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COMMENTARY

Synergistic reduction path of plastic and greenhouse gases: Key explorations in global plastic governance

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In the contemporary era of globalization, plastic pollution has emerged as a pressing global concern. The rapid increase in production and consumption of plastics have triggered a series of environmental and resource issues, such as microplastic pollution and the massive consumption of fossil fuels. Moreover, the entire process of plastic production, processing, and final disposal is a major source of greenhouse gas (GHG) emissions. In the absence of novel policy interventions, global plastics lifecycle emissions are projected to increase from 1.8 gigatons of CO_2 equivalent (Gt CO_2e) in 2019 to 4.3 Gt CO_2e in 2060, growing from 3.7% to 4.5% of global emissions. If no effective intervention measures are taken in a timely manner, it is predicted that the global demand for plastics will double by 2050 and triple by 2100, and related CO_2 emissions will also increase simultaneously.[1]

Plastic pollutants and related carbon emissions originate from the same production, consumption, and disposal processes. Therefore, promoting the coordinated reduction of pollution and carbon emissions has become the key to solving these two major environmental problems. However, there are biases and ambiguities in the data of plastic products and waste. These issues hinder the quantification of plastic pollution flow in the environment, prompting the academic community to explore methods such as optimizing models and using machine learning to fill data gaps. It is urgent to develop a globally coordinated solution, such as the Global Plastic Treaty, to effectively control plastic pollution through the close cooperation of countries around the world. This study focuses on the contribution of plastic inventories to understanding the plastic flow in sectors and global regions, and deeply explores the feasible paths of synergistic emission reduction from the three aspects of plastic production, consumption, and waste management. Our findings not only help to accurately quantify and mitigate the negative impact of plastic waste on the environment, but also provide strong reference for the subsequent negotiations of the Global Plastic Treaty.

CHARACTERISTICS OF GLOBAL AND SECTORAL PLASTIC INVENTORIES

Plastic waste has a wide range of sources, and its flow patterns in the environment are complex, thus a comprehensive plastic inventory is essential for tracing the origins and dissemination routes of plastic pollution in global regions. Similar to carbon emission baselines in international climate agreements, signatories of the Global Plastic Treaty need a scientific

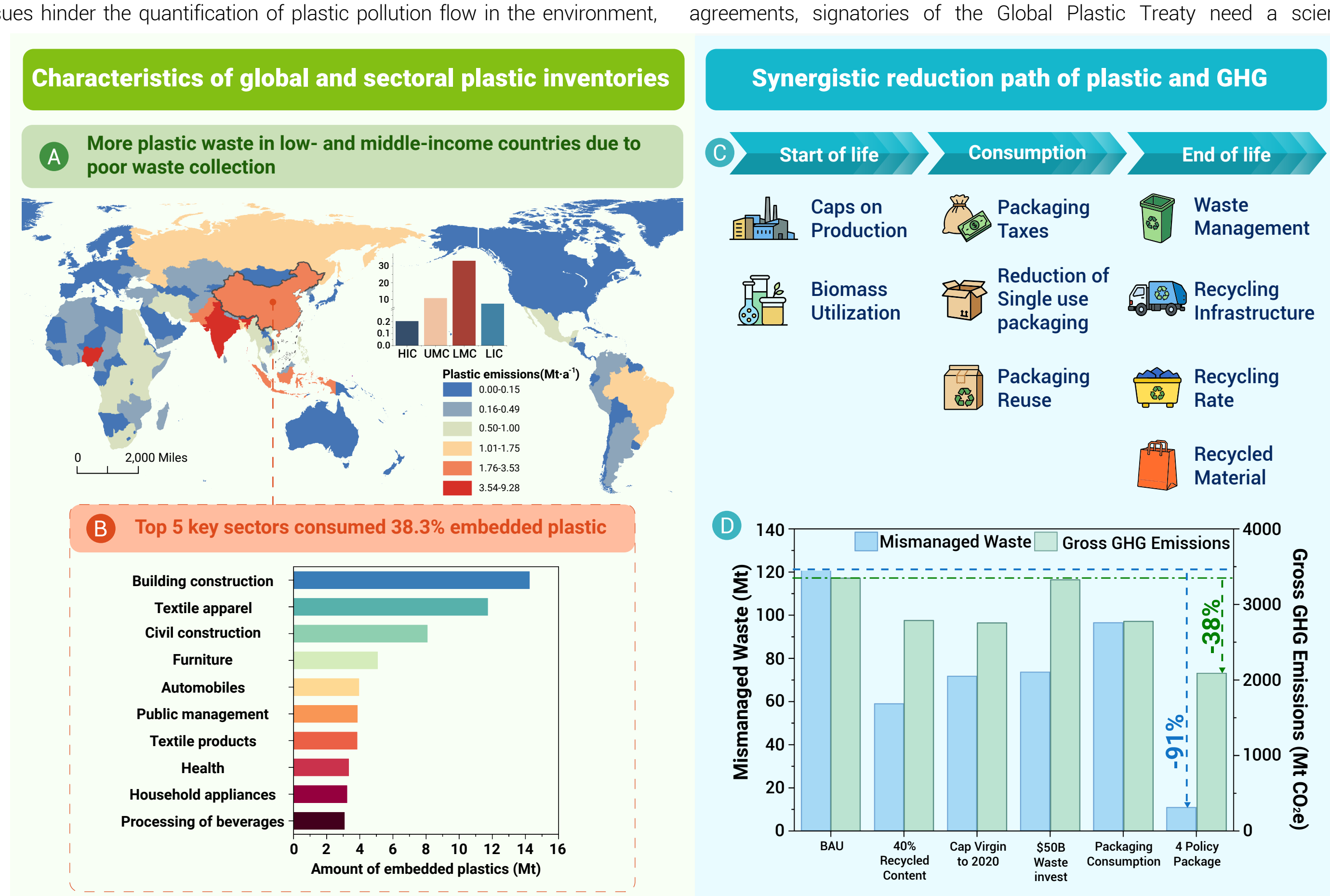

Figure 1. Analysis of global plastic emissions, consumption by sectors and policy impacts (A) Plastic emissions (Mt/a) of global regions in 2020. (HIC: High-income country, UMC: Upper middle-income country, LMC: Lower middle-income country, LIC: Low-income country) (B) Plastic consumption by final demand sectors. The top 10 sectors in final demand category are included. (C) The emission reduction measures corresponding to the three stages of the plastic lifecycle. (D) Policy impacts on plastic and greenhouse gas (GHG) emissions. Projected impacts of four policies under consideration in the United Nations plastics treaty on mismanaged plastic waste and gross plastic-related GHG emissions. The impact of each policy is measured relative to business as usual (BAU) in 2050.

approach to calculate and set plastic waste emission baselines for international comparison. High-precision estimations of plastic emission enable in-depth investigations into the causes, extent, and nature of plastic pollution, thereby providing robust support for countries to formulate targeted action plans. Cottom et al.[2] compiled the 2020 global inventory of plastic pollution by integrating an emission mechanism conceptual model with measurable activity data. On a global scale, approximately 52.1 million tons of plastic waste were discharged into unmanaged systems (the environment; uncontained state) in 2020, accounting for 21% of the total global urban plastic waste. Among these unmanaged plastic wastes, about 57% are open burned, while 43% remain as unburned debris. At the national level, countries in South Asia, Sub-Saharan Africa, and Southeast Asia have high plastic pollution emissions. China's plastic pollution emissions are 2.8 million tons per year, ranking fourth, lower than those of India, Nigeria, and Indonesia (Figure 1A). From the perspective of different income countries, about 69% of global plastic waste emissions mainly come from 20 countries, including 4 low-income countries (LICs), 9 lower-middle-income countries (LMCs), and 7 upper-middle-income countries (UMCs). Notably, low-income and middle-income countries (LIMICs) generally have relatively low plastic waste generation rates. However, due to inadequate waste collection and disposal infrastructure, their plastic pollution emissions are disproportionately high. The proportion of uncollected waste is 80% for LICs, 66% for LMCs, and 69% for UMCs. For example, the number of dumpsites in India is 10 times that of sanitary landfills. In contrast, high-income countries (HICs) generate large amounts of plastic waste, but most of them have 100% collection coverage and standardized disposal, preventing them out of the top 90 most polluted countries. The characteristics of global plastic inventory clarify waste management and emission mechanisms worldwide. Interventions should focus on upstream material reduction and improving collection infrastructure in LIMICs. These intervention measures require a multi departmental collaborative approach, therefore technology transfer and management systems from developed regions are necessary.

Global and regional plastic inventories help coordinate countries' responsibility allocation in plastic pollution governance. Within a country, it is essential to quantify industrial sectors' contributions to plastic inventory for developing mitigation strategies. For example, Zhang et al.[3] compiled an inventory covering 150 types of plastic products in China, providing the comprehensive information from plastic supply to demand side. In 2018, the amount of embedded plastics consumed in China reached 123.5 million tons. From the supply perspective, this embedded plastic was predominantly utilized to supply materials for cotton production (21.5%), construction (9.9%), and other categories. From the demand side, the total embedded plastic was consumed mainly in construction (21.2%), textiles (16.2%), food sectors (6.5%) and other categories (Figure 1B). Specifically, about 75.5% of embedded plastics was used domestically, 21.3% was exported, and 3.2% was scrapped or lost during the manufacturing process. Sectoral plastic production chains reveal that 35.2% of the embedded plastic was used or discarded in the industrial sector before it reaches the final demand side. The plastic waste generated by agriculture, industrial production, and the service sector is 1.3 times that of households, contributing more significantly to plastic pollution. This indicates that plastic recycling and emission reduction policies should adopt a supply-chain management approach for full-chain supervision. By optimizing the plastic flow among various sectors and rationally adjusting plastic demand, it can help build a plastic efficient utilization system. Plastic inventories at the sector level reveal the overlooked resource transfer issues in plastic exports and industrial consumption, providing important clues for in-depth research on the impact of plastic trade on the regional environment and social economy.

SYNERGISTIC REDUCTION PATH OF PLASTIC AND GREENHOUSE GASES

The effective control of plastic pollution and associated GHG emissions is significantly affected by the measures implemented during the three stages of plastic production, consumption, and waste management. Pottinger et al.[4] developed a model to simulate the impacts of eight policy interventions on globally mismanaged plastic waste and related GHG emissions. To minimize mismanaged plastic waste, four policies were selected for combination (limiting the global production of virgin plastics to the 2020 level, imposing a high packaging consumption tax, setting a minimum recycling rate of 40%, and investing $50 billion in waste management). Compared to the "business as usual" scenario, the combined implementation of these four policies is projected to reduce mismanaged plastic waste from 121 Mt to 11 Mt by 91% in 2050. Meanwhile, the total plastic-related GHG emissions in 2050 are expected to decrease by one-third, from 3.35 Gt CO_2e to 2.09 Gt CO_2e (Figure 1D). Whether used alone or in combination, these four policies would have a substantial impact. Although HICs can achieve recycling goals by utilizing existing waste collection systems, LIMICs may need to develop targeted policies. LIMICs that bear the main burden of plastic pollution may face financial and technological barriers in implementing these measures. Additional international assistance in these areas could therefore help to explore the best policy system for cooperative governance to reduce pollution and minimize carbon emissions in the global plastics system.

Furthermore, the continuous improvement of the policy system requires the support and guarantee of relevant synergistic emission reduction technologies. Stegmann et al.[1] analyzed three alternative CO_2 emission reduction technology paths for the global plastic industry from 2000 to 2100, covering the entire life cycle from production to waste management. The first path is to combine non-degradable bio-based plastics with landfilling, which can sequester a cumulative 75 Gt of biochar from 2000 to 2100, equivalent to 275 Gt of CO_2 reduction. However, this path focuses on primary plastic production and landfilling, and the energy and material inputs are still relatively high. The second path is the circular economy model. By phasing out landfilling and promoting recycling pathways, it can reduce resource consumption by 30% and achieve a 10% greater emissions reduction by 2050, compared to the pathway that lacks circular economy measures. The third path is the circular bio-economy approach that combines recycling with enhanced biomass utilization. This approach can eventually make the plastic industry a net carbon sink, while effectively reducing resource consumption. Considering the economic feasibility of recycling, each plastic-importing country should set a minimum plastic waste recycling rate of 63%. This condition can reduce China's net carbon emissions from processing trade plastic waste in 2018, from 0.13 Mt CO_2e to -60 Kt CO_2e.[5] Therefore, formulating a circular bio-economy strategy can achieve a synergistic effect between climate and circular economy goals.

In conclusion, investigating the characteristics of plastic inventory not only clarifies differences in plastic pollution distribution across income levels, but also provides data support for targeted control of plastic emission among sectors. Policy interventions and technologies for plastic-related greenhouse gas emissions show a positive prospect for the path of synergistic emission reduction. Global collaboration in policy, technology, and economy can help achieve the dual goals of reducing pollution and carbon emissions in plastic systems, creating favorable conditions for global sustainable development.

REFERENCES

1. Stegmann P., Daioglou V., Londo M., et al. (2022). Plastic futures and their CO_2 emissions. *Nature* 612:272–276. DOI:10.1038/s41586-022-05422-5
2. Cottom J. W., Cook E. and Velis C. A. (2024). A local-to-global emissions inventory of macroplastic pollution. *Nature* 633:101–108. DOI:10.1038/s41586-024-07758-6
3. Zhang S., Li J. and Tan Q. (2024). Hidden giant of embedded plastics in China. *Environ. Sci. Technol.* 58:22603–22614. DOI:10.1021/acs.est.4c04814
4. Pottinger A. S., Geyer R., Biyani N., et al. (2024). Pathways to reduce global plastic waste mismanagement and greenhouse gas emissions by 2050. *Science* 386:1168–1173. DOI:10.1126/science.adr3837
5. Li K., Ward H., Lin H. X., et al. (2024). Economic viability requires higher recycling rates for imported plastic waste than expected. *Nat. Commun.* 15. 7578. DOI:10.1038/s41467-024-51923-4

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AUTHOR CONTRIBUTIONS

R.L.: writing – original draft, review and editing, fund acquisition, expedition planning. H.H.: data acquisition, data analysis, writing – original draft. Y.L.: analytical methodology, data acquisition. Y.L.:analytical methodology, data acquisition and data analysis. X.Z.: resources, data acquisition. H.L.: supervision, fund acquisition. All authors contributed to the manuscript and approved the final version

DECLARATION OF INTERESTS

The authors declare no competing interests.