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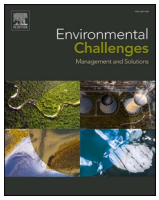
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Role of regulatory frameworks in plastic waste value chain and management

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ABSTRACT

This study critically examines the impact of regulatory frameworks on the plastic waste value chain and its management, offering a comprehensive analysis of how different governmental policies shape the effectiveness of plastic waste processes from generation to recycling and disposal. This review explores the dynamics between regulatory approaches and their practical outcomes in plastic waste management via a systematic review of global legislation and case studies. This review further categorizes these frameworks into stringent, moderate, and lenient, correlating each category with corresponding outcomes in terms of plastic recycling rates, innovation in waste processing technologies, and sustainability practices. Furthermore, this review addresses the challenges and opportunities presented by Extended Producer Responsibility (EPR) schemes, and how this influences corporate behavior and technology adoption in the plastic industry. Additionally, this work synthesizes key factors that determine the success of regulatory frameworks in fostering a circular economy by leveraging data and findings from multiple sources. Finally, the research efforts in this study provides policy recommendations for enhancing the regulatory environment to better manage plastic waste and encourage the transition towards more sustainable practices. The conclusions drawn from this review not only shed light on effective strategies and gaps in current regulatory practices, but also offer a roadmap for policymakers, industry leaders, and environmental advocates to collaboratively improve the management of plastic waste globally. This study aims to serve as a foundational reference for future research and policy development in the realm of sustainable plastic waste management.

1. Introduction

Amidst global challenges in fossil fuel supply for virgin plastics, nations must prioritize the recovery, reuse, and remanufacture of single-use plastics (SUPs) (Hossain et al., 2022a). With only 9 % of the 90 billion tons of petroleum-based plastics recycled annually, this issue demands urgent attention (Geyer et al., 2017). Such low recycling rates, as highlighted by the Commonwealth Scientific and Industrial Research Organization (CSIRO), adversely affect the environment and human health. Global plastic waste, estimated at 300 million tons yearly and 6.8 billion tons generated between 1950 and 2020, sees <10 % recycled, with the majority ending up in landfills, as litter, or incinerated (Geyer et al., 2017). This alarming trend poses threats to both human and aquatic life. The disparity between plastic waste generation and management, coupled with increasing generation rates surpassing recycling efforts, underscores the need for significant improvements. Therefore, emphasizing the recovery of reusable plastic waste over prevalent municipal landfilling practiced in many countries today (Olatayo et al., 2022) is imperative for progress.

Plastics are widely utilized across diverse applications due to their superior mechanical, thermal, and chemical properties (Medupin et al., 2017; Abubakre et al., 2023; Lawal et al., 2023; Medupin et al., 2020, 2019). Despite the promotion and implementation of policies aimed at fostering circularity in the plastic value chain (Peng et al., 2017;

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Tibbetts, 2015; Thompson et al., 2009; Ayeleru et al., 2020) significant challenges persist. For instance, having in place the Environmental Conservation Acts of 1989 in South Africa to regulate waste management and curb pollution does not translate to a reduction of the over to 90 % of waste that ends up in landfills (Sun et al. 2022; Tun and Juchelkova, 2018; Quadrini et al., 2013). Adopting a Circular Economy (CE) model, which emphasizes transition to renewable materials and integrates waste management into the forward supply chain, is crucial. This approach prioritizes recovery through reuse and recycling (Hossain et al., 2022b; Castro-Amoedo et al., 2024). Thus, to address the significant environmental challenges posed by plastic waste, a shift is necessary, viewing plastic waste as a resource to bridge the gap between material circulation and waste management (Jung et al., 2023; Mohammed et al., 2015; Ramu et al., 2019; Medupin et al., 2013).

While significant strides have been made in policy development by different governments worldwide, there is a seemingly passive engagement with consumers of single-use plastic (SUP) materials, posing the initial hurdle to commercializing products from plastic waste. Federica et al. (2023) highlighted bans and suspensions as key elements in enforcing regulatory measures to reduce plastic waste in cities, especially in the top 10 regions with the global highest plastic materiaals production (Fig. 1). There is a clear correlation between production and consumption, hence, the reason why Asia is the most impacted continent as far as plastic waste pollution is concerned. It can be seen that China and the rest of Asia maintained an unenviable position in plastic production platform in both 2021 and 2022, necessitating quick actions for improvement. Yet the effectiveness of bans and suspensions remains questionable, with many countries still struggling with waste management and transitioning to economically viable recycling regime (Brooks et al., 2018; Wang et al., 2019). Economic instruments, such as levies and financial incentives promoted by campaigns, education, and research are also employed, but their success rates are debatable (Ezeudu et al., 2021; Vuppaladadiyam et al., 2024; Chun et al., 2023). Therefore, domesticating effective strategies is imperative, especially for developing economies. In South Africa, similar to what obtains in Kenya, for instance, Godfrey and Oelofse (2017) noted that progress through four stages of waste development (landfilling, recycling, regulation, and drive for extended producer responsibility) holds every stakeholder in the plastic value chain responsible for its management. It is currently at the fifth stage where sustainability takes center stage within the circular economy framework. To this end, this study aims to explore innovative approaches to enhancing the value of plastic waste through circular economy practices, particularly in the context of re-manufacturing.

In the same breath, Olatayo et al. (2022) highlighted that existing plastic policies in South Africa mainly address Material Flow Analysis (MFA) stages such as production, trade, consumption, and recycling, neglecting crucial administrative aspects. These efforts are commendable compared to other African countries where little to no action is being taken following pronouncement of bans. The policy documents often overlook the important administration phase, a common trend among developing nations concerned with legislating plastic waste management. Furthermore, the document predominantly supports reuse and recycling while disregarding other options outlined in the 9R Waste Hierarchy System. This omission poses significant risks to both plastic waste management and environmental safety. Notably, plastic waste in landfills can take centuries to decompose, exacerbating environmental vulnerabilities (Tulashie et al., 2019; Mandal and Seikh (2023). However, the plastic waste industry presents significant economic potential if properly leveraged (Shahsavar et al., 2022). Therefore, concerted efforts are needed to address key hindrances to sustainable plastic waste management within the ecosystem, aiming to transition fully to a circular economy model.

Lee and Wong (2023) stand out among the few researchers who reported various facets of mixed plastic waste end-of-life processes, focusing on mechanical recycling for raw material utilization in the built environment. This underscores the complexity of plastic waste management, necessitating the integration of diverse policies for effective mitigation (Phan et al., 2023). Therefore, employing a combination of regulation ("the stick") and economic incentives ("the carrot") seems logical to engage all stakeholders in the plastic value chain (Tan et al., 2023). Consequently, while navigating through the regulatory landscapes of developing economies to assess their readiness for plastic waste management, this review aims to address key questions to draw attention to the potential of plastic waste and its role in promoting circularity, investigate how the plastic industry is responding to the worldwide initiative for recycling plastic waste within a circular value chain. The major novelty of the study lies in its comprehensive examination of how different regulatory strategies influence the entire lifecycle of plastic waste. It uniquely identifies and analyzes the intersection between government policies and the operational phases of plastic waste management, from collection and sorting to recycling and disposal. It highlights how specific frameworks can either foster efficient recycling and sustainable practices or contribute to systemic inefficiencies and increased environmental damage. By providing comparative insights into the effectiveness of various global regulatory models, this work presents new empirical data and recommendations tailored to enhance policy efficacy, contributing to filling a critical knowledge gap, guiding policymakers, industry stakeholders, and environmental organizations in structuring more effective environmental regulations and fostering a sustainable circular economy in the plastic industry.

2. Analysis of literature: identification, screening, and eligibility

Relevant peer-reviewed scientific articles from Scopus and Web of Science were consulted to conduct this systematic review, focusing on sustainable plastic waste management over the past 6 years. Following the Preferred Reporting Items for Systematic Review and Meta-Analysis

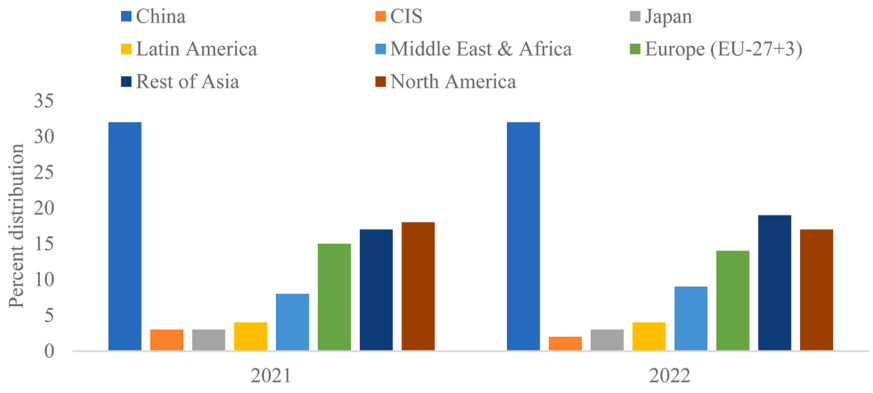


Fig. 1. Distribution of global plastic material production (Statista Research Department, June 28, 2024).

(PRISMA) guidelines (Goyal et al., 2021; Gregorio et al., 2018; Homrich et al., 2018; Merli et al., 2018; Prieto-Sandoval et al., 2018; Medupin et al., 2023), we used a reproducible and transparent three-step process, outlined in Fig. 2 to answer the research questions.

Using keywords such as "strategies, "plastic waste" "regulatory framework/effort," "circular economy," "recycle," and "sustainable solid/plastic waste management," 209 relevant peer-reviewed articles, scientific journals, conference proceedings, and book chapters were initially identified. Subsequently, we eliminated duplicate and non-peer-reviewed publications, retaining the others for screening. After carefully reviewing the abstracts, introductions, and conclusions of these publications, articles that meet our eligibility criteria for the review were selected. Publications not directly addressing the research questions were excluded, resulting in a qualitative analysis of 78 articles for this review.

Addressing plastic leakage demands collective actions rather than the individualistic approaches currently adopted by many countries. Achieving this by 2040 is hinged on ambitious, globally coordinated efforts. While certain nations have made significant strides in this direction, their methods are not easily transferable. Therefore, it is important to secure the commitment of neighboring countries to achieve sustainable success. The projected increase in plastic leakage to water bodies from 6 million tons in 2020 to 9 million tons by 2040 underscores the urgency of reassessing existing strategies and policies to foster synergy among various options. This aspect has received limited attention in existing literature and, therefore, necessitates further exploration, underscoring the significance of this review. A recent article by Phan et al. (2023) shed light on citizens' adaptive behavior for sustainable plastic waste management. Their report shows that the consensus is centered around the adoption of a zero-waste lifestyle as a means of taking full responsibility without relying on government coercion. The study was captured in three scenarios: i) enhancing community awareness, ii) community engagement, and iii) adapting plastic waste management, to guide policymakers in establishing suitable adaptive strategies, highlighting roles of different domains of adaptive capacity and circular economy. Such a shift will engender inclusivity and ownership of the activities, particularly among rural and urban dwellers. This is with the assistance of coordinated awareness campaigns - the anticipated future of developing countries. However, this approach alone may not fully address plastic waste management concerns. Despite

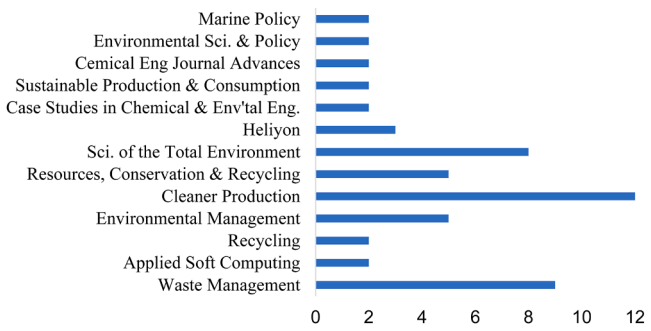


Fig. 3. Ranking of sources having contributed more than one article (n = 56).

significant efforts in plastic waste control and management, the persistence of plastic waste in the environment remains evident, as reflected in the volume of research articles published annually on the subject (Velenturf and Purnell, 2021; Adams et al., 2017; Kahlert and Bening, 2020; MacArthur, 2017; Sun et al., 2019; Lui et al., 2019; Zhao et al. 2018).

In this review, we analyze quantitative results related to the quality characteristics of 78 selected articles to gain a deeper understanding of the advancements in the research domain. Specifically, we presented the major findings from eligible articles to assess the authors' contributions to the study area. This includes examining commonly adopted methods of controlling plastic wastes vis-à-vis the adoption of the stick-and-carrot approach, methodologies, and advancements in re-manufacturing over the past six years. Among the 78 reviewed scientific publications, 56 sources were documented, with 28.2 % contributing only one article each. The Journal of Cleaner Production led with 12 articles (15.4 %), followed by Waste Management and Science of the Built Environment journals with 9 (11.5 %) and 8 (10.3 %) published articles, respectively. Other notable contributors include the Journal of Environmental and Sustainability Indicator and Environmental Management, contributing 5 (6.4 %) publications each. While Chemical Engineering Journal Advances, Environmental Science and Policy, Sustainable Production and Consumption, Case Studies in Chemical and Environmental Engineering, Marine Policy, Applied Soft Computing, and Recycling each contributed 2 scientifically published articles, Heliyon contributed 3

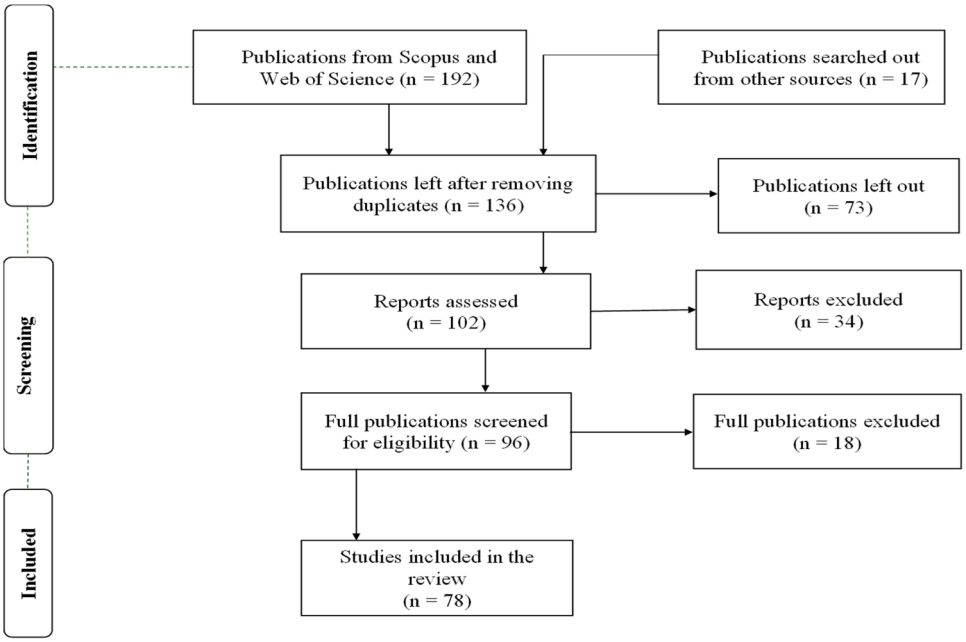


Fig. 2. The review process guided by PRISMA guidelines (Page et al., 2021).

published articles (3.9 %) among the eligible publications (Fig. 3). The majority of this literature either investigated recycling plastic waste from the point of view of environmental protection measures via a stringent legal framework or economic incentives for eliminating plastic waste, thereby generating job opportunities within the value chain. A multi-sectoral approach involving government, stakeholders, and direct consumers of plastic waste to transition to a circular economy has been gaining attention in recent years, necessitating further research efforts to drive change in the field. Fig. 5 illustrates that the decline witnessed in 2023 is temporary, with the volume of literature in the first quarter of 2024 showing signs of resurgence.

2.1. Global outlook of research output on plastic waste management (2019–2024)

The geographical affiliation of the first and second authors of the reviewed articles was considered in the analysis to gauge their contributions to eligible publications. This analysis assumed that first and second authors typically play significant roles in scientific studies as noted by Tscharntke et al. (2007). In a total, of 36 countries across different regions, 151 first and second authors contributed to plastic waste management in the last six years. Notable authors from Australia, India, the United Kingdom, China, and the Republic of Korea dominated scientific publications in this field accounting for a substantial 45 % of the 151 authors with a particularly strong presence from Asian authors (Fig. 4). Conversely, <6 % of the contributing authors were affiliated with African institutions, representing the least contribution. Similarly, American contributions were modest, comprising about 7 % of the authors the 78 eligible publications. Fig. 4 provides a clear visual representation of the geographical distribution and performance of each region in this research field.

2.2. Trend and distribution of literature on global plastic waste management

Siew et al. (2019) authored a pivotal study among the seventy-eight eligible articles investigated in this review. Their research explored the policy framework of commercial and domestic organic waste in the UK. The authors projected alternative waste management strategies while examining challenges and opportunities across the economic, environmental, and social dimensions of sustainable waste management approaches. Their work is so crucial for shaping future discussions on waste management in that they x-rayed the challenges and opportunities of implementing a collaborative method in waste control to improve coordination among the commercial, domestic, and waste management sectors toward a circular economy. They projected system thinking approach to resource recovery through multilevel system analysis, scenario creation, and sustainability assessment methodologies while stressing promotion of food waste recycling through anaerobic digestion by the UK government. This is expected to boost the production of biogas and digestate, towards unlocking the full potential of resource recovery from waste diversion from landfills. Their conclusion, as captured in Fig. 6, indicates that introducing more supportive incentive scheme for anaerobic digestion technology will change the narrative as far as resource recovery and increased diversion of waste from landfill through a collaborative approach are concerned. This study has a far-reaching implication on subsequent studies in that its findings can be adapted for the management of wastes in other climes.

Responses to this work initially saw slow uptake, with only a few studies conducted in the subsequent year of 2020. However, interests surged in 2021, likely influenced by the Chinese government's plastic ban order, which prohibited single-use non-degradable plastic straws, tableware, and bags in major cities, leading to increased scientific literature in 2022 (Fig. 5). This aligns with the growing momentum of circular economy promotion, particularly in response to actions from the

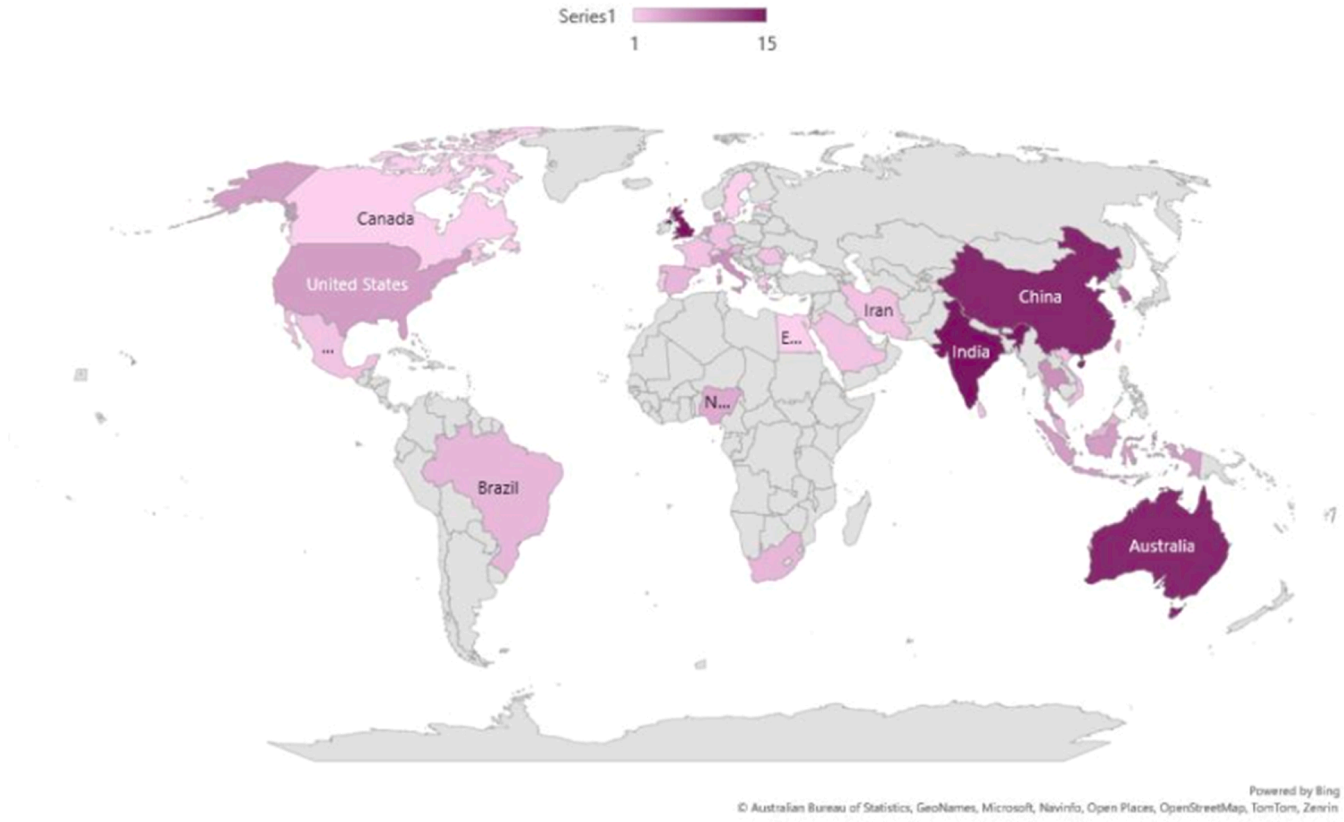


Fig. 4. Frequency of scientific publications by 1st and 2nd authors globally.

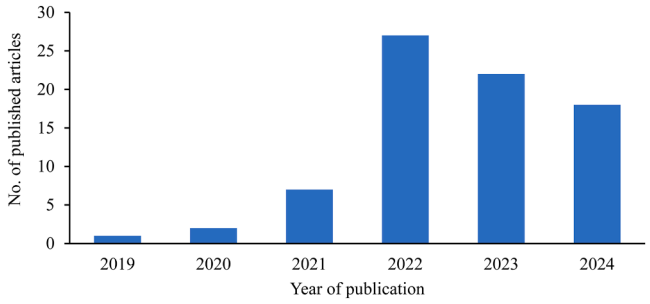


Fig. 5. Number of reviewed papers with year of publication ($n = 78$).

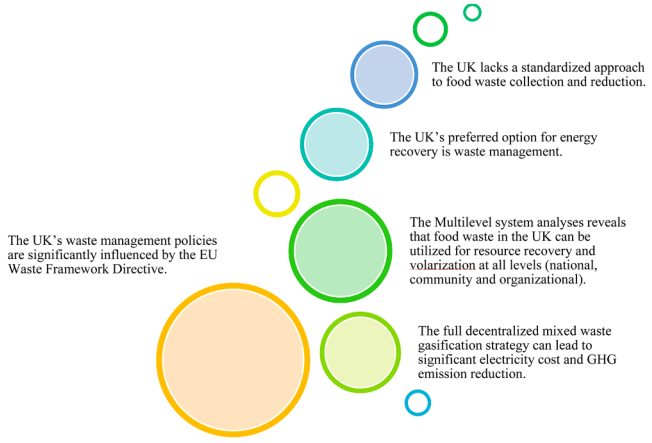


Fig. 6. Conclusion of Siew et al. (2019) on the UK's food waste management (Siew et al., 2019).

biggest SUP markets.

Reports have it that about 50 % of the world plastics is produced in Asia. Therefore, while earlier pronouncements of ban aginst plastics attracted less attention, the Shanghai declaration of 2021 practically sent jitters to the entire world as the implication is far-reaching: massive shipment of plastic products to countries yet to implement plastic bans was imminent. Ayeleru et al. (2020) drew inspiration from the work of Siew et al. (2019) in their examination of current practices in plastic lifecycle and the associated challenges with plastic waste management in sub-Saharan Africa and other developing countries. They advocated for public participation alongside government regulations. This mirrors Wu's (2020) proposal for the establishment of an international legal framework as a measure to protect human life, health, and the environment, emphasizing a multi-sectoral approach to encourage public participation and ownership in plastic waste management, especially the prevention of marine plastic debris. While earlier international legal instruments: 1) the United Nation Convention on the Law of Sea (UNCLOS), 2) the International Convention for the Prevention of Pollution from Ship (MARPOL), and 3) the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention), imposed general marine environment protection obligations on contracting parties to prevent pollution from land-based sources, vessels, and the ocean dumping practices, Wu (2020) reported that these all fail to tackle marine plastic debris especially. Therefore, the establishment of a global or regional clean-up and monitoring mechanism was suggested by the Basel Convention in order to address the trend of pollution in the ocean majorly contributed by the countries highlighted in Fig. 7. However, under London Protocol of 1996, specific permits are required to be sought for suitable materials for disposal at sea. In a bid to protect non-contracting parties, therefore, the Basel Convention, amended in 2019, included mixed unrecyclable and contaminated plastic waste in the list of hazardous wastes to block

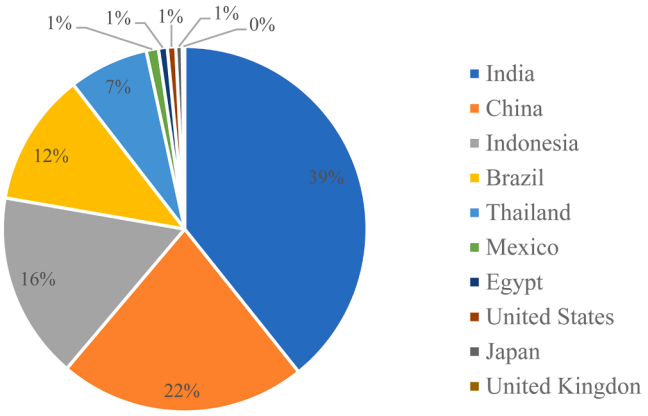


Fig. 7. 2022 top 10 countries with the highest amount of plastic pollution in the ocean (CIWEM, 2022).

illegal flow into developing countries from export/import related infractions (Fig. 8) and eventual leakage into the ocean.

3. Plastic waste control: circular economy perspective

Loy et al. (2023) conducted a comprehensive study on plastic waste management, aiming to shed light on cooperation strategies and or policies among different countries to address the economic, environmental, and energy requirement challenges associated with plastic waste. They identified incineration, landfill, downcycling, and recycling as the major routes for managing plastic waste (Fig. 9). While they acknowledged recycling as the most economically viable route, they strongly advocated for downcycling as the most environmentally feasible route for achieving long-term sustainability. Although landfilling appears economically favorable in Korea considerations, downcycling, and recycling routes are projected for most countries in line with circular economy principles. Despite global concerns regarding the uncoordinated plastic waste usage, cross-boundary transportation of waste via different media, typically from developed to developing countries persists without proper waste management plans, hindering efforts towards plastic waste circularity. In a recent study, Pignataro et al. (2024) contributed novel insights into addressing the challenges beyond recycling, proposing the use of plastic-degrading transgenic model insects to close the waste cycle for the production of fertilizer and waste-to-energy conversion – a novel concept beneficial across various sectors including agriculture (Poveda, 2021; Alfiko et al., 2022) and, hence, human nutrition (Nowakowski et al., 2022).

In the last six years, volumes of works have been published, each offering significant contributions to the better management of plastic

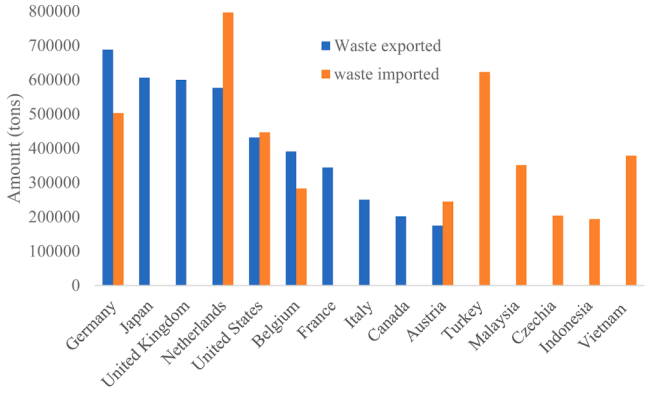


Fig. 8. Top 10 countries with most plastic waste imported/exported per annum (Jordan, 2024).

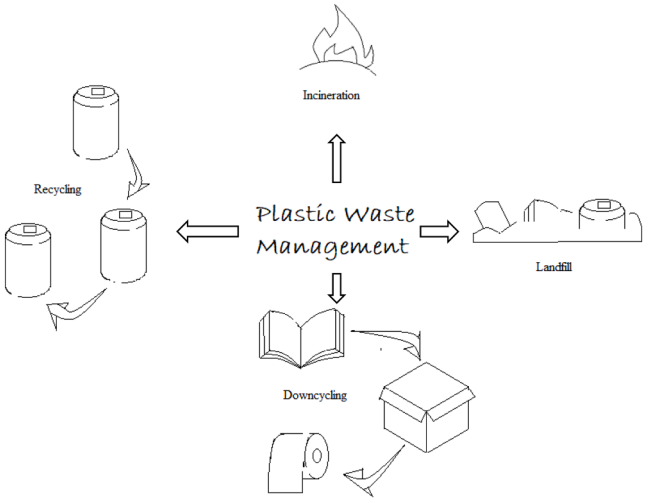


Fig. 9. Major routes of plastic waste management.

waste, all advocating for the concept of plastic waste circularity. Table 1 highlights recent works strongly advocating for a circular economy as a more sustainable strategy for mitigating the challenges of plastic waste pollution. Agovino et al. (2024) investigated the implication of waste management policies on the attainment of circular economy objectives in the EU; implementing Shift-and-Share Analysis, using data from Eurostat for 28 Member States in two periods of 1995 – 2008 and 2009 – 2018. Their findings reveal strong compliance of Member States to EU regulatory frameworks, thereby fostering commitment from both citizens and governmental bodies towards the common goal of creating value from plastic waste. Similarly, Tejaswini et al. (2022) reviewed plastic waste treatment technologies for sustainable utilization and economic benefits. They believe that legislative approach is vital for the successful implementation of circular economy principles in the management of plastic waste in developing countries. Similarly, Shahsavar et al. (2022) proposed a new integrated Multi-Criterion Decision-Making (MCDM) approach for green city concepts and Sustainable Development Goals (SDGs) to manage plastic waste in cities. These efforts geared towards circular economy align with the drive towards sustainable plastic consumption.

Table 1 captures some contributions to the field of plastic waste circularity. However, it is worthy to note that the rate of scientific contribution to thois field has diminished in recent years as researchers have increasingly prioritized research on Sustainable Development Goals (SDGs) 11 and 12 on Sustainable Cities and Communities and Responsible Consumption and Production than plastic waste circularity. For instance, Shahsayar et al. (2022) and Castro-Amoedo et al. (2024) proposed a decision-making methodology for thermal and material valorization of plastic waste for efficient incineration, coupled with simplified waste logistics, which contrasts with circular economy advocacy. In a different perspective to PWM, Bagastyo et al. (2023) highlighted in an assessment of stakeholders' attitudes and involvement at different levels, that awareness alone does not translate to participation in the plastic waste value chain. Therefore, they emphasized that innovative methodologies much more than traditional methodologies are needed to manage plastic waste in both urban and rural settlements. This is in line with the findings of Tumu et al. (2023) who investigated recycling challenges. They observed nations with extended producer responsibility (EPR) systems and landfill bans or tax applications exhibit higher recycling rates, improved recycled product quality, and reduced sortation costs. However, the success of the scheme hinges on a number of factors including the creation of infrastructure for effective takeoff and smooth running without disefranchising any stakeholders. The implementation of deposit and return scheme, as well as establishment of materials recovery facilities requires huge capital investment. The scheme is also plagued with fragmented collection of plastic waste, large loss of materials to landfills and the environment while transporting them, and high materials leakage from recyclers (Amin et al. 2022).

4. Safety and plastic waste control: focus on the global environment

The consensus in the literature is clear: mismanagement of plastic waste poses significant threats to human life and the entire ecosystem (Ganguly et al., 2024; Chakravarty and Edwards, 2022; Rukshan et al., 2022; Hariadi et al., 2021). With sustainability as the overarching goal, mounting pressure is placed on all stakeholders within the plastic waste value chain to adopt effective practices for mitigating plastic pollution (Prasittisopin et al., 2023). Despite the widespread concern regarding microplastics (MPs), there remains a notable lack of reliable data on their global environmental presence (Deme et al., 2022). This section discusses into the literature on plastic ecotoxicity, exploring its implications for both human and aquatic life safety.

4.1. Major routes of plastic waste contamination

Leaching stands out as a significant process through which plastic waste infiltrates marine environments, posing a threat to aquatic life and water bodies (Prasittisopin et al., 2023). The proliferation of developmental activities along coastal regions accelerates the subtle movement of micron-sized plastic wastes into the water. While initial pollution occurs near production and consumption sites, the majority of microplastics enter water bodies post-use and disposal, escalating with global manufacturing rates (Long et al., 2022; Brandon et al., 2019; Dong et al., 2020; Matsuguma et al., 2017; Turner et al., 2019; Wang et al., 2018; Xue et al., 2020). In regions reliant on fishing, fishing ropes emerge as a significant source of microplastics (Xue et al., 2020). Additionally, human activities along coastlines, including construction projects and structures, contribute substantially to plastic particle contamination (Prasittisopin et al., 2023). Notably, over 50 % of the world's nuclear power plants are situated along coastlines, amplifying concerns about water body contamination (Yu et al., 2020). And every single one of China's nuclear power stations is sited in coastal regions; including over 20 new sites in northeast China in 2022 (Wang et al., 2022). Research on microplastic levels in the Yangtze River Basin indicates seasonal fluctuations, with peak volumes observed in October, suggesting a correlation with river flows (Li et al., 2022). Meanwhile, aquatic life inadvertently ingests microplastics, posing indirect risks to human health. In the same way, beyond aquatic contamination, manufacturing activities expose humans to microplastics through ingestion, skin contact, or inhalation. Floating microplastic is a rising worry for human exposure and environmental pollution. The prevalence of floating microplastics heightens concerns regarding human exposure and environmental pollution, particularly in urban environments (Verschoor et al., 2014). Urban dust, originating from sources like rubber tires, construction, and synthetic textiles, serves as a significant carrier of microplastics. Although the skin's epidermal membrane acts as a barrier against microplastic penetration, openings such as cuts, sweat glands, and hair follicles provide avenues for entry. Of all the various exposure routes, environmental and seafood sources constitute the greatest risks of absolute exposure (Yee et al., 2021).

To mitigate plastic contamination, manufacturers of plastic products play a pivotal role in ensuring proper waste management practices and sustainable recycling (Bening et al., 2021). Also, empowering waste management departments across stakeholders is imperative to capturing even the smallest microplastics and preventing unrestricted access to water bodies. Moreover, collaborative efforts between policymakers, enforcement agencies, and manufacturers are essential to researching and implementing strategies for mitigating air contamination from vehicle tire emissions and minimizing human inhalation of plastic nanoparticles.

Table 1
Summary of findings of recent scientific publications in plastic waste management circularity (2020–2024).

S/N	Focus of studies	Plastic waste control strategies projection	Level of CE input	Findings from studies	Reference
1	Examination of policies, legislations, and regulations, on microplastic pollution control in Africa to develop a sustainable, harmonized framework for the coordinated reduction of plastic waste generation across Africa.	Private-public waste management (bottom-up hybrid regulatory approach)	Zero	Analysis of the interventions revealed most African countries employed command-and-control approaches	Deme et al. (2022)
2	Evaluation of willingness-to-pay under hypothetical scenarios of future adaptive municipal solid waste (MSWM) management retribution.	Community based-incentives.	Low	Established three adaptive municipal solid waste management scenarios for sustainable services with the optimization of the MSWM system and infrastructure, community-based MSWM, and smart MSWM system and infrastructure.	Suryawan and Lee (2023)
3	Explores the main features, challenges, and effectiveness of existing international legal norms aimed at marine pollution prevention.	Multiple-level governance and cooperative approach	High	Actions and legally binding instruments are required to reduce the global production and consumption of plastic at a multilayer governance level without further delay.	Wu (2020)
4	Examination of plastic types employed in construction and the built environment. Fabrics or textiles, fibers, and plastics in cementitious systems, paints, tires, and roads.	Use of high-strength concretes and surface-hardening agents to encapsulate the microplastics inside the matrix	High	Polypropylene, polyethylene, and polyvinyl chloride account for 60 % of the world's thermoplastic output in the building and construction sectors.	Prasittisopin et al. (2023)
5	Addressing key aspects of plastic circularity through evaluation of a framework for comparison of plastic initiatives.	Synergies and cooperation among stakeholders across the plastic circularity value chain.	High	Current suggestions for circular economy initiatives targeting plastic may have impacts without the support of new regulations and changes in plastic demand and consumption.	Lisiecki et al. (2023)
6	Global Extended Producer Responsibility (EPR) regulations to coordinate domestic/international policies and business towards overcoming recycling challenges.	EPR and SUP laws as guides to the use and design of SUP to facilitate collection and recycling	Low	Countries that prioritize EPR systems and landfill bans/tax applications possess higher recycling rates, improved recycled product quality, and reduced sortation costs.	Tumu et al. (2023)
7	Verification of life cycle environmental performances of SUP bag and alternatives in real-world	Reducing bag weight and promoting the purchase of local products to shorten travel distances and shifting towards cleaner energy sources	Zero	HDPE plastic bags have relatively lowest environmental footprints regarding acidification and global warming potential.	Tan et al. (2023)
8	Identifying current strategies for converting plastic waste into carbon-based electrodes using less expensive and more efficient competitive protocols	Transform trash into high-valued materials	High	This review also proposes promising options for a sustainable cycle of plastic waste and supercapacitors	da Silva et al. (2023)
9	This study aims to provide explicit insight into possible cooperation strategies between countries on the post-treatment and management of plastic.	Metamorphosis of waste into energy by employing greener technologies.	High	Cross-boundary transportation of plastic wastes, typically from advanced countries to developing countries	Loy et al. (2023)
10	Application of Choice Experiment method to evaluate citizens' preferences concerning strategies for PWM in Danang, Vietnam.	Cooperation between government, NGOs, and local associations, and applying a SUPs ban at supermarkets and restaurants	Low	Multi-stakeholder cooperation, a policy on banning single-use plastics, the adoption of green life and zero-waste events, the establishment of waste collection stations, and the introduction of eco-friendly alternatives are effective PWM	Phan et al. (2023)
11	Explore the future development of plastic waste management measures and motivate efforts toward reducing the nuisance caused by plastics.	Source reduction of plastic products and find alternative materials for plastic products. Strengthen publicity and guidance, enhance citizens' awareness of environmental protection,	Zero	Predicts the generation trends and management costs of plastic waste in China from 2020 to 2035 under different scenarios	Sun et al. (2022)
12	Bio-recovery of municipal PWM based on a new integrated Multi-Criterion Decision-Making (MCDM) approach	Robust decision-making framework for green city concept	High	Municipal waste industries development, smart city goals' meeting, hazardous material	Shahsavar et al. (2022)

(*continued on next page*)

Table 1 (*continued*)

S/N	Focus of studies	Plastic waste control strategies projection	Level of CE input	Findings from studies	Reference
		and SDGs to manage PW in the cities		emission from municipal solid wastes is high	
13	Review of treatment technologies for sustainable utilization of plastic wastes and costs and benefits arising therefrom	Circular economy with legislative approach on PWM	High	A sustainable PWM model is proposed for developing nations to utilize the circular economy concept and EPR rule in managing plastic waste.	Tejaswini et al. (2022)
14	Material flow analysis of plastic waste material from industrial sectors to assess the status of PW recycling and treatment	Formulation of a new management strategy for plastic waste following the Waste Control Act.	Low	PW sorting is vital to the effective recycling of plastic	Lee et al. (2021)
15	Comparative assessment of environmental impacts of strategies are comparatively evaluated using the lifecycle assessment (LCA) technique	Lifecycle assessment (LCA) technique	High	LCA results indicate that industrial incineration is the most potential preferential strategy for Hong Kong as it can utilize locally generated wastes and replace imported coal for the cement industry.	Hossain et al. (2021)
16	Overview of the plastic lifecycle and problems associated with PWM in sub-Saharan Africa	Robust cross-boundary interaction	High	Challenges of acute PW generation can be tackled by implementing a circular economy	Ayeleru et al. (2020)
17	Assessment of attitudes and involvement of stakeholders at different levels regarding SUP waste reduction.	Enforcement of regulations on plastic waste through penalties and disincentives	Low	Awareness does not translate to participation in the PW value chain	Bagastyo et al. (2023)
18	Qualification of environmental and economic impacts of compostable plastic packaging (CPP) waste management schemes using Life Cycle Assessment and Costing.	CPP and conventional PW sorting and recycling	Zero	Collection with plastics for closed-loop mechanical recycling is the best option, from the viewpoint of environment and cost	Federica et al. (2023)
19	Investigates super worms (Zophobas atratus larvae) for polybutylene succinate (PBS) waste management	Waste valorization via organic treatment	High	Recycling PBS waste to generate insect biomass, employing insect gut and frass for PBS degradation and fertilizer, and harnessing insect residue as a food source.	Jung et al. (2023)
20	Investigate the impact of EU waste management regulations through a circular economy lens	Citizens' pro-environment attitudes and proper oversight of waste collection activities by the government for economic gains	High	Alignment of regulatory frameworks with EU member states to create a socio-economic context where citizens and governmental bodies foster the necessary levels of cooperation.	Agovino et al. (2024)
21	Decision-making methodology for thermal and material valorization of plastic waste	System integration and holistic analysis	Low	Efficient burning, as well as simplified waste logistics, can compete with existing mechanical recycling strategies in terms of emissions and costs.	Castro-Amoedo et al. (2024)
22	Study the impact of EU waste management regulations on the attainment of circular economy objectives	Shift-and-share analysis	High	Some Member States are aligning their regulatory frameworks with EU directives and creating a socio-economic context where citizens and governmental bodies foster cooperation	Agovino et al. (2024)

4.2. A paradigm shift in plastic waste management strategies

Despite the large volume of scientific literature on plastic waste management at various levels, there appears to be a deliberate oversight regarding the pivotal role played by plastic product manufacturers in the transition to a circular economy and the fight against environmental contamination. While researchers acknowledge them as stakeholders in the plastic waste ecosystem, they have not been given due recognition in achieving sustainable circularity. This section aims to highlight this group as the vanguard in the battle against plastic waste.

End-of-life (EOL) management of plastic waste is a global concern in both developed and developing nations as the volume of plastics in the ecosystem continues to rise alarmingly (Jia et al., 2023; He et al., 2024; Qian and Ren, 2024; Mong et al., 2024; Arun et al., 2024). The contamination level has become so unpredictable that microplastics are found in virtually every living organism. In terms of managing plastic waste among the three key stakeholders, product manufacturers who directly interact with end users emerge as the most reliable partners. Policymakers must rely on them to communicate the message of plastic circularity effectively to end-users, as environmental goals cannot be achieved through coercive tactics alone. Research shows that human behavior can be positively influenced through reward systems rather than threats of sanctions for non-compliance. If force were effective, plastic waste would have already vanished, and landfills would no longer exist.

The concept proposed in this study has the potential to significantly advance the cause of circular economy and environmental safety, if embraced. While laws and regulations governing plastic waste disposal may be enforceable in urban areas, rural settings present a different challenge, as they constitute a significant portion of plastic product users. Enforcers often face resistance from rural dwellers who perceive such laws as harsh and unjust. However, the same message could be received more positively if communicated through intermediaries with whom they have daily interactions. By deemphasizing coercion and highlighting the benefits and rewards of cooperation, this approach may garner greater acceptance and support in the shortest possible time.

5. The future of global plastic waste management

The future of plastic waste management hinges on a more civil approach to enforcing existing regulations of governments. This principle is receiving increasing support in the literature and its underlying idea has been proven as further advocacy efforts are crucial to garnering support from relevant stakeholders across the plastic value chain. Beyond bans and sanctions, success in plastic waste control depends more on the active participation of the producers of plastic materials. These stakeholders play a pivotal role and act as intermediaries between the government that wields the instrument of coercion to enforce compliance and end users. Surprisingly, this intermediary role has received limited attention in existing literature. The following section discusses transboundary synergies and cooperation among key stakeholders within individual countries.

5.1. Synergy amongst regional blocs

Given the global scale of challenges in plastic waste management and the trend of developing nations becoming recipients of plastic waste from their developed counterparts, cross-border agreements are imperative (Onyeabor and Obuka, 2024). Such agreements safeguard weaker partners and prompt stronger ones to embrace their socio-economic responsibility in recycling, reuse, and the ongoing push for circularity. Plastic waste continues to inundate our oceans alongside rising global production and waste discharge rates (Hurley et al., 2018; Jambeck et al., 2015; Law and Thompson, 2014; Lebreton et al., 2017; Ryan and Moloney, 1993), with over 50 % of plastics ending up in marine bodies (Frias et al., 2016; Moore, 2008). Despite numerous solutions proposed in the literature, many face implementation hurdles due to their economic implications. For instance, Jiao et al. (2024) suggested a reduction in plastic waste consumption, enhancing waste management, and seeking sustainable alternatives to single-use plastics (SUPs), echoing sentiments across the plastic value chain. However, without a legal framework to hold PW-producing countries accountable and protect weaker economies, the cycle of plastic waste influx will persist indefinitely, rendering diplomatic efforts ineffectual. Therefore, mutually agreeable ways among partnering countries to address the challenges must be put in place to ensure continuous safe buying and selling.

Vuppaladadiyam et al. (2024) studied swerving challenges and up-to-date technologies in plastic waste control and highlighted the obstacle of a synergistic approach to solving the problem. They attributed the surge in plastic usage to societal evolution. This trend is poised to maintain its dominance in global solid waste as the energy requirements of plastic production remain low when compared to other alternatives. Agovino et al. (2024) identified a lack of consideration of individual Member States when establishing common targets for plastic waste management in the EU. While some nations excel in environmental awareness and circularity initiatives, others struggle and rely on stronger allies within the bloc. Consequently, until steps are taken to empower these dependent members with the means to manage their waste through re-manufacturing technologies, their inclusion in the circular economy transition remains uncertain.

According to Strat et al. (2018) and Arsova et al. (2022) , Regional CE is the bedrock of efficient global CE. Coordinated national efforts drive international circular economy implementation, necessitating supportive governance frameworks, incentives, innovation, and information sharing to establish a unified sustainability template. However, such regional initiatives are often underreported in the literature. Therefore, to attain regional sustainability benchmarks and sufficiently transition to plastic circularity, concerted efforts must prioritize stakeholder engagement across regions, boost awareness, and economically strengthen vulnerable members to safeguard against ecosystem degradation from poor plastic waste management practices. This collective action is crucial for fostering transborder sustainability.

5.2. Synergy amongst sub-national stakeholders

None of the major contributing countries to global waste have adequately managed the challenge of municipal plastic waste, a burden felt keenly in key cities worldwide, with the United States of America and China leading the pack as primarily global contributors. As plastic production continues to rise globally, Circular Economy and Life-Cycle-Assessment (LCA) are deemed crucial for effective plastic recovery (Schwarz et al., 2021). Moreover, the complexity of human social demographics and attitudes (Rosner., 2022) poses a daunting challenge, exacerbated by socio-economic inequalities that foster indifference among stakeholders in low-income zones.

Surwayan and Lee (2023) conducted a study on citizens' heterogeneous preferences and assessed willingness-to-pay (WTP) within theoretical frameworks of future adaptive Municipal Solid Waste Management (MSWM) retribution. Their findings offer valuable insights. Rather than willingness and sacrificial commitment to sustainability and CE, citizens' responses are predominantly influenced by their capacity and social standing. Reports indicate that full support for such schemes primarily comes from those with means, residing outside slum areas, aged forty and above, and well-informed about climate change and existing MSWM infrastructure. This underscores the necessity for policymakers to look beyond mere enforcement measures to secure the support of those at the lower rungs of the plastic value chain pyramid (Fig. 10). Thus, those tasked with tackling the menace of plastic waste pollution must recognize the impoverished end-users as crucial partners and collaborate closely with them to achieve lasting solutions.

Given the escalating challenge of burgeoning plastic landfills and growing citizen apathy, it is imperative to elevate the involvement of local authorities through impactful campaigns, fostering citizen participation. While some publications underscore the importance of citizen considerations, they predominantly advocate for bans and sanctions as primary solutions to mitigate plastic waste pollution. However, these approaches overlook the pivotal role that plastic product producers can play. Implementing well-publicized reward systems across various media platforms and establishing convenient collection points in major cities for citizens to return used plastic waste could gradually eliminate landfills and pave the way for sustainable practices across all strata of the society.

6. Prospects of plastic waste circularity

After thoroughly reviewing scientific publications on plastic waste management from the past six years and examining their insights into circular economy practices (Evode et al., 2021; Drzyzga and Prieto,

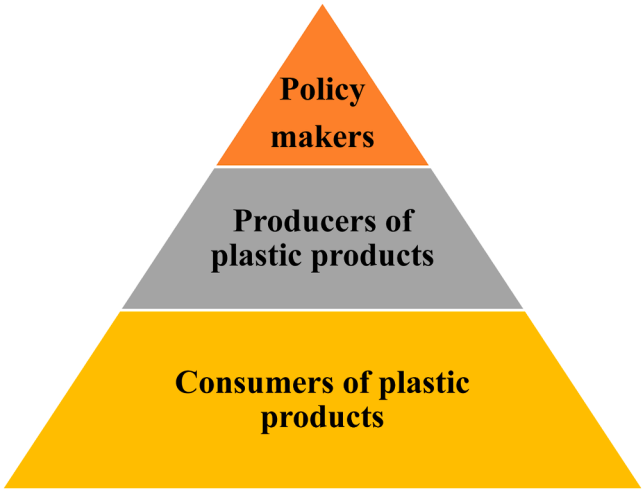


Fig. 10. Plastic value chain pyramid.

2019; Huang et al., 2022), this study established that there is an urgent need for a paradigm shift to meet future expectations. While efforts are underway globally to manage this crisis and engage various stakeholders in achieving a plastic-free environment, the reality persists that these wastes remain a persistent challenge. Hence, it is crucial to question whether major stakeholders in the plastic waste value chain truly recognize effective waste management as essential for their business success. This review sheds light on a strategy that has yet to gain widespread adoption globally. Merely relying on legislation and stringent enforcement of plastic laws may not suffice, and this work proposes an alternative approach.

Despite efforts, achieving a plastic-free world will remain elusive if end-users are solely relied upon to lead the charge (Bharadwaj et al., 2023). While their involvement is pivotal, particularly as the final destination for plastic products, it is the government's responsibility to integrate consumers into the circularity system. Top plastic waste-generating countries like China, the USA, India, Vietnam, and Brazil have invested in and implemented various strategies, but with little success stories (Kumar et al., 2022; Janmaimool et al., 2024). Even bold measures like China's ban on non-biodegradable plastics or Japan's pricing mechanism for plastic bags have faced challenges, demonstrating the enormity of the task (Bourtsalas et al., 2023; Shan et al., 2024). In 2021, South Korea legislated a national action plan on marine litter and contaminated segments to control wastes from plastics and microplastics using eco-friendly methodologies. Not much, however, has been reported on the level of success regarding this long-term goal policy (Han et al., 2024). Interestingly, of the countries dedicated to tackling plastic waste, only the USA appears humane in the approaches, yet has not addressed the challenges adequately.

To chart a new course, therefore, we must look to plastic manufacturers. These stakeholders can complement government efforts in waste management, offering a promising path forward. By fostering synergy among all stakeholders, we can develop a holistic approach that addresses the issue comprehensively, without discrimination. The key lies in incentivizing end-users through a reward system, fostering a sense of patriotism towards environmental stewardship. Plastic manufacturers, already deeply entrenched in the industry, can facilitate waste collection effortlessly. In this collaborative model, enforcing laws governing plastic usage, disposal, and recovery becomes less cumbersome, as manufacturers seamlessly engage with end-users, who are the primary custodians of plastic waste. Consequently, governments can save resources that would otherwise be spent on legal enforcement, focusing instead on establishing collection sites across cities and in close proximity to manufacturing facilities.

7. Conclusion

The fight against plastic waste pollution is still ongoing with the global effectiveness of management strategies under continuous scrutiny. As efforts to combat the widespread issue of single-use plastics intensify, there is a clear shift towards adopting a circular economy model, drawing significant attention from key stakeholders. This review has presented and discussed the critical role of regulatory frameworks in shaping the plastic waste value chain. By examining the interaction between waste management practices and plastic production, the consequence of robust regulations in reducing environmental impact and promoting sustainable solutions within the industry becomes evident. Findings from this study indicate that while bans and penalties contribute to addressing the issue, they are insufficient to resolve the plastic waste crisis. Therefore, a more comprehensive approach to plastic waste management, extending beyond punitive measures, is essential for the success of global circular economy initiatives. This study has emphasized the pivotal role of plastic waste producers in achieving a future free from plastic and microplastic pollution, positioning them as primary influencers and responsible parties, even more so than governments and consumers. Future research efforts in plastic waste circularity could focus on extensive, but systematic review of extended producer responsibility from the stick-and-carrot perspective in order to galvanize all stakeholders, whether regional or continental, towards ensuring plastic-safe ecosystems.

CRediT authorship contribution statement

Rasaq O. Medupin: Writing – original draft, Formal analysis. **Kelvin O. Yoro:** Writing – review & editing, Formal analysis, Conceptualization. **Kingsley Ukoba:** Validation, Data curation. **Orevaoghene Eterigho-Ikelegbe:** Writing – review & editing, Visualization. **Tien-Chien Jen:** Validation, Supervision.

Declaration of competing interest

All authors unanimously declare that there is no conflict of interest in the publication of this manuscript.

Data availability

Data will be made available on request.

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