers, lakes, and oceans. We do not distinguish the types of water bodies here, and take the average value of microplastic abundance in all water bodies in a certain area as the value of WM.

- Microplastics Content in Soil

Due to the late start of the research on microplastics, most of the current research focuses on the microplastic content in water, and the limited literature on soil research focuses on the measuring methods. We find it is very hard to search useful data of SM, but there is a research [8]which shows soil may contain 4 to 23 times as much microplastic as the ocean, and the amount of microplastic that goes into the soil each year is larger than that of the ocean. Based on this point, we can roughly measure the value of SM with 10 times the WM, which is:

$$SM \approx 10WM \tag{3-8}$$

- The Calculation Formula of PWL

Considering that the territorial area and water area of each country are different, the impact of WM and SM on PWL is also different. So we introduce the land-water factor λ, which is defined as the ratio of water area S_{water} to land area S_{land} in the region, that is:

$$\lambda = \frac{S_{water}}{S_{land}} \tag{3-9}$$

Due to the large differences in WM in different sea areas, we normalize WM in logarithmic form. According to formula (3-9), we finally get the calculation formula of PWL as follows:

$$PWL = \frac{\lambda \ln WM + \ln SM}{1+\lambda} = \ln WM + \frac{\ln 10}{\lambda + 1} \tag{3-10}$$

3.4 Environmental Plastic Pollution Assessment Model (EPAM)

In most countries and regions all over the world, there is plastic pollution in the current environment. Based on our assumptions, the pollution degree of the country or region's environment will become more and more serious without human intervention to mitigate plastic pollution, while the degree of environmental pollution will slow down or even improve under effective man-made measures. To simplify the model, we only consider the process of IEL being slowed down by PWI. To measure the relationship of PWI inhibiting the reduction of IEL, we define Environmental Level (EL) and Decrease Index (DI) as functions of PWL:

$$EL(PWL) = IEL - DI(PWL) \tag{3-11}$$

In order to quantify DI more conveniently, we refer to the logistic function which is put forward by Pierre-Franois Verhulst when researching population dynamics[9], and define DI as follows:

$$\frac{d(DI)}{d(PWL)} = \frac{1}{PWI} \bullet DI\left(1 - \frac{DI}{\alpha}\right) \tag{3-12}$$

where adjustment factor α is defined to determine the lowest limitation for the current state of the environment. For each countries or regions.

By solving the differential equation of formula(3-12), we get the following result:

$$DI(PWL) = \frac{\alpha}{1 + \alpha e^{-\frac{PWL}{PWI}}} \tag{3-13}$$

So the final result of our model is as follow:

$$EL(PWL) = IEL - \frac{\alpha}{1 + \alpha e^{-\frac{PWL}{PWI}}} \tag{3-14}$$

IV. Tasks Analysis

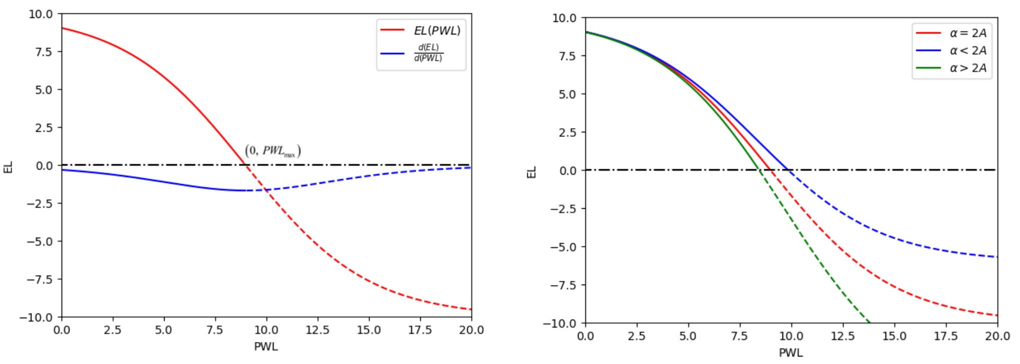
4.1 Task 1: Evaluation of *the Maximum Levels*

4.1.1 The Application of EPAM in the Evaluation of *the Maximum Levels*

For the functional relationship between EL and PWL, we can differentiate it to get the following form:

$$\frac{d(EL)}{d(PWL)} = -\frac{\alpha^2 e^{-\frac{PWL}{PWI}}}{PWI\left(1 + \alpha e^{-\frac{PWL}{PWI}}\right)^2} \tag{4-1}$$

Then we make the graph of the function and its derivative function in the same coordinate system, and we can thus analyze it intuitively.



(a) (b)

Fig 2. The relationship between EL and PWL

As shown in *Fig 2(a)*, according to our definition of EL, we believe that when EL drops to 0, the region reaches its minimum environmentally safe level, and the corresponding PWL is its maximum level $PWL_{\max}$, which is:

$$PWL_{\max} = PWI \bullet \ln(2IEL) \tag{4-2}$$

According to the model, we only consider the case of $PWL < PWL_{\max}$, so the part of EL <0, which is the dashed part of the curve in *Fig 2(b)*, does not make sense. We make different curves for different values of α as shown in *Fig 2(b).*

Combining with EL's derivative, we get the limitation of α, $\alpha \geq 2IEL$, which is mainly because of the following statements:

- There is such a rule based on the facts: As the PWL increases, it is difficult to slow down the decreasing trend of EL. However, PWL tends to slow down before reaching its maximum value in the curve of $\alpha < 2IEL$, while we should not consider this situation.
- $\alpha \geq 2IEL$ is a reasonable range. At this time, the relationship between EL and PWL complies with the rule above.

We find that the absolute value of the derivative function is maximized when $EL = 0$ in the condition of $\alpha = 2IEL$. In other words, when $PWL = PWL_{\max}$, EL has the largest slope to PWL. It is ensured that the effect of PWL on EL is large enough. Therefore, in the analysis and verification of the model, we choose $\alpha = 2IEL$.

4.1.2 The Application of EPAM in Turkey

In this section, we will use our model to measure plastic pollution and estimate the maximum levels of single-use or disposable plastic product waste that can safely be mitigated without further environmental damage (PWL_{max}) in Turkey. The main reasons we choose Turkey are as follows.

- Turkey is a major producer of disposable plastics. Turkey produces 0.24kg of plastic waste per capita per day, which is ahead of most countries in the world. Therefore, it is of far-reaching practical significance to study PWL_{max} in a country with a high consumption of plastics like Turkey.
- Waste plastics management in Turkey is poorly managed. According to the statistics[10], there is about 16% of waste plastic in Turkey which has not been safely disposed.
- Turkey's geographical location is typical as it straddles both Europe and Asia.

We calculated the IEL, PWI, and PWL of IELM, PWIM, PWLM models using the data from Turkey in 2017, the result is as *Table 7* shown.

Table7. The score of Turkey

	IEL	PWI	PWL
value	7.645	1.8165	7.009

Then we substitute the results into EPAM and make the PWL-EL curve of Turkey as *Fig 3* shows.

According to our definition, the abscissa of the intersection point of the curve and the abscissa axis is PWL_{max} and the abscissa is the minimum of environmentally safe level. According to the value of IEL and PWI, we can calculate that the PWL_{max} of Turkey equals to 4.954, which means the current value of PWL is larger than PWL_{max}. The plastic waste in Turkey is beyond its maximum level which can safely be mitigated.

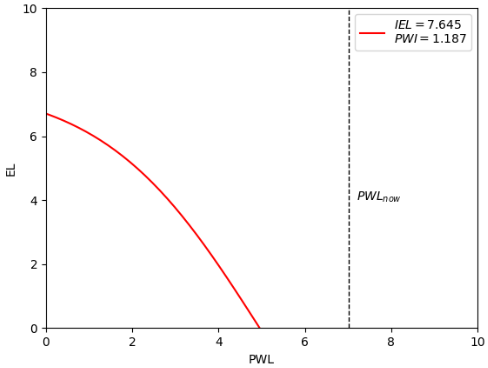


Fig 3. PWL-EL curve of Turkey

4.2 Task two: The Environmentally Safe Level

In this section, we only discuss the short-term effective methods according to assumptions and change the values of IEL and PWI to achieve the environmentally safe level, while ignoring the changes in the value of PWL. That is mainly because PWL is hard to change heavily in a short period of time.

4.2.1 Analysis on IELM

Based on the indicators in IELM, we find that Turkey is rich in natural resources, especially forest resources, with a few natural disasters. However, after China banned the import of plastic waste, Turkey filled this position and ranked second with 80,000 tons of waste imports. All in all, there are various reasons which cause unsatisfactory scores in such two aspects, *The Extent of The Current Waste Problem* and *The Availability of Resources to Process the Waste*. If Turkey pays enough attention to plastic pollution and makes improvements in the both aspects above, it is more easily to improve Turkey's score of IELM.

Assuming Turkey is improving the indicators above at a rate of 3% per year, we make the curves to respect their changes after six years.

What needs to pay attention is that we do not consider the indicator *Plastic Products Production*. Although the decline of this indicator is beneficial to Turkey's domestic environment, we believe that the development trend of the Turkish plastic industry is irreversible in the short term, so it is meaningless to discuss this indicator.

We can see that the changed PWL_{max} in Turkey is closer to the current PWL through the contrast of two curves. Although the current PWL is still larger than PWL_{max}, which means Turkey has not reached the environmentally safe level yet, the fact proves that improving these two indicators is targeted for Turkey.

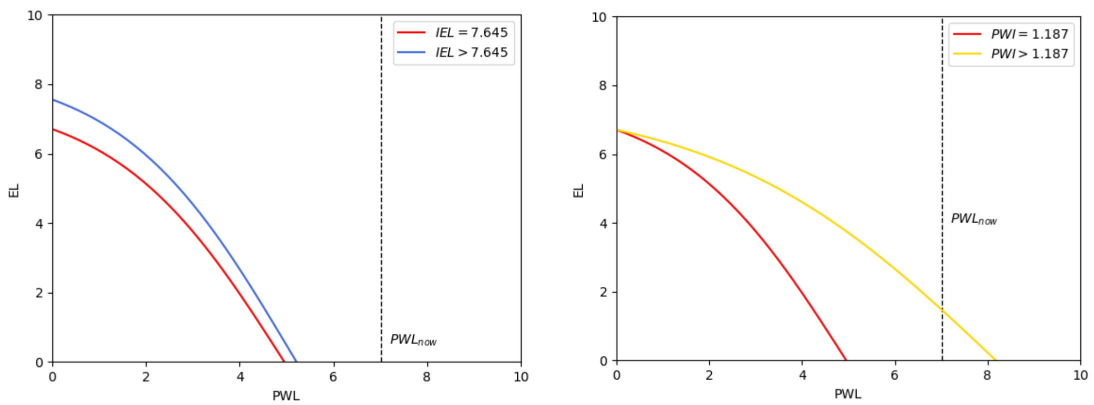


Fig 4. Curve with different IEL and PWI

4.2.2 Analysis on PWIM

In Turkey, the two most common methods of waste disposal are landfilling and dumping. Currently, the country does not levy a landfill tax, but encourages landfill disposal to replace dumping which is more harmful instead. The total amount of urban solid waste collected by the Turkish waste management industry in 2017 was 28.011 million tons, of which 9.936 million tons were disposed of by dumping, accounting for 35.47% of the total; 17.807 million tons were accepted for landfill disposal, accounting for 63.57%[11]. Additionally, with insufficient investment in plastic waste projects, Turkey's scores in PWIM are not satisfactory.

In light of Turkey's national conditions, there is still much improvement in the two indicators *per capita investment in solid waste treatment projects* and *waste plastic recycling rate*. By increasing the investment in treatment projects and the domestic waste plastic recycling rate, Turkey can further strengthen artificial improvement to increase PWI, thereby improving PWL_{max}, and bringing Turkey back to the environmentally safe level. Assuming that Turkey is improving the indicators above, it gets new score of PWI as 3, we make the curves to show the improvement.

We can find that the changed PWL is below PWL_{max}, Therefore, it is effective to bring Turkey's environment to the environmentally safe level by improving the per capita investment in solid waste treatment projects and the recovery rate of waste plastics both from the perspective of model improvement and the actual circumstance. From the perspective of PWIM, increasing the scores of other indicators of the model can also achieve similar results. In terms of Turkey's specific national conditions, the two indicators above, are more effective.

4.2.3 Suggestions for Turkey

Combining results of our model with actual conditions, we have the following suggestions for Turkey.

- **Slow down the growth rate of plastic production.** Turkey's current plastic market prospects are still very broad, and can even grow further. Therefore, we think it is not realistic to suggest the Turkish government slowing down the plastic production. In fact, the growth rate of Turkish plastic production has behaved improvement in recent years. Compared with some other countries that urgently need to develop the plastic industry, the annual growth rate of plastic production in Turkey can be slowed down.

- **Strengthen domestic waste plastics harmless treatment, and improve the waste plastics recycling system.** In 2015, 98% of Turkey's waste was disposed of in landfills, including plastic waste. Due to the lack of waste sorting measures, the annual economic loss caused by poor waste disposal in Turkey amounts to € 302 million[12] according as the Environmental Foundation CEVKO estimates. Therefore, it is necessary to strengthen the harmless disposal capacity of waste plastics in Turkey, otherwise Turkey's environment will be more difficult to return to the safe level.
- **Increase crop planting area and afforestation.** We should realize that plastic is degradable though the process may take hundreds of years and the will continue to produce pollution during the degradation process. But we can accelerate this process based on human effort. We can increase biodegradation by increasing crop area and afforestation. We also recommend that the Turkish government invest more funds in researching degradable plastics to reduce the production of plastics which are slower to degrade.
- **Protect domestic water resources.** Abundant water resources provide a good environment for microbial reproduction. Per capita renewable water resources in Turkey dropped from 7339 cubic meters in 1962 to 2621 cubic meters in 2017, with decrease of 64.3%. We believe that it is necessary for Turkey to protect domestic water resources and not develop at the expense of the environment.

4.3 Task 3: Target and Impact

4.3.1 Problem Analysis[4]

According to the United Nations, the plastics industry will account for more than a fifth of total oil use in 30 years at the current growth rate. What's more, a quarter of these plastic products are disposable products, which cost the ocean $10 billion a year. Therefore, setting a feasible target for the use of plastics is critical.

In the first two tasks, our application of the model to specific countries has achieved good results. Next, we will apply the model to the whole world. Before applying the model, we need to make additional assumptions to make our model more realistic.

Additional Assumptions

- **The distribution and the status of disposable plastic pollution is roughly even all over the world.** We ignore artificial constraints such as national boundaries and use data that are globally average, so our model can only reflect average global pollution levels.
- **For missing data, we use data from mid-level countries instead.** We believe that the global development is equilibrium and the overall levels tend to be average.

Application of the Model

Our data are mainly from the World Bank[5] and water-related data are from the UN world water development report[5]. Our data year is mainly 2015. Based on the assumption that the world develops relatively smoothly, we use interpolation method to supplement the missing data. The above assumptions add great convenience to our data acquisition. Even so, due to the difference of indicator setting, we have to use similar indicators to replace the original indicators for some indicators that are different from the model setting. Because some indicators, such as the content of microplastics in water quality (WM) and soil microplastics content (SM), are obviously regional, we chose the indicators of calvi bay on Corsica in the Mediterranean Sea, whose pollution level is located in the middle level in the world, as an approximate substitute.

We still use the index system in *Table 1*, and use IELM to figure out IEL_g.

$$\begin{aligned} IEL_g &= 10(\omega_B ND + \omega_C NR + \omega_D EW + \omega_E AP) \\ &= 10(-0.731 \cdot ND + 1.52 \cdot NR - 1.5 \cdot EW + 1.711 \cdot AP) \\ &= 6.628 \end{aligned}$$

Similarly, we figure out $PWI_g = 1.91$, $PWL_{g\ now} = 7.581$

By plotting the function we defined (As shown in *Fig 5*), we get $PWL_{g\max} = 4.936$

So $PWL_{g\ now} > PWL_{g\max}$

In the process of applying the model, it may not be reasonable to assume that global pollution tends to average and that the data used to assess pollution may be biased. However, the PWMg solved by our model has already exceeded the maximum level, that is, the use of disposable plastic products has caused serious pollution to the environment in the world. That's to be expected, and it's a warning.

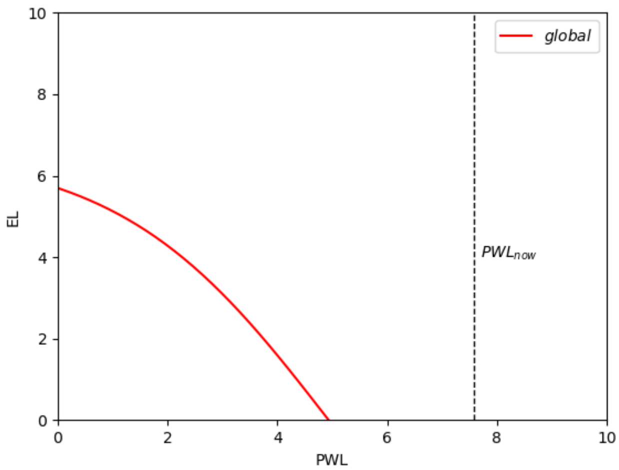


Fig 5. Global level

4.3.2 Target and impact

Determination of Target

To tackle the global plastic pollution crisis, it is necessary to set a realistic target. To make targets meaningful and conducive to their realization, we refer to the established model and define the target:

$$Let\ PWL_{g\ now}\ go\ down\ to\ PWL_{g\max}$$

Impact of Target Achievement

Let's discuss the impact of achieving targets in terms of three specific aspects: the altered life, the environmental impacts and the plastic industry.

- For life, we focus on three aspects: society, health and safety, rules and constraints. We discuss the close relationship and impact with human life on these aspects.
- For the plastic industry, we divide the achievement into short, medium and long - term stages, we briefly describe the problems they will face and solve as well as the results achieved.

- For the environmental impact, we discuss both Marine pollution and land pollution, and look forward to the results after achieving the target.

We draw the following map to show the impact of the achievement of the target briefly.

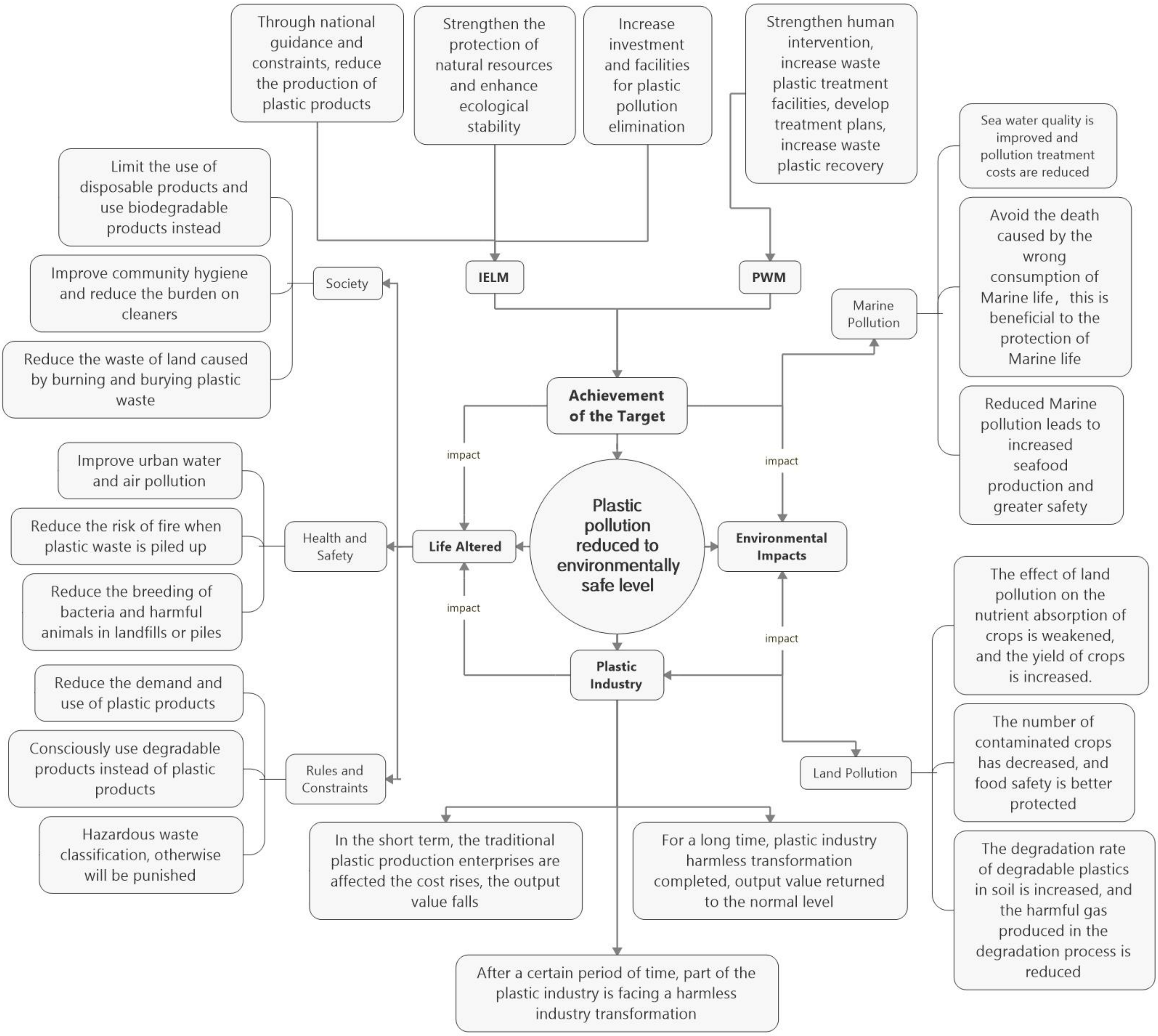


Fig 6. The impact of the achievement of the target

4.4 Task 4: Equity issues

4.4.1 Analysis and Restatement

In recent years, with the recognition of a community of shared future for mankind, people's sense of equity in plastic pollution has been strengthened.

According to a British research institute, one in ten of the world's rich produce half of its carbon emissions, compared with just one in ten for the poorest half[12]. In areas with high pollution levels, the governance capacity may not match the pollution level and control it. The environmental pollution can only be borne by other parts of the world, which are passive victims.

In the process of model analysis of various countries, we also found such fairness problems. We believe that there are three types of equity issues in plastic pollution:

- Equity problem caused by the mismatch between pollutant discharge level and governance input between regions.
- Direct equity between polluters and victims in the region.
- Indirect equity problem caused by Policy differences on plastic pollution control among different regions.

For these problems, we only consider the first kind of equity. The reason is that the first kind of question is essential and most significant. The origin of this problem mainly comes from two aspects: First, the industrial level of different countries varies greatly, and the pollution level also varies; second, different countries attach different importance to pollution and take different measures.

In response to this problem, at present, national boundaries are generally regarded as the boundary of environmental governance. We believe that this way has little effect. The reason is that there exist competition and cooperation between countries, and the expenditure of pollution control is relatively high[12]. Under the market competition, few countries will consciously pay full attention to the pollution investment generated by the plastic industry and the corresponding investment.

4.4.2 Solutions and Suggestions

Taking South America as an example, we propose the following solutions.

Solutions

- **Establishing Community for Plastic Pollution Control.**

Taking the intercontinental boundary as the regional boundary, the countries in each continent form a plastic pollution control community

- **Establish responsibility system: Who pollutes, who governs.**

With PWL, we can judge the contribution to the plastic pollution of each country in South America. We believe that countries that produce more pollution naturally have an compelling obligation. As shown in *Fig 7*, Argentina, Chile and Brazil are responsible for the plastic pollution.

- **Establish the aid system: Who developed, who guide.**

From the perspective of IELM and WPM, we can easily understand the environmental status and development level of each country. We believe that developed countries with outstanding pollution control have more responsibilities to control pollution plastics and assist the other underdeveloped countries. As shown in *Fig 7*, we believe that Uruguay and Argentina, Chile should play a leading role and help countries with serious pollution and weak economic capacity such as Venezuela and Guyana.

- **Establish supervision system:**
  The governance effect of countries with serious plastic pollution shall be supervised by all members of the community. Each country should supervise the plastic pollution control of the assisted countries.

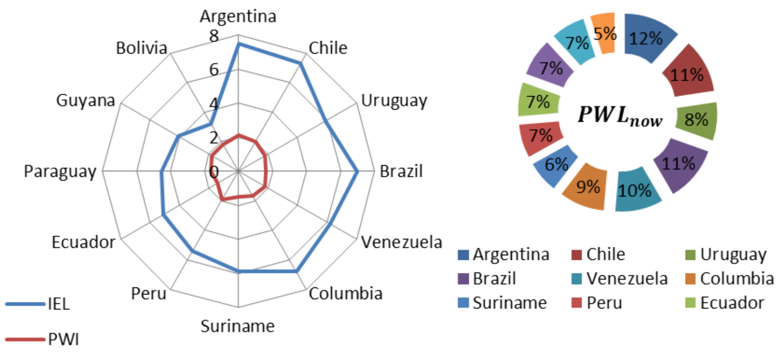


Fig 7. PWI, IEL and proportion of PWL in South America

Suggestions to ICM

- In order to awaken people's awareness of the fairness of plastic pollution, we suggest to build a **Community for Plastic Pollution Control** based on intercontinental units.
- In order to embody the principle of fairness of plastic pollution, we advocate the establishment of pollution responsibility system: who pollutes, who governs. Every country should be responsible for its own plastic pollution.
- In order to reflect the concept of a community with a shared future for mankind, we advocate the establishment of an aid system. Countries with strong comprehensive strength should play a leading role and assist countries with serious pollution and weak strength in economy.
- In order to ensure the effect of pollution control, we advocate the establishment of a supervision system. The results of plastic pollution control in countries with serious plastic pollution and those assisted should be supervised.

V. Sensitivity Analysis

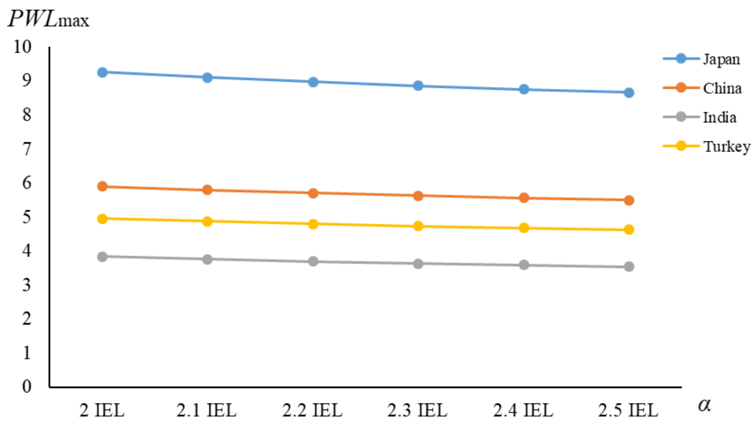


Fig 8. Sensitivity Analysis of α

Our model contains an adjustment factor α. In the application of the model, we artificially set $\alpha = 2A$ and believe such selection is the best. In this section, we verify the reliability of the model by changing the value of α. In *Fig 8*, we analyze 4 countries, which reflect the different levels of plastic waste in the world. We access these data by changing α from 2 IEL to 2.5 IEL.

When α increases, the PWL_{max} of all these countries decline slightly, but it is not difficult to find the impact is global and it hardly affect the ranking of countries and regions. Therefore, we are reasonable to draw the conclusion that the EL model is not sensitive to the adjustment factor α.

VI. Improvement and Prediction

In this section, we will predict the actual global minimum target level of disposable plastic product waste that can reach, the timeline to reach that level, and anything that may accelerate or hinder the achievement of the target and timeline.

According to our model, the global PWL_{max} is 4.9363. We will analyze the time required to reach this target from a model perspective.

6.1 Model improvements

In the original model, we only considered the changes in IEL and PWI, and we thought that PWL was unchanged. Our explanation for this is that PWL is related to the local microplastic content, and the microplastic content in soil or water will hardly change in a short period of time. Therefore, our original model is suitable for short-term forecasts but not for long-term forecasts. We believe that transforming the global environment is a relatively long-term process. Thus, the original model is not suitable for this forecast. In addition, some of the indicators of our original model were evaluated using interval scoring, and the scores were relatively discrete. Therefore, we need to make some modifications to the model.

- In long-term forecasts, we consider changes in PWL. We looked up some literature on plastic waste degradation experiments, and we chose a degradation formula of PWL over time[13]:

$$PWL(t) = PWL_0 e^{-0.00002t} \quad t > 718d \tag{6-1}$$

where PWL_0 is the initial value of PWL when t = 0, and t> 718d indicates that the function is valid only when the test time is greater than 718 days.

- When considering continuous growth, we improved the interval scoring method. Since our task is to predict and improve the global PWL_{max} over the long term, we consider that all indicators of PWL will not increase to the interval corresponding to 5 points, that is, $[C_5, +\infty)$ is not considered. At the same time, we changed the intervals from 0 to 4 points to continuous flat partitions, such as:

In the original model, when $C_2 < C < C_3$, $S_c = 2$ where S_c is the score of the corresponding index of C

In the improved model, when $C_2 < C < C_3$, $S_c = 2 + \dfrac{C - C_2}{C_3 - C_2}$ where S_c is the score of the corresponding index of C

We name the improved model as PWIC. Hence, our improved overall model is as follows:

$$EL(PWL) = IEL - \frac{\alpha}{1 + \alpha e^{-\frac{PWL_0 e^{-\frac{t}{50000}}}{PWIC}}} \quad t > 718d \tag{6-2}$$

6.2 Long-term Prediction

The current level and the target level are as follows.

Table 8. Global level and target level.

	IEL	PWIC	PWL	PWL_{max}
value	6.628	1.916	7.581	4.9363

- **Ideal Forecast**

We only consider those indicators that can be improved through human efforts and do not consider natural indicators or indicators which is negative to environment. Also, we set a stationary growth rate for indicators that have a positive effect on the environment.

In recent years, China has made effective achievements in environmental governance, and formulated a series of policies and actions to protect the environment. We believe that it is reasonable to use the growth rate of China's indicators in recent years as our forecasted ideal speed. Finally, we determined the annual growth rate of IEL and PWIC, $v_{IEL} = 0.9\%$ and $v_{PWIC} = 5.3\%$.

We substitute the annual growth rate into formula (6-2) and the solution shows t = 6.88 years. So we think global pollution level need nearly 7 years to reach a safe level if the growth rate of the indicators maintains as that high level.

- **Forecast in Less Ideal Situation**

We believe that it is not realistic to reach and maintain a high growth rate for several years until global pollution level turn safe, so it is necessary to make a little change to the growth rate. We assume that the growth rate of negative indicators and natural indicators maintains zero, and that the annual growth rates of IEL and PWIC maintains $v_{IEL} = 0.9\%$ and $v_{PWIC} = 1.0\%$.

Similarly, we substitute the annual growth rate into formula (6-2) and the solution shows t = 20.83 years. This means global pollution level need nearly 21 years to reach a safe level.

- **Analysis to the result of prediction**

With certain assumptions on the growth of PWL and PWIC, we have obtained the time required for global pollution levels to reach safe levels, which is from 6.88 to 20.83 years. We consider this to be a reasonable hypothetical result without considering the growth of negative indicators. In fact, if further growth of negative indicators is taken into consideration, PWL and PWIC not only fail to reach the growing rates mentioned before, but may also experience negative growth, which means further deterioration of plastic pollution.

VII. Conclusion

With a determination to contribute to the improvement of the plastic pollution, we first establish an Environmental Plastic Pollution Assessment Model (EPAM) based on the Entropy Weight Method (EWM), Structural Equation Model (SEM) and Logistic equation, so as to measure the current level of plastic waste pollution.

Next, we apply the model to Turkey and find that the level of plastic pollution in Turkey has exceeded the level of environmental safety. To improve the undesirable state of Turkey, we put forward meaningful suggestions to alleviate the plastic pollution combining the model with actual situation. We simulate the implementation of the plan and verified the rationality of the model.

To explore the global applicability of our model, we apply the model to the world and shows that the world is also under the environmental safety level. We set an achievable target and consider the impact of the target from various aspects. Moreover, we predict the timeline for achieving the target in both optimistic and pessimistic estimate. At the end of this article, we will present these findings to the ICM in a memo. In addition, we discuss the equity issues caused by the plastic pollution crisis. In response to the crisis, we come up with innovative solutions based on the model.

Finally, we carried out sensitivity analysis and verify the robustness of the model.

In general, our model can evaluate and predict the environmental safety level of plastic pollution well. It could play a guiding role in setting targets and measures for plastic pollution. We hope to continue to improve our model in the future work and make contributions to the improvement of plastic pollution.

Strength

- In the analysis of task two, we combine our model with the actual situation to improve IEL and PWI, which meets reality. Moreover, when studying IELM and PWIM separately, we find that the effect of improving PWI is more apparent from the perspective of the model, which is also consistent with the actual situation.
- In the establishment of PWIM and IELM, the large gaps in the values of some indicators in many countries may affect the standardization and weights of each indicator. We use interval scoring to improve this situation and make our model more stable and applicable.
- The safe level we define is determined based on the state of the environment and related policies in each country. We think this will make our model more stable and flexible.

Weakness

- There is the interval scoring method in our model, each indicator corresponds to the model's numerical changes with a jump. In fact, the effect of adopting improvement measures on each index of the PWM changes continuously.
- As we believe that SM is approximately equal to 10 times of WM, this conclusion is not appropriate for areas where the water area is much smaller than the land area and areas with little water, which will bias the results. In fact, 10 times is also not accurate enough.

MEMORANDUM

To: ICM
From: Team 2012368
Subject: The Global Target and Timeline.
Date: February 17, 2020

Researchers estimate that over the past 60 years, humans have produced more than 8.3 billion tons of plastic waste, of which only 21 percent is treated well. And the other garbage has been polluting our planet. The researchers say there is no other piece of land on the earth that does not contain micro plastics. Faced with the fact that plastic pollution is increasing, it is of great significance to study the solutions to plastic pollution. We write the memo to describe a realistic global target and give the minimum achievable level of global single-use or disposable plastic product waste, a timeline to reach this level, and some situations that may accelerate or hinder the achievement of the target and timeline.

1. Global objectives

After defining our model, we define a global target which is related with our model: the content of micro plastics in the global soil and seawater are less than the safety level. By comparing the above two indicators, we can judge whether the global plastic pollution has reached the safety level at this moment. If not, what measures should be taken to make plastic pollution level reaches or close to it? Which measure has higher implementation benefit? And by taking these actions, how many years it will take to reach the level. Considering the degradation of micro plastics and the improvement in environment, we will use our model to make judgments, predictions and suggestions for the global pollution level.

2. Time forecast

According to our estimation of the current global situation, we believe that the current global plastic pollution level hasn't reached the safety level. Therefore, we will make some further predictions.

(Note: All of our predictions assume that the indexes of force majeure such as climate disaster and the indexes of negative factors such as the growth of plastic output, etc. will maintain zero growth, and the annual growth rate of positive factors will remain unchanged.)

In order to consider the actual situation in a comprehensive manner, we made two predictions:

2.1 The first prediction is to consider the ideal situation.

We select the annual growth rate of China's indicators (*Initial Environmental Level* 0.9%, and *Plastic Water Pollution Improvement* 5.3%) as the annual growth rate of global indicators. The reasons for choosing China are:

- China's current level of plastic pollution is closer to the world average. We believe that countries at this level have a lot of room for improvement in treating waste plastics and improving the environment.

- China has made a series of achievements in treating waste plastics in recent years. The growth rate of China's indicators is far ahead, compared with other countries,

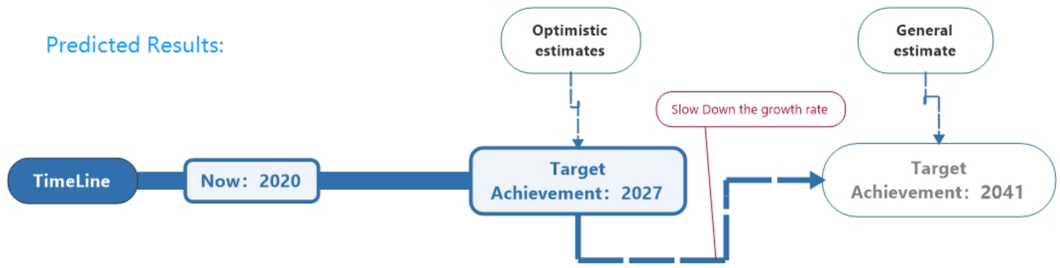
Plugging the data into our model and the calculations result show that it will take 6.88 years to achieve the global target of the minimum achievable level of disposable or disposable plastic products.

2.2 The second forecast is to consider the general situation.

We choose a lower annual growth rate (*Initial Environmental Level* 0.9%, *Plastic waste pollution improvement* 1.0%) as the annual growth rate of various global indicators.

Plugging the data into our model and the calculations result show that the time for the second forecast is 20.83 years.

Hence, if the growth rate won't be changed in the next few decades, we think it will take 6.88 to 20.83 years for the global plastic pollution level to reach the safety level.



3. Other factors

3.1 Situations that may accelerate the achievement of target and timeline:

- All countries are actively responding to the call to tackle plastic pollution, and the speed of environmental improvement is unprecedentedly accelerated. We use China's growth rate in recent years to reflect the ideal situation. If the global average growth rate exceeds the standard, then the timeline will undoubtedly advance.

3.2 Situations that may hinder the achievement of target and timeline:

- The number of extreme events has increased. For example, extreme events such as the *COVID-19 Outbreak* and *African Locust Infestation* can cause serious harm to the local economy, nature and society.
- The indicators of negative factors no longer maintain zero growth. If the negative indicators (such as the production of plastic products and the import of waste plastics) have further increased, the timeline for global plastic pollution to reach safety levels will continue to be delayed.
- Developed countries have not assisted developing countries. The domestic situation in many developing countries are still in turmoil. Without the help of developed countries, it is very difficult for their environment to improve.
- Developed countries further transport plastic waste to other countries. For many developing countries, the transportation and disposal costs of plastic waste are too high, and receiving these waste plastics have little effect on their economic development.

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X. Appendix

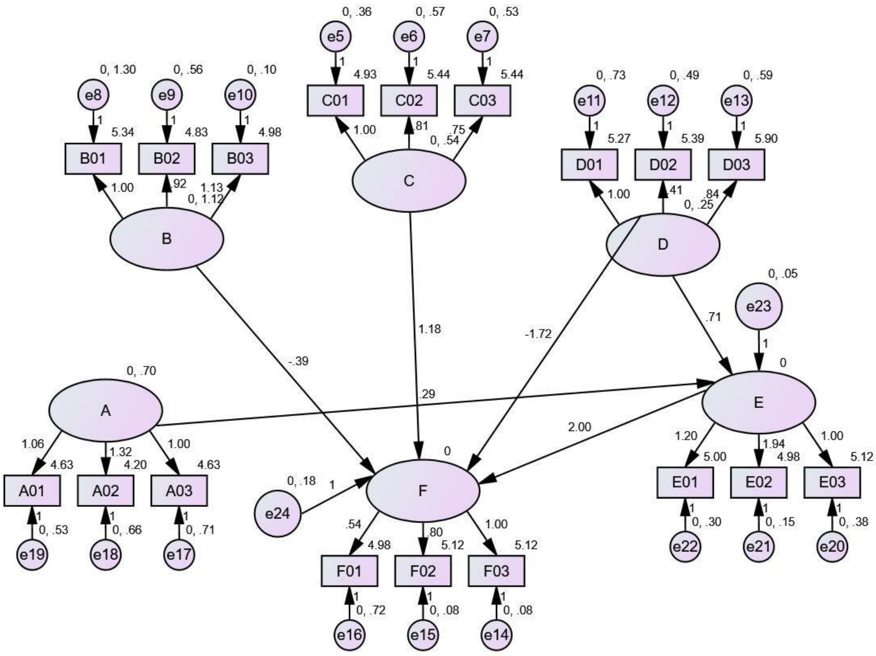

Fig A-1. IELM Non-Normalized Path Coefficient

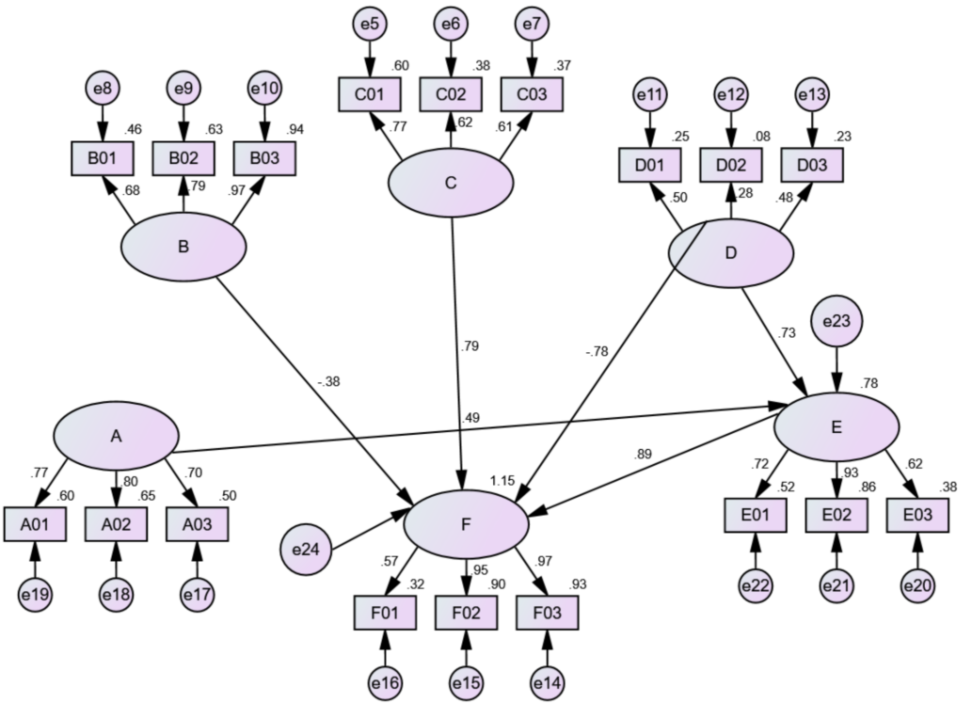

Fig A-2. IELM Standardized Path Coefficient

Table A-1. Criteria for the global model fitness test.

Evaluate item	The standard of adaptation
χ2	The smaller the better, The significance probability value p＞0. 05
NC	1＜NC＜3 shows the degree of reduced fitness NC>5 model needs to be modified
RMSEA value	<0.05 which fits well;<0.08 good fit;< 0.10 suitable;> 0.10 does not fit well

Table A-2. Test results of the adaptability of the whole model.

Test index	χ2 value	degree of freedom	associated probability,	NC	MSEA
test results	20.887	36	0.820	0.792	0.003

Table A-3. Internal adaptability.

			Estimate	S.E.	P				Estimate	S.E.	P
E	<---	A	0.286	0.115	**	D01	<---	D	1		
E	<---	D	0.711	0.293	**	D02	<---	D	0.412	0.277	**
F	<---	B	-0.392	0.107	***	D03	<---	D	0.843	0.376	**
F	<---	C	1.176	0.222	***	F03	<---	F	1		
F	<---	D	-1.724	0.829	**	F02	<---	F	0.798	0.059	***
F	<---	E	2.005	0.709	0.005	F01	<---	F	0.535	0.128	***
C01	<---	C	1			A03	<---	A	1		
C02	<---	C	0.813	0.205	***	A02	<---	A	1.315	0.01	***
C03	<---	C	0.754	0.194	***	A01	<---	A	1.058	0.255	***
B01	<---	B	1			E03	<---	E	1		
B02	<---	B	0.919	0.198	***	E02	<---	E	1.939	0.068	***
B03	<---	B	1.133	0.228	***	E01	<---	E	1.195	0.32	***