Research on the Stock and Flow of Plastic Resources in China's Environment

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Abstract. The waste of plastic resources and environmental pollution with the rapid growth of plastic production and consumption is becoming more and more serious, so the study of the metabolic process of plastic resources is very important to save resources and protect the environment. This paper examines the life cycle metabolic process of plastics accumulated through 2018 in China from production and use to eventual abandonment. The research shows that the metabolic scale of plastic in China is huge, and the influence of disposable plastic products on plastic metabolism is very large. Waste plastic is a very important direction for resource loss.

Keywords: Plastic resources; Life cycle; Stock; Flow.

1. Introduction
Plastics are ubiquitous in our lives and are being used in a growing range of applications, making them the fastest growing engineering material in the past 50 years, and together with steel, wood and cement, they are today's four basic materials. With the increase of plastic production and consumption, the waste of resources is becoming more and more prominent. On the one hand, plastic is petrochemical products, its large-scale production and widespread use increased the consumption of petrochemical resources; On the other hand, plastic is discarded in the environment to accumulate, not only occupy space resources, pollution of the environment, but also waste recyclable waste plastic resources. In order to improve the efficiency of plastic resource utilization and reduce waste of resources and environmental pollution, it is very important to analyze the life cycle metabolism process of plastic resources scientifically.

Indonesia, Norway, Serbia, Austria, India, Thailand and other countries have cases of plastic flow analysis. In these studies, all plastics are generally used as a class of substances and do not distinguish between plastic categories. Some of the research has also focused on a particular category of plastics, especially PVC, due to its high environmental risks. Research on the flow analysis of plastic substances in China has only begun to appear in recent years. Dai Tiejun and others set up a plastic packaging waste material flow analysis framework to study the metabolism of plastic packaging waste in China; Xin Yiming and others carried out material flow analysis on the recycled plastics industry in Qingyuan City, Guangdong Province.

Therefore, this paper studies the metabolic process of plastics in China, accounts for the flow and stock of different types of plastics in their life cycle, analyzes the key nodes of waste of different plastic
resources, in order to improve the utilization rate of plastic resources and reduce the environmental impact of their life cycle.

2. Key Flow and Stock Accounting

From oil cracking to the final disposal of waste plastics (see Figure 1), every aspect of the plastic life cycle has an impact on the environment, and as demand increases, the impact on the environment throughout the life cycle is bound to increase.

Based on the production, consumption and service life of plastic products in China's social and economic system, the production of waste plastics from 1949 to 2018 can be calculated by using the normal distribution function, and the other flow and stock of plastic metabolism can be further calculated by combining the law of quality conservation with the relevant calculation formula.

According to the basic calculation method of material flow analysis, the main flow and stock calculation formula is as follows:

Plastic consumption (C) is calculated as follows:

\[ C_n = P_n + \text{Import}_n - \text{Export}_n \] (1)

\( P \) represents the production of plastics in the nth year, \( \text{Import} \) represents the import volume of plastics in the nth year; \( \text{Export} \) represents the export volume of plastics in year n.

In this paper, the life distribution of plastic products is characterized by a normal distribution model, and the calculation formula for the scrap rate (\( G_m \)) of plastic products in m years is as follows:

\[ G_m = \int_{m-1}^{m} \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right) dt \] (2)

The amount of plastic scrap (\( W_n \)) is further calculated, as follows:

\[ W_n = \sum_{m=m_{\min}}^{m_{\max}} (C_{n-m} \times G_m) \] (3)

(3) \( C_{n-m} \) represents the consumption of plastics in the n-m year; \( m \) represents the actual useful life; \( M_{\min} \) represents the minimum useful life; \( M_{\max} \) represents the maximum useful life. The amount of recycled plastic, the amount of incineration, the amount of landfill and the amount of waste are multiplied by the amount of end-of-life plastic and the recovery rate, incineration rate, landfill rate and waste rate respectively. According to the law of quality conservation in the use stage, the use stock \( S_{ni} \) and the loss stock \( S_{nl} \) can be calculated.

\[ S_{ni} = \sum (C_{n} - W_{n}) \] (4)

\[ S_{nl} = \sum (L_{n} + D_{n}) \] (5)

Type: \( L_n \) represents the amount of landfill of waste plastic in year n, and \( D_n \) represents the amount of waste plastic waste in year n.
3. Refine Results

3.1. Plastic Critical Flow Analysis

(1) Plastic production and import and export volume

Plastic production has been increasing slowly 1949-2000 years, with an average annual growth rate of 0.3Mt. After 2000 year, the growth rate of plastic production accelerated from 13.8Mt to 129.3Mt in 2018, with an average annual growth rate of 6.4Mt. In terms of plastic categories, the share of PE and PP decreased year by year, from 20.2 per cent and 20.8 per cent (2006) to 14.6 per cent and 13.6 per cent (2010), respectively, as a result of the plastic restriction order. PET's share is increasing, from 21.2 per cent (2000) to 33.6 per cent (2018). On the one hand, because of the rapid growth of the demand for engineering plastics, on the other hand, PET bottles are widely used. PVC's share of potential environmental health risks is declining, from 18.8 per cent (2000) to 14.8 per cent (2018).

(2) Plastic consumption

During the 1949-2018 years, China consumed a total of 2205.6 Mt of plastic. From 1949 to 2000, plastic consumption increased slowly, with an average annual growth rate of 0.6 Mt. Plastic consumption accelerated after 2000, from 29.9 Mt to 193.1 Mt in 2018, with an average annual growth rate of 9.0 Mt. Pet is also widely used in dairy products, beer and other beverage bottle packaging, and clothing shoes and hats are mainly PET fiber, so PET increased from 8.6% to 28.8%. In addition, PP and PVC accounted for a higher proportion, accounting for 18.9% and 11.8%, respectively.

(3) The amount of waste plastic produced

From 1949 to 2018, China produced a total of 1404.8Mt of waste plastics from different types of waste plastics and by-products. The production of waste plastics increased slowly before 2000 and accelerated after 2000, from 19.8Mt to 140.5Mt in 2018, with an average annual growth rate of 6.8Mt.

(4) Waste plastic recovery, terminal handling and waste

Over the past few years, China has recycled 407.4Mt of waste plastic, incinerated 204.5Mt, landfilled 512.0Mt, abandoned 280.9Mt (30.0% recycled, 14.0% burned, 36.0% landfilled, 20.0% untreated directly into the environment). Abandonment continued to increase until 2002, increasing to 12.6Mt in 2002 and then gradually decreasing to 9.2Mt in 2018. Waste incineration treatment started late, because of the complex operation, waste classification is not in place, lack of capital investment and other reasons, but by learning from successful experience abroad, according to local conditions, incineration technology has gradually begun to develop, after entering the 21st century, plastic incineration from 1.1 Mt (2001) to 36.5 Mt (2018). Plastic recycling accelerated after 2000, increasing from 3.0 Mt to 45.0Mt in 2018, with an average annual growth rate of 2.3 Mt. Pet (37.2%) of waste plastics are recycled, which is due to the fact that PET bottles in China can be recycled at a rate of up to 90%, which is highly recyclable.

3.2. Analysis of Key Stocks of Plastics

(1) Plastic use stock

The stock of plastic use increased slowly between 1949 and 2000, with an average annual growth rate of 1.5Mt. After 2000, the stock of plastic use accelerated, from 75.0Mt to 630.0Mt in 2018, an average annual growth rate of 30.8Mt. Since the stock of use was relatively small before 1970, only the pattern of changes in plastic use after 1970 is discussed. Specifically for end-products, the share of the stock used in building materials is decreasing, from 49.9 per cent (1971) to 33.6 per cent (2018), indicating that plastics are becoming more widely used and more widely distributed. In addition, clothing shoes and hats, household goods and household appliances are the use of larger areas of stock.

(2) Plastic loss stock

The stock of plastic loss increased slowly before 2000, and the stock of plastic loss accelerated after 2000, from 142.4 Mt in 2000 to 870.2 Mt in 2018, with an average annual growth rate of 40.4 Mt. In the case of end-of-life products, the share of packaged waste and agricultural end-of-life products in the loss stock decreased gradually, from 64.4 per cent and 13.9 per cent (1971) to 37.1 per cent and 10.5 per cent (2018), respectively, indicating an increasing dispersion of uses, use and loss stocks. In addition,
used clothing shoes and hats, household goods and household appliances are the loss of the stock of large areas. Similar to waste plastic production, long-lived end products lost less stock, such as waste building materials, accounting for only 1.9%.

Similar to waste plastic production, long-lived end products lost less stock, such as waste building materials, accounting for only 1.9%. For different types of plastics, PE, PP loss stock ratio is decreasing, from 35.3% and 19.5% to 22.7% and 16.3%, respectively, and PVC and PET are the loss of the stock of plastics accounted for a larger proportion, accounting for 10.7% and 18.8%, respectively. Of all the loss stocks, 66.7 per cent were accumulated in landfills, 33.3 per cent were randomly discarded in the environment, compared with 2.0 per cent in 1971, and the remaining 98.0 per cent were randomly disposed of in the environment.

4. Summary
In this paper, the life cycle metabolic process of different types of plastics is studied, and the key flow and stock are accounted for. The main conclusions are as follows: (1) From 1949 to 2018, the proportion of plastic sub-end products in consumption, packaging products, clothing shoes and hats, building materials and agricultural products are higher. PET and PE account for a large proportion of all plastic consumption. End-of-life plastic products are mainly packaging waste, used clothing shoes and hats, household goods and agricultural products, waste PET and PE accounted for a relatively large. (2) From 1949 to 2018, China's plastic use stock mainly exists in building materials, clothing shoes and hats, household appliances and household goods and other 4 categories of products, the future of related products will increase year by year; The loss stock of plastics was 870.2Mt, mainly in four categories: packaging waste, used household goods, clothing, shoes and hats and agricultural products, of which 66.7 per cent were piled up in landfills and 33.3 per cent were disposed of at will in the environment. (3) At present, plastic resource metabolism scale is huge, waste plastic is the key node of resource loss, the biogeochemical behavior and ecological risk of plastic in the environment need to be studied in depth.

Based on the changes in the flow and stock of plastics in China, the following suggestions are put forward:
(1) In view of the huge scale of plastic metabolism in China, the use of plastics, especially disposable plastics, can be restricted through policies and regulations such as plastic restriction orders and resource and environmental taxes, while accelerating the development and application of biodegradable plastics. In addition, packaging can be reduced, consciously reduce the use of disposable packaging plastics; Improve agronomic technology to achieve the reduction of agricultural film, and actively promote the application of biodegradable agricultural film.
(2) For waste plastics with key nodes of plastic loss, compulsory classification and recycling policies should be implemented, relevant standards and regulations should be improved, recycling infrastructure should be improved and supervision strengthened. Therefore, in-depth research on waste plastic material recovery and energy recovery technology is very necessary.

Compared with some studies that focus only on waste plastic recycling treatment, there are still some limitations in this study: Only the plastic resources from production and processing, use to scrap treatment of the life cycle metabolic process analysis, the production process of plastic raw materials has not been analyzed and studied, while waste plastic into the environment and distribution and other issues, also need to be further explored.

References
[1] Ministry of Housing and Urban-Rural Development of the people’s Republic of China. China Urban Construction Statistical Yearbook. Beijing: China Statistics Press, 1999-2017.
[2] Bai M Y, Zhu L X, An L H, et al. Estimation and prediction of plastic waste annual input into the sea from China. Acta Oceanologica Sinica, Vol. 37 (2018) No. 11, p. 26-39.
[3] Zhou Y C, Yang N, Hu S Y. Industrial metabolism of PVC in China: A dynamic material flow analysis . Resources, Conservation and Recycling, Vol. 73(2013), p. 33-40.
[4] Chen Y D, Cui Z J, Cui X W, et al. Life cycle assessment of end-of-life treatments of waste plastics in China. Resources, Conservation and Recycling, Vol. 146 (2019), p. 348-357.

[5] Hong J L, Li X Z, Cui Z J. Life cycle assessment of four municipal solid waste management scenarios in China. Waste Management, Vol. 30 (2010) No. 11, p. 2362-2369.