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Closing the Loop: A Comparative Policy Analysis of China, India, Japan, and Thailand towards Effective Plastic Waste Management and UN SDGs

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Abstract: The issue of plastic waste management has gained significant attention in recent years due to its impact on the environment and human health. In response to this, many countries have formulated policies and strategies to address the issue of plastic waste management, with the aim of achieving the United Nations 2030 Agenda for Sustainable Development Goals (UN SDGs). This paper presents a comparative policy analysis of plastic waste management in four Asian economies: China, India, Japan, and Thailand. These countries, while demonstrating geographical and economic diversity, have implemented varied approaches to tackle the complex challenges of plastic waste management. The analysis focuses on how these nations are operationalizing key frameworks, including the 3R Plus model, Extended Producer Responsibility (EPR), the Circular Economy, and the Bio-Circular-Green (BCG) economic model. The study finds that while all four countries have introduced significant legislation to address plastic pollution such as China's plastic waste import ban and India's evolving EPR framework challenges persist. Key gaps include the limited public and stakeholder understanding of circular economy principles, inadequate infrastructure, and the need for greater upstream intervention. The paper highlights the crucial role of circular economy education in bridging these knowledge and behavioral gaps, empowering all stakeholders from policymakers to the informal waste sector to drive change. By examining the strategies of these nations, the paper concludes that combining robust upstream policies, such as eco-design and single-use plastic products restriction, with effective downstream management and widespread education is essential for creating a sustainable and circular future.

Keywords: plastic waste; 3R (reduce, reuse and recycle); 3R plus renewable and recovery; extended producer responsibility; circular economy; Bio-circular-green economy; circular economy education; UN SDGs

1. Introduction

Urbanization is a rapidly growing global phenomenon, with 55% of the population currently residing in urban areas. This percentage is expected to increase to 68% by 2050, resulting in a surge of approximately 2.5 billion individuals living in urban areas [1]. This rapid expansion intensifies environmental pressures, particularly plastic pollution, through greater resource consumption and waste generation, presenting major obstacles to sustainability, climate resilience, and ecosystem health [2,3]. The majority of plastics are presently manufactured using fossil fuels, which results in the depletion of natural resources throughout the extraction process and results in the release

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of greenhouse gases (GHGs), contributing to climate change [4]. While urbanization undoubtedly leads to cities' economic growth and societal advancement, it simultaneously presents pressing obstacles to the environment and society [5]. It is important to address these challenges to ensure a sustainable future for generations to come.

Plastic has become integral to our daily routine, from grocery bags to cutlery to water bottles. While plastic materials are intricately associated with economic advancement and other socio-economic determinants, mishandling and mismanagement of plastic waste have raised serious concerns. This waste clogs overflowing landfills and waterways, posing a threat to aquatic biodiversity. Shockingly, every year, about 8 million tonnes of plastic waste end up in our oceans [6]. This influx of plastic negatively impacts crucial industries such as tourism, shipping, and fishing, affecting people worldwide. It hampers the achievement of the United Nations Sustainable Development Goals (SDGs), such as SDG 12 (responsible consumption and production) and SDG 14 (conserving oceans) [7], while endangering biodiversity and undermines key industries. The challenges of plastic waste management are compounded by policy gaps, limited infrastructure, low stakeholder engagement including in upstream sectors and a lack of public awareness and circular economy education, and implicitly SDG 4, to ensure inclusive and equitable quality education for all.

Despite increasing policy interventions, the scale of plastic production and waste generation continues to expand at a pace that outstrips current management capacity. Global plastics production more than doubled between 2000 and 2019 to approximately 460 million tonnes per year, while plastic waste generation increased from about 156 million tonnes to 353 million tonnes over the same period [8]. Under business-as-usual scenarios, plastic waste generation is projected to almost triple again by 2060, reaching roughly 1014 million tonnes annually [8]. At present, only about 9% of plastic waste is effectively recycled, with the remaining majority either incinerated, landfilled, or inadequately managed, contributing to widespread environmental leakage [9]. Recent global assessments estimate that approximately 19–23 million tonnes of plastic waste leak into lakes, rivers, and oceans each year, causing significant ecological degradation and increasing risks to human health and biodiversity [9]. Urban regions in rapidly developing economies are identified as major hotspots of plastic leakage due to rapid consumption growth, insufficient collection infrastructure, and limited recycling capacity [8]. Without decisive interventions targeting product design and consumption patterns, plastic waste generation and environmental leakage are projected to continue increasing, placing growing pressure on waste management systems and undermining progress toward circular economy objectives. Despite the scale of the problem outlined above, existing studies largely examine plastic waste management at national or sectoral levels, with limited comparative policy analysis across countries.

While the global imperative to address plastic pollution is clear, national responses vary widely in their scope, implementation, and effectiveness. Existing literature often examines policies in isolation or within similar economic contexts, leaving a critical gap in comparative policy analysis across diverse Asian economies at different stages of development and with distinct governance models. This study provides a policy-oriented comparative analysis of China, India, Japan, and Thailand countries selected for their diversity in development, legislative frameworks, and approaches to plastic waste. By examining how these countries operationalize key concepts such as the 3R Plus model, Extended Producer Responsibility (EPR), the Circular Economy, and the Bio-Circular-Green (BCG) economic model, this paper seeks to identify transferable lessons, persistent challenges, and the critical enabling role of circular economy education.

Increased Plastic Demand and Management Challenges

The plastic demand continues to escalate due to its durability, versatility, and low cost, driving production from 15 million tonnes in 1964 to 311 million tonnes in 2014, with further increases anticipated in the coming decades. [10]. Recent estimates according to the Organization for Economic Co-operation and Development (OECD) global plastic waste generation could surge from 353 million tonnes annually in 2019 to over one billion tonnes by 2060, especially in rapidly urbanizing regions of Asia and Africa [8], including packaging, household goods, healthcare, construction, food chains, energy, and transportation [6].

Plastic is often seen as a cost-effective material, which has led to its widespread and irresponsible use by humans. While its durability is advantageous in many applications, plastic waste that leaks into the environment, particularly marine ecosystems, is a growing concern, especially in urban areas. This 'plastic leakage' results in the accumulation of plastic waste, posing a significant threat to both ecosystems and human health [11]. Plastic waste has been found in all major sea basins, on shorelines, in waterways and lakes, and in land and air habitats. In 2019, it was estimated that 22 million tonnes of plastic waste leaked into the environment, with projections indicating a potential doubling to 44 million tonnes by 2060 [8]. A significant portion of marine plastic pollution originates from land-based activities. The packaging industry is a major consumer of virgin plastics, followed by

the building and automotive industries [12]. The rising consumer demand for plastics across economic sectors is a primary driver of unmanaged plastic waste. For instance, it is estimated that one million plastic bottles are purchased every minute globally, and up to five trillion plastic bags are used annually [1]. Figure 1 enables a direct comparison of plastic demand across the selected countries and highlights clear inter-country differences, thereby strengthening the discussion on increased plastic demand in a regional context.

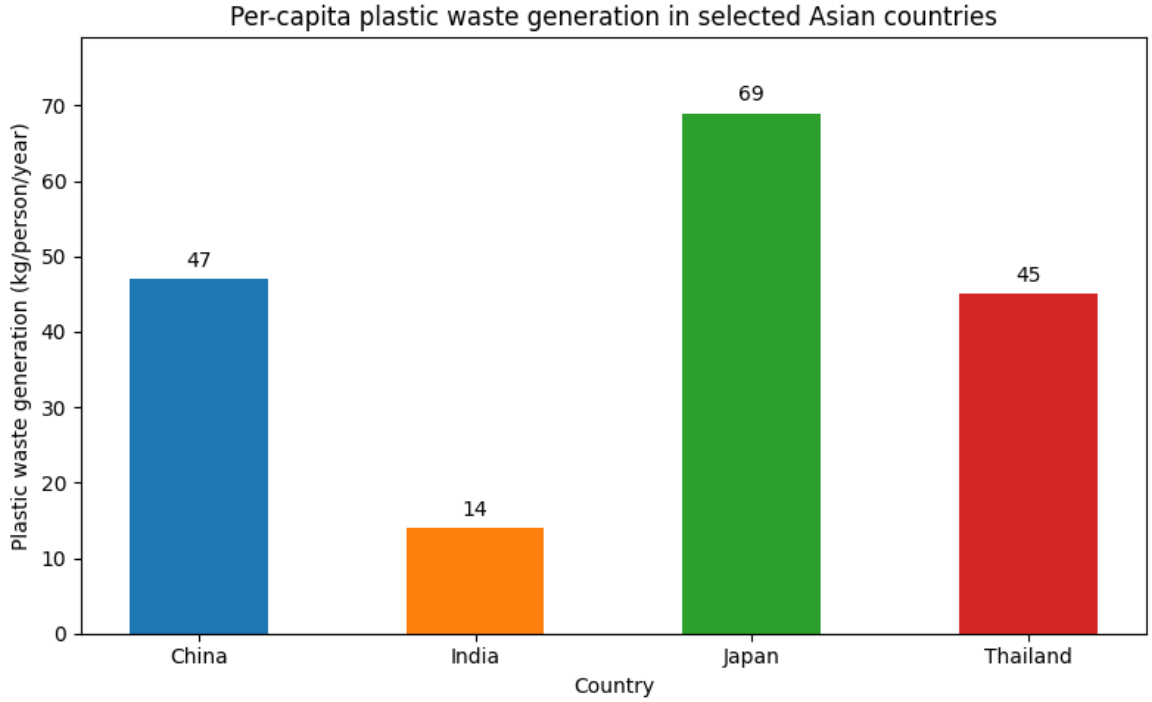

Figure 1. Comparison of per-capita plastic waste generation in selected Asian countries. Values represent plastic waste generated per person per year and are used as a proxy for plastic demand [8].

Plastic waste poses risks to both human health and the environment. A significant amount of plastic waste that enters the ecosystem does not break down easily and instead breaks up into smaller pieces called microplastics, which can be less than 5mm in diameter and even become nanoplastics [13]. This makes it more likely that humans and the environment will be exposed to plastic particles, posing a serious risk. When plastic items are exposed to beach weathering, the plastic becomes brittle and microcracks can develop, releasing small particles that can be carried by the wind or waves into the ocean [14]. Furthermore, producing plastic feedstock requires a lot of energy and GHG emissions. Additionally, managing plastic waste also requires energy and produces direct emissions. Plastic pollution is driven by multiple challenges, including inefficient resource use due to the linear economy, rising GHG emissions, and plastic pollution from improper waste management practices.

2. Conceptual Framework and Theoretical Approach

This study applies to an integrated conceptual framework to analyze plastic waste management, drawing on circular economy principles, the 3R Plus approach, EPR, BCG economic model, and circular economy education as shown in Figure 2. Collectively, these pillars form a foundation for transitioning from traditional linear models toward sustainable resource cycles, which is essential for achieving the UN (SDGs, especially in the context of China, India, Japan, and Thailand. The linear economy, characterized by a ‘take-make-dispose’ approach, is fundamentally unsustainable and contributes to resource depletion and waste accumulation. In contrast, the circular economy offers a regenerative alternative, emphasizing waste and pollution elimination, continuous product and material circulation, and natural ecosystem regeneration [15]. This approach underpins systemic change across product life cycles, fosters eco-innovation, and supports climate and biodiversity targets.

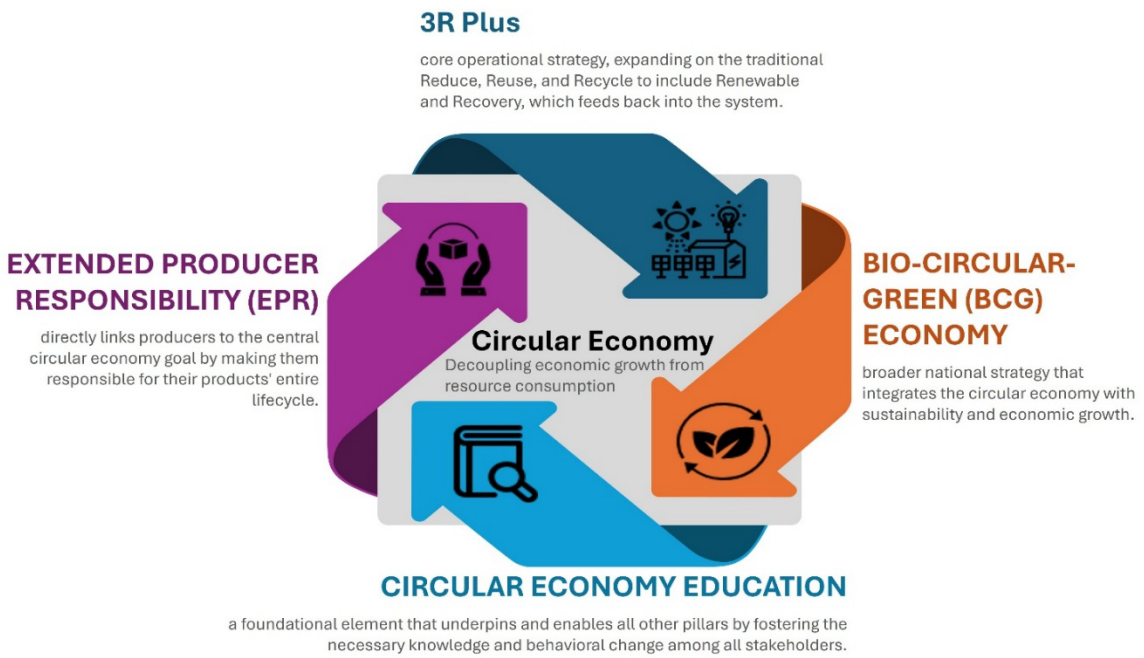

Figure 2. Conceptual framework of circular economy and enabling mechanisms (Created by authors).

2.1. 3R (Reduce, Reuse, and Recycle)

The 3R framework, Reduce, Reuse, and Recycle represents a foundational approach to sustainable waste management and resource conservation. In 1967, the Basic Act for Environmental Pollution Control was passed, which made it mandatory for individuals to prevent and reduce pollution and waste [16]. Over time, the 3R concept has evolved as a response to the growing awareness of environmental issues and the need to address waste management and resource conservation. Priority is given first to reducing material consumption and waste at the source, followed by reusing products or their parts, and ultimately recycling materials into new products. Recovery of value beyond these stages further complements the approach [17].

Effective implementation of 3R programmes depends fundamentally on public awareness and education, shaping attitudes and behaviors essential for success. Reduction strategies conserve energy and resources while mitigating pollutant emissions, offering significant environmental benefits. For instance, repurposing plastic materials reduces demand for virgin plastics, lowering raw material use and associated greenhouse gas emissions [18]. Moreover, recycling initiatives reduce reliance on fossil-based feedstocks and help limit contaminant accumulation in ecosystems, as plastics can absorb persistent organic pollutants and heavy metals throughout their life cycle and present in the environment [19,20]. This 3R approach also supports chemical safety by minimizing hazardous waste generation and promoting environmentally sound disposal. Beyond environmental protection, this encourages individuals, businesses, and communities to reduce, reuse, and recycle resources, promoting responsible consumption and production, safeguarding the environment, and stimulating the economy [21].

2.2. 3R Plus 'Renewable and Recovery'—Expanding the Paradigm

Building on the traditional 3R principles, the "3R Plus" philosophy advocates for the utilization of renewable resources and the recovery of materials, focusing on reducing the accumulation of plastic waste in the environment, promoting reuse and recycling, and transitioning towards using sustainable resources [22]. It is essential to consider the conventional 3R principles and the concept of the 3R Plus principle, especially concerning plastic waste. The 'Renewable' aspect encourages substituting fossil-derived plastics with bio-based alternatives, emphasizing the use of sustainable resources that can replenish natural capital. The 'Recovery' component encompasses two facets: recovering materials from waste streams and reclaiming energy through thermal or biochemical processes. In particular, recovering energy from plastic waste contributes to decreasing fossil fuel consumption but requires careful management to avoid emissions trade-offs [23,24].

Mechanical recycling is the process of transforming waste plastic into new plastic goods using physical methods, which is only practical when dealing with a waste stream that is uniform in composition and may not be proper because of separation techniques of different types of plastic waste [25]. From a renewability standpoint, the recovery and reuse of heat and the retrieval of marine plastics are critical in mitigating GHG emissions,

enhancing the efficient utilization of non-renewable fossil resources, and preventing the detrimental effects of microplastics on marine ecosystems. The use of renewable materials is also crucial in enhancing resource circulation. This entails reducing single-use plastic products through various strategies, such as halting their distribution, using products made of alternative materials, and improving customer service to discourage usage. However, building renewable energy production facilities, technologies, and supporting infrastructures requires substantial amounts of critical raw materials, composites, plastics, metals, and concrete, making them resource intensive. Thus, it is crucial to rebuild current systems and technologies for resource circulation and waste management to achieve a decarbonized society.

2.3. Extended Producer Responsibility (EPR)—Shifting the Burden Upstream

EPR is defined as an environmental policy that requires producers to take responsibility for their products beyond the point of sale and to manage them throughout their lifecycle [26] (OECD, 2001). Grounded in the polluter-pays principle, EPR incentivizes producers to incorporate environmental costs into product design and to develop systems for collection, recycling, and safe disposal [27]. EPR mechanisms empower producers to innovate eco-friendly products with improved recyclability and durability, fostering eco-design. This also facilitate coordinated waste collection infrastructures, standardization (e.g., labelling), and create market incentives for recycling through deposit-refund schemes or quota systems [28,29]. Through internalizing external costs, EPR reduces negative environmental impacts and promotes a circular economy by closing the product lifecycle loop [30]. By recycling plastic packaging, it is possible to reduce the environmental impact [27] of waste management.

2.4. Circular Economy—Beyond Linear Constraints

The concept of a circular economy differs greatly from that of a linear economy. In a linear economy, raw materials are extracted, processed, and turned into goods that are eventually thrown away once they've served their purpose. This process is unidirectional, from extraction to disposal. However, in a circular economy [15], emphasizes designing out waste, maintaining products and materials at highest utility, and regenerating natural systems. All the raw material cycles are closed, which requires a more comprehensive approach than just recycling [31]. It seeks to decouple economic growth from resource extraction and environmental degradation, advancing resilient and sustainable economies. Reike et al. [32] presented a waste hierarchy that ranges from 3R (Reduce, Reuse, and Recycle) to 10R (Refuse, Reduce, Resell/Reuse, Repair, Refurbish, Remanufacture, Re-purpose, Recycle, Recover energy, Re-mine) and beyond 12R. This hierarchy is used to map circular economies, including "produce and use" and "design and life cycle".

This framework is based on three principles centered around design: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature. This system requires thinking about reducing the unnecessary use of materials, rethinking design at the initial stage [33]. By halting the depletion of natural resources, minimizing environmental harm caused by new material extraction and use, and reducing pollution throughout the entire lifecycle of materials from production, consumption, and disposal, the circular economy [34,35] can make significant contributions to achieving sustainable development. discussed how integrating the circular economy with resource decoupling helps to make products reusable and move towards energy efficiency, with the involvement of environmental development strategies [36].

The circular economy has the lowest environmental footprint and the most efficient use of natural resources and aims to minimize the disposal of materials at the end of their life cycle [37]. This is achieved by prioritizing the efficient use of resources and waste prevention, especially in the manufacturing industry. The circular economy involves effective and efficient recycling to mitigate the negative effects of plastic waste [38]. The circular economy promotes sustainable consumption and production patterns through digitalization and Industry 4.0, facilitating resource efficiency [39,40]. A circular economy minimizes material and energy flows by using eco-effectiveness and retaining previously wasted materials as resources. Shanker et al., [41] also emphasized that using multi-sensor-based artificial intelligence and blockchain technology can effectively segregate and recycle plastic waste in a more environmentally friendly manner [42].

2.5. Bio-Circular-Green Economy (BCG Economy)—An integrated Sustainability Model

The Bio-Circular-Green (BCG) Economy framework synergizes three interlinked domains Bioeconomy, Circular Economy, and Green Economy to promote inclusive, resilient, and sustainable development [43]. BCG Economy uses science, innovation, and technology to encourage the effective utilization of resources, preservation and restoration of ecosystems, and waste reduction. This model aims to establish a conducive environment for the growth of both government and corporate sectors, while preserving social equity, the environment, and

sustainability, and promoting economic growth. It is a strategy that combines ideas from the bioeconomy, green economy, and circular economy. The priorities of the BCG economy model include utilizing sustainable resources, reducing waste and pollution, and creating goods and services with added value. With the advancement of science, technology, and innovation, this model is for future economic growth, increasing competition, and producing more income for nations.

The BCG economy model focuses on three main principles: Bioeconomy, Circular Economy, and Green Economy. The bioeconomy promotes the sustainable use of biological resources such as plants, crops, and forests, while preserving biodiversity and promoting the development of bio-based goods, bioenergy, and biomaterials. The circular economy aims to create a closed-loop system with minimal waste by producing durable, repairable, and recyclable products and by promoting the cooperative use of resources. The green economy prioritizes minimizing adverse effects on the environment, increasing resource efficiency, and combating climate change by implementing sustainable technologies and eco-friendly practices in various industries. The BCG model facilitates business in industries by employing cutting-edge technology and innovation [44] to the maximum extent feasible.

2.6. Circular Economy Education—The Enabling Catalyst

Education is pivotal in embedding circular economy principles across society, fostering the skills, knowledge, and mindsets necessary for sustainable development. It serves as a key enabler, empowering stakeholders from policymakers and businesses to communities and individuals to understand and implement sustainable resource management practices. By integrating circularity concepts into curricula, professional training, and public awareness programs supports innovation and collective action, bridging knowledge gaps, and fostering a culture of stewardship and responsibility [45]. A robust and integrated plastic waste management policy must combine upstream measures (3R Plus, EPR, BCG), systemic design changes (circular economy), and transformative education (circular economy literacy) to achieve the UN SDGs and secure long-term environmental and social well-being. By cultivating environmental stewardship, systems thinking, and innovation culture, circular economy education bridges technology and behavioral gaps, empowering informed decision-making and collaborative action essential for closing resource loops and minimizing plastic pollution [46].

3. Methodology

This study employs a multi-faceted comparative approach to assess plastic waste management policies, strategies, and legislation in four nations: China, India, Japan, and Thailand. The selection of these countries was advantageous due to their unique circumstances. China is one of the earliest countries that issued policies in combating plastic pollution and was the largest nation that imported plastic waste before 2017. Japan, despite having modern waste management systems and regulations in place, is located in a region susceptible to marine pollution, and plastic garbage can cause severe environmental damage, affecting marine life. India faces a significant challenge of plastic waste due to insufficient infrastructure for waste management and inappropriate disposal practices, leading to the pollution of rivers and oceans and adversely affecting water quality. Similarly, Thailand is experiencing problems related to the accumulation of plastic waste in aquatic ecosystems. Both India and Thailand are rapidly urbanizing and industrializing, and plastic pollution can have detrimental effects on the environment and social well-being. As a developed country, Japan is responsible for setting an example and establishing a model for a responsible waste management system. Its efforts to reduce plastic waste contribute to global efforts to combat plastic pollution.

The methodology integrates qualitative policy analysis and comparative evaluation of national policy instruments. This assessment is centered on the principles of the 3R Plus, EPR, circular economy implementation, and the BCG economic model. This comprehensive lens allows assessment of how each country adapts and operationalizes these concepts to mitigate plastic waste and align with UN SDGs. The primary data sources include official government reports, enacted legislation, and policy roadmaps, supplemented by regional studies and technical assessments such as UNCRD [47] and national implementation documents. For instance, the study references China's response to the 2017 import ban, Japan's legislative efforts in plastic recycling, India's evolving EPR frameworks, and Thailand's roadmap for plastic waste control. A critical component of the methodology is the exploration of circular economy education across these nations. The study investigates the extent to which educational and capacity-building initiatives inform stakeholders ranging from policymakers and industrial actors to local authorities and the public, thus fostering sustainable behavioral change and reinforcing policy effectiveness. This emphasis recognizes that embedding circular economy literacy into diverse learning settings is indispensable for achieving sustained improvements in plastic waste governance and moving toward the SDGs related to responsible consumption, production, and environmental conservation.

4. Case Studies

This section provides an in-depth analysis of the plastic waste management strategies in China, India, Japan, and Thailand, highlighting their distinct policy approaches and key developments.

4.1. Case of China

China has established a comprehensive, multi-ministry system to combat plastic pollution, led by the National Development and Reform Commission (NDRC) and the Ministry of Ecology and Environment (MEE). The revised Law on the Prevention and Control of Environmental Pollution of Solid Waste (2020) prohibits or restricts the production and use of certain non-degradable single-use plastics and promotes reusable and easily recyclable and degradable alternative products [48]. This is complemented by a series of action plans, including the Guideline for further strengthening the control of plastic pollution [49], and the 14th Five-Year Plan of Action for Plastic Pollution Control [50] were enacted in 2020 and 2021 separately, which set targets for reducing certain plastic products, accelerating recycling, and conducting waste clean-up campaigns [51]. Nine specific types of plastic products, such as ultra-thin plastic shopping bags with a thickness of less than 0.025 mm, single-use plastic cotton swabs, single-use foamed plastic cutlery, etc., are banned from products and use [52]. A key policy shift was China's 2018 ban on importing plastic waste, which fundamentally reshaped the global waste trade and spurred the development of its domestic recycling infrastructure. Since 2008, the collection and transportation of municipal solid waste in China have increased year by year; up to the end of 2024, the municipal solid waste environmentally sound treatment rate reached 99.99%, and treatment capacity reached 1.17 million tons/d, among which waste-to energy capacity accounts for 78.09% [53].

China also establishes different specific regulations and standards in different sectors such as Measures for the Management of Agricultural Films (2020) establish a supervisory system covering agricultural film production, sale, use, and recycling [54]. Measures for the Management of Recycling and Treatment of Pesticide Packaging Waste (2020) establish a pesticide packaging waste recycling system and encourage and support the resource utilization and environmentally sound disposal of pesticide packaging waste [55]. Measures for the Administration of Mail Express Packaging (2021) strengthen the management of green packaging of Mail Express and standardize the packaging behaviour of Mail Express [56]. In addition, tens of standards covering national, provincial, and association levels are also issued. This holistic approach, encompassing a robust legal framework, a comprehensive import ban, and targeted sectoral policies, showcases a "whole-chain management" system that has positioned China as a leader in domestic plastic pollution control. While acknowledging the need for a global agreement, China has emphasized the need to tackling plastic pollution not plastic itself.

4.2. Case of India

India has progressively evolved its plastic waste management framework, moving from general municipal solid waste rules to a comprehensive system centered on Extended Producer Responsibility (EPR). The Plastic Waste Management Rules, 2016 first introduced the concept of EPR, holding producers, importers, and brand owners (PIBOs) financially and physically responsible for managing post-consumer plastic waste. Subsequent amendments in 2018, 2021, and 2022 have further strengthened these rules by banning specific single-use plastic items and setting mandatory EPR targets for plastic packaging [57–59]. A key development is the Central Pollution Control Board's (CPCB) online centralized EPR portal, which enhances transparency, traceability, and accountability. The portal allows producers, importers, and brand owners (PIBOs) and plastic waste processors (PWPs) to register, issue certificates for waste collection, and manage their EPR obligations. This digital system helps monitor compliance and holds stakeholders accountable through the "polluter-pays" principle, imposing environmental compensation for non-compliance in accordance with the "Guidelines on Extended Producer Responsibility for Plastic Packaging" [60].

The effectiveness of the Plastic Waste Management Rules as a remedy to hold producers accountable and formalize the plastic waste management system has been examined [61], and the highest priority from both an environmental and economic perspective has been analysed. The most significant impact of plastic waste has been identified, and countermeasures such as implementing an EPR policy, incentivizing recycling businesses, and promoting the use of bioplastics [62]. The Plastic Waste Management (Amendment) Rules, 2025, represent the latest update, effective from 1 July 2025. This amendment mandates that producers, importers, or brand owners provide specific product information on their plastic packaging, such as via a barcode or QR code. The CPCB will maintain a quarterly updated list of compliant companies, further streamline the system and encourage responsible practices [63]. India's policies reflect a clear shift toward formalizing the plastic waste management system and actively engaging producers in the circular economy. A key voice in the Plastics Treaty negotiations, advocating

for a "polluter-pays" principle that holds nations responsible for their plastic consumption and waste exports. India has also called for a strong emphasis on waste management and recycling, arguing that these are more pressing issues for nations than limiting primary plastic production.

4.3. Case of Japan

Japan's approach is defined by a mature regulatory framework and a focus on the 3R Plus concept, which expands the traditional "Reduce, Reuse, Recycle" model to include "Renewable" and "Recovery." The "Fundamental Law for Establishing a Sound Material-Cycle Society" (2001) and the "Containers and Packaging Recycling Act" (1995) provided the early foundation for its waste management system [16]. However, recognizing the limitations of these policies, the government introduced the "Resource Circulation Strategy for Plastics" (2019) to promote a life-cycle approach. "The Plastic Resource Circulation Act" [64] outlines a range of strategic approaches, including minimizing waste generation, reclaiming reusable resources, utilizing biodegradable materials, initiating marine waste management, promoting global advancement, and improving infrastructure. The first milestone of the policy aims to reduce single-use plastics by 25% through aggregation by 2030. The second milestone seeks to achieve 100% effectiveness by reusing and recycling all plastic waste by 2035. The third milestone focuses on the recycling and utilization of biobased plastics, with the goal of doubling the amount of recycled content by 2030 [65].

The "3R Plus" philosophy is central to Japan's strategy. "Renewable" promotes the use of bio-based plastics, while "Recovery" emphasizes material and thermal energy recovery, along with the retrieval of marine plastics. Sakai [22] discussed the three main lessons from the 3R policy: reducing waste generation, biological circulation treatment, and carbon-neutral heat recovery. 3R Plus is essential to consider when it comes to renewability, heat recovery, and the recovery of marine plastics. Japan's commitment to combating marine plastic pollution is evident in its "Marine Plastic Litter Implementation Action Plan" (2019) [66] which focuses on preventing illegal dumping and fostering international cooperation. Japan's policies showcase a move towards a zero-waste and carbon-neutral society by integrating technological innovation with clear, actionable policy targets. Despite this advanced policy framework and a highly diligent public, Japan's plastic recycling rates face significant challenges. recycling rate of over 85% is a deceptively high figure, as it includes "thermal recycling," which is the incineration of plastic for energy recovery rather than its re-materialization [67]. In fact, only about 20% of Japan's collected plastic waste is actually recycled into new products. This stagnation can be assessed through the framework of a "circularity gap," where the volume of new plastic production continues to outpace the capacity for material recycling. Japan advocates for a comprehensive instrument that addresses the entire plastic lifecycle, from production to disposal. It emphasizes the need for international cooperation, knowledge sharing, and technology transfer to help other nations improve their waste management systems.

4.4. Case of Thailand

Thailand's plastic waste management strategy is guided by its overarching Bio-Circular-Green (BCG) economic model. The "Thailand's Roadmap on Plastic Waste Management" (2018–2030) sets an ambitious target of recycling 100% of plastic waste by 2027 [68]. The roadmap is structured in two phases, with the first (2020–2022) focuses on changing consumer behaviour to reduce and stop using single-use plastics, such as plastic cap seals for drinking water bottles and microbeads used in cosmetics. The campaign to reduce single-use plastics, including thin plastic bags, polystyrene foam food containers, soft plastic cups, and plastic straws, has been successful in department stores, supermarkets, and convenience stores. The second phase, which runs from 2023 to 2027, focuses on the product life cycle approach in preventing plastic waste. This phase aims to promote eco-design and sustainable consumption, and to segregate solid waste according to the final disposal. It also introduces EPR measures for plastic packaging management, which aim to minimize the final disposal and maximize material and energy recovery. The critical measures in this phase include: (i) producing plastic in an environmentally friendly way; (ii) reducing plastic waste during the consumption process; (iii) managing post-consumer plastic waste; and (iv) managing marine plastic waste.

From 2023 to 2024, importing plastic scrap from abroad will be strictly prohibited in both free zones and general areas, with plans to ban it entirely by January 1, 2025. During the two-year interim period, it is important to focus on developing a sufficient supply of domestic plastic scrap in terms of both quality and quantity to meet the needs of industrial sectors. The holistic policy planning is essential, and understanding the effects of national roadmaps on plastic waste flows can be achieved through material flow analysis [69]. Wichaiutcha et al. [70] emphasized the importance of effective infrastructure for plastic waste collection and sorting for recycling, which benefits the circulation of material and results in reduced energy consumption and carbon footprint.

The Bioeconomy leverages biological resources, the Circular Economy promotes closed-loop systems, and the Green Economy focuses on resource efficiency and climate change mitigation. This model includes infrastructure development in the Eastern Economic Corridor (EEC) and industrial upgrading policies under the banner of Thailand 4.0. Thailand 4.0 is a long-term national initiative [71] that aims to promote innovation-driven growth to escape the middle-income trap. The BCG economy model aims to build a production and consumption system with less environmental impact by promoting agriculture and biotechnology-related industries, encouraging recycling, and introducing renewable energy. A comparative review study by [72] showed the importance of the BCG economy model in creating innovation that drives the economy in a future environment and has the capacity to push forward regional, local, and global goals. The BCG economy model also helps to build international coordination and understanding. Thailand's stance reflects its commitment to building its domestic recycling infrastructure and transitioning to a circular economy, viewing the agreement as a mechanism to secure international support for its national goals. It has pushed for provisions that enable better access to sustainable technologies and promote private sector investment in the circular economy [9].

5. Results and Discussion

This section presents the results of a comparative analysis of plastic waste management policies in four nations: China, India, Japan, and Thailand. The analysis reveals that the 3R Plus principles (renewable resources and recovery) and EPR policies are crucial in reducing waste and mitigating the environmental impact of products throughout their lifecycle in these diverse contexts. These two frameworks are not just complementary but mutually reinforcing: EPR makes producers financially and logistically accountable for their products' full lifecycle, which in turn incentivizes them to adopt 3R Plus principles, designing for durability, promoting reuse, and improving recyclability. Table 1 summarizes the comparative overview of the core policies and frameworks of plastic waste management. The circular economy model, a key framework for sustainable development, aims to integrate the three pillars of sustainability, economic, environmental, and social, through the recovery of energy and materials from waste, the design of durable products, and the extension of product lifespans [73]. Within the context, national EPR can be viewed as a policy tool that facilitates the transition to a circular economy. By assigning responsibility to producers, EPR encourages them to integrate sustainable design practices from the outset, thus extending product lifespans and maximizing resource utility. This fosters a shared responsibility among all stakeholders and aligns with the core goals of the circular economy: waste elimination and resource circulation.

Table 1. Comparative overview of plastic waste management policies (created by authors).

Policy Area	China	India	Japan	Thailand
Core Framework	National whole-chain management, Import Ban	Evolving EPR Framework	3R Plus + Material-Cycle Society	Bio-Circular-Green (BCG) Economy Model
Key Legislation	Law on Prevention & Control of Solid Waste (2020), 14th Five-Year Plan	Plastic Waste Management Rules (2016), EPR Guidelines (2022, 2025)	Fundamental Law for Material-Cycle Society (2001), Plastic Resource Circulation Act (2021)	Plastic Waste Management Roadmap (2018–2030)
Upstream Measures	Import ban on plastic waste, sectoral regulations (e.g., agriculture, express mail)	EPR for plastic packaging, bans on single-use plastics	3R Plus (Renewable, Recovery), eco-design, mandatory plastic bag fees	Phased ban on plastic scrap imports, promotion of bio-based products
Downstream Measures	Standardized recycling, high waste-to-energy capacity	Online EPR portal, formalizing the informal sector	Advanced recycling and waste-to-energy technologies	National recycling target (100% by 2027), marine waste management
Education & Awareness	Gap in local understanding of circular principles, need for targeted initiatives	Focus on empowering informal sector, community-driven initiatives	High public awareness, shift toward promoting systemic circularity	Tailored education for industries and coastal communities

The findings show that while the four nations share a similar theoretical foundation, their implementation varies. India, for instance, has a well-established EPR framework that mandates producers to collect and manage multilayered plastic waste and enabling local municipal authorities to establish EPR mechanisms for plastic waste management [74]. In contrast, Thailand is still in the early stages of developing its EPR system, with organizations like the Thailand Institute of Packaging and Recycling Management for a Sustainable Environment (TIPMSE) focusing on capacity building and data management for recycled packaging information [75]. Despite these differences, a common challenge is integrating into the informal recycling sector, which, while processing a significant amount of waste, can also contribute to plastic leakage [76,77]. However, the analysis confirms that a well-designed national EPR system, supported by robust legislation and clear responsibilities for all parties, can mitigate these risks. This, in turn, supports the development of effective packaging collection systems and incentivizes producers to design products that are compatible with circular economy principles [78]. By

formalizing the recycling chain, EPR helps to reduce single-use plastic waste, improve collection efficiency, and create a market for recycled materials [79].

Moreover, the findings indicate that EPR is crucial for facilitating the transition to a BCG economy, particularly in Thailand. The BCG model integrates the bioeconomy (sustainable use of biological resources), circular economy (closed-loop systems), and green economy (resource efficiency) to promote sustainable development. EPR supports this model by encouraging the use of renewable and biodegradable materials, which are central to the bioeconomy pillar. The interconnectedness of these frameworks, EPR, 3R Plus, and BCG, is evident across all four countries, demonstrating a collective effort to advance toward the UN SDGs related to sustainable consumption, production, and environmental conservation, as illustrated in Figure 3.

Figure 3. Interconnected relationship between 3R Plus, BCG and Circular Economy to achieve UN SDGs. (Created by authors).

While all four countries have introduced policy measures to address plastic pollution, their approaches reflect distinct governance priorities and implementation pathways. China's policy framework is characterized by strong upstream regulatory controls and centralized enforcement, enabling relatively rapid policy implementation, although with limited flexibility at the local level. In contrast, India's approach places greater emphasis on EPR and market-based mechanisms, which enhance stakeholder accountability but remain constrained by enforcement capacity and the scale of the informal waste sector. Japan prioritizes downstream efficiency through the 3R Plus framework and well-established waste management systems. However, the continued reliance on thermal recovery highlights a trade-off between operational efficiency and material circularity. Thailand's BCG economy model represents a more integrative strategy that aligns environmental objectives with industrial development, although its effectiveness depends on scaling domestic recycling capacity and sustained private-sector participation. Taken together, these differences indicate that effective plastic waste governance is highly context dependent and requires tailored combinations of regulatory, economic, and institutional instruments rather than reliance on a single universal policy model. For instance, EPR schemes (as in India) are more effective when coupled with upstream design standards (as promoted in Japan's 3R Plus) and supported by broad stakeholder education. Furthermore, each

country's policy trajectory is significantly influenced by its position in the global waste trade, as seen in China's and Thailand's import bans, which were upstream interventions with profound domestic and international repercussions.

6. Role of Circular Economy Education in Shaping Plastic Waste Management Policies and Strategies

The success of effective plastic waste management policies and circular economy strategies in China, India, Japan, and Thailand hinge on robust legislative frameworks and a well-informed and actively engaged network of stakeholders across these nations. Circular economy education plays a pivotal role in equipping policymakers, industries, local authorities, and the general public in each nation with the essential knowledge, skills, and mindset to support sustainable waste management practices and promote resource efficiency, to tackle plastic pollution [40,80], thereby contributing to the achievement of the UN SDGs.

6.1. China: Bridging the Policy-to-Practice Gap

Despite the China's proactive approach to formulating policies to reduce plastic waste, a notable gap persists in stakeholder understanding of circular economy principles. This is particularly evident at local governance levels and among small and medium-sized enterprises (SMEs). Targeted educational initiatives that emphasize life cycle thinking and resource recovery are crucial to bridge this gap, ensuring that national policies are effectively translated into practical actions at the grassroots level throughout China [81]. For instance, integrating circular design principles into educational curricula can promote modular designs that facilitate reuse and repair, reducing waste streams. Public awareness campaigns focusing on sorting recyclables and understanding environmental impacts can further enhance compliance with waste management regulations in urban and rural areas [82].

6.2. India: Empowering the Informal Sector

India faces distinct challenges due to its large informal waste sector and infrastructural limitations. In this context, circular economy education can empower local communities and informal waste workers by introducing innovative waste management practices and demonstrating resource recovery's economic and environmental value [83]. Furthermore, integrating circular economy principles into formal education curricula at all levels can cultivate a generation of environmentally conscious citizens in India, equipped to advocate for and implement sustainable policies and business practices [84]. For example, India's National Circular Economy Roadmap emphasizes the importance of community-driven initiatives to reduce single-use plastics and improve recycling rates. These efforts can be complemented by technical training programmes for informal workers to enhance their waste segregation and recycling efficiency [85,86].

6.3. Japan: Innovating on an Advanced Foundation

Japan, a nation recognized for its advanced waste management systems, can leverage circular economy education to further strengthen existing frameworks and drive innovation. While Japan has demonstrated leadership in recycling and waste-to-energy technologies, education can facilitate a transition from traditional waste management approaches to more holistic circular strategies. This includes promoting designing for recyclability, reducing material use, and extending product longevity. By embedding these concepts in professional training programmes and public awareness campaigns, Japan can enhance its role as a global leader in sustainable resource management [87].

6.4. Thailand: Fostering Domestic Circularity

As Thailand is rapidly industrializing, urbanization has intensified plastic pollution challenges, particularly in aquatic ecosystems. In this context, circular economy education, tailored to the specific needs of industries, municipalities, and coastal communities, can play a vital role in mitigating these adverse impacts. For instance, a temporary ban on plastic scrap imports underscores the need for domestic recycling capacity development through targeted educational initiatives for local industries [88]. By promoting sustainable production and consumption patterns and highlighting the economic opportunities associated with circular economy models, education can foster collaboration among stakeholders to effectively address plastic waste challenges [89].

Across all four nations, China, India, Japan, and Thailand, circular economy education serves as a catalyst for behavioral change, policy alignment, and innovative thinking. It cultivates a shared understanding of the interconnectedness of environmental, economic, and social systems, empowering stakeholders to collaborate effectively towards shared sustainability goals. This educational component is essential for achieving the UN SDGs, notably SDG 4 (Quality education for all), SDG 12 (Responsible Consumption and Production), SDG 13

(Climate Action), and SDG 14 (Life below Water). Table 2 directly connects the policies of the four nations to the relevant UN SDGs, providing a clear and compelling summary of their global impact. Integrating circular economy education into formal systems such as schools, professional training programmes, and informal channels like community workshops ensures widespread adoption of sustainable practices [90]. Furthermore, by empowering stakeholders with the necessary knowledge and tools, these nations can foster a circular economy that reduces plastic waste and contributes to a cleaner, healthier environment for future generations.

Table 2. Linking plastic waste management policies to the UN SDGs (created by authors).

UN SDG	Key Targets Related to Plastic Pollution	How the Studied Nations' Policies Align
SDG 4: Quality Education	4.7: Ensure all learners acquire the knowledge and skills needed to promote sustainable development.	Policies in all four nations emphasize circular economy education to bridge knowledge gaps and foster behavioral change.
SDG 12: Responsible Consumption and Production	12.5: Substantially reduce waste generation through prevention, reduction, recycling and reuse.	The 3R Plus, EPR, and BCG frameworks directly target waste reduction and resource circulation throughout the plastic lifecycle.
SDG 13: Climate Action	13.2: Integrate climate change measures into national policies, strategies, and planning.	Upstream measures like reducing virgin plastic production and promoting renewables (3R Plus) directly cut GHG emissions linked to plastic manufacturing.
SDG 14: Life Below Water	14.1: By 2025, prevent and significantly reduce marine pollution of all kinds.	National marine plastic litter action plans (e.g., Japan), waste import bans (China, Thailand), and improved waste management systems directly reduce plastic leakage into oceans.

7. The Role of Upstream Measures in Ending the Plastic Pollution Crisis

A truly long-term solution to the global plastic pollution crisis cannot be achieved through downstream measures like recycling alone. While critical, recycling and waste management systems are burdened by the ever-increasing volume and complexity of plastic products [91]. To make a lasting impact, policymakers must prioritize upstream measures, interventions that prevent plastic from becoming waste in the first place by influencing product design, production, and consumption [92]. This approach eases the pressure on waste management infrastructure and has significant economic benefits, including driving innovation, creating new jobs in the reuse and repair sectors, and reducing the high societal costs of plastic pollution.

Upstream measures offer a more systemic and economically sound pathway to a circular economy. Tackle directly the root causes of plastic pollution: the design of non-recyclable products, the prevalence of single-use models, and unsound management of plastic waste. upstream interventions ease the pressure on waste management infrastructure, which often struggles to keep pace with demand. A study by [77] highlighted that even with a massive scale-up of recycling, we can't recycle our way out of the crisis. Upstream solutions, such as restricting unnecessary plastic products and promoting reuse, are projected to be far more effective at curbing plastic leakage [80]. Moreover, these measures can have significant economic benefits by driving innovation, creating new jobs in the reuse and repair sectors, and reducing the high societal costs associated with plastic pollution, such as cleanup and public health impacts.

The case studies of China, India, Japan, and Thailand demonstrate a growing recognition of upstream measures as a core component of their strategies. China's landmark 2018 ban on plastic waste imports was a powerful upstream policy that forced the nation to address its domestic waste streams and invest in its own circular economy, rather than relying on other countries for disposal. India's evolving EPR framework is increasingly focused on upstream accountability, with regulations requiring producers to take responsibility for packaging from the design stage onward, promoting the use of mono-materials and recycled content. By promoting bio-based plastics and energy recovery, Japan is actively decoupling its economy from fossil-fuel-based plastic production. Similarly, Thailand's phased ban on plastic scrap imports and its overarching BCG economic model are strategic upstream policies designed to build a self-sufficient domestic circular economy. The plastic waste management alternatives and options are now presented graphically as a qualitative heatmap matrix Figure 4, comparing the management strategies adopted in China, India, Japan, and Thailand. This visualization highlights relative differences in policy emphasis and dominant treatment pathways across countries, thereby enhancing the clarity and value.

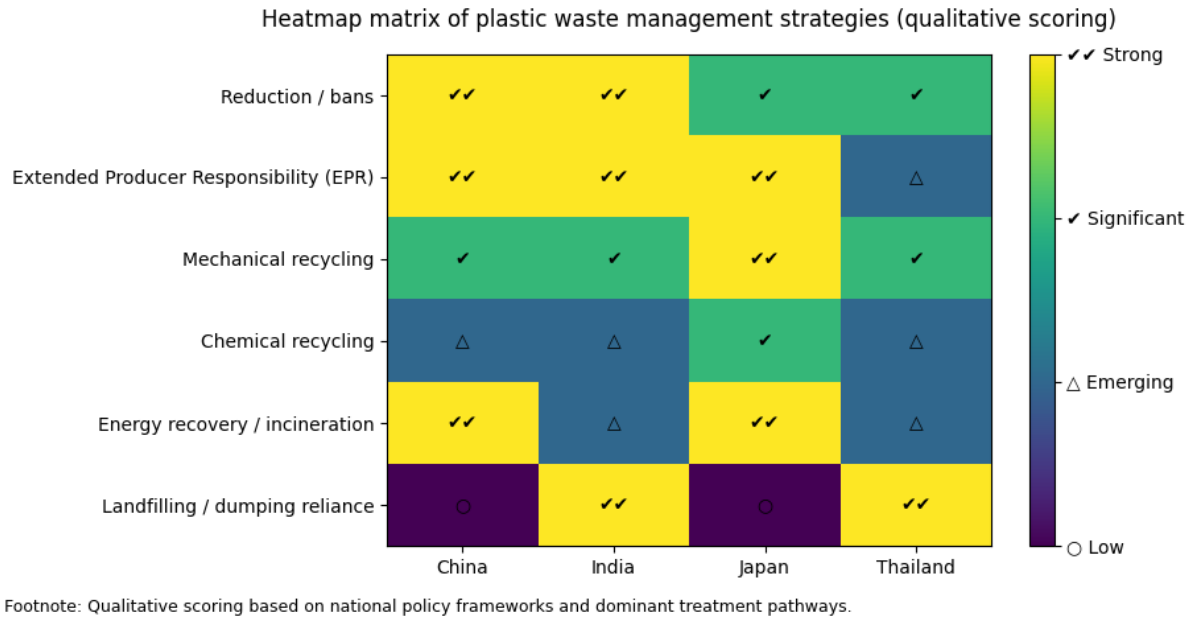

Figure 4. Heatmap matrix illustrating plastic waste management alternatives and strategies adopted in selected Asian countries (China, India, Japan, and Thailand). The qualitative scoring reflects the relative maturity and emphasis of policy instruments and dominant treatment pathways, ranging from low (○), emerging (Δ), significant (√) to strong (√√). (Created by authors).

Advanced recycling, also known as chemical recycling, refers to a suite of technologies (like pyrolysis and depolymerization) that break down plastic waste into its molecular building blocks [93]. This process can handle mixed and contaminated plastics that mechanical recycling cannot, producing high-quality, "virgin-like" materials. However, its widespread adoption is limited by high initial investment costs and operational expenses [94]. Upstream measures provide the most comprehensive pathway to achieving this, ensuring that plastic is treated as a valuable resource to be kept in circulation, rather than a disposable commodity. The ongoing global Plastics Treaty negotiations represent a critical opportunity to enshrine these principles in a legally binding framework, thereby accelerating the transition to a global circular economy [40].

8. Conclusions and Outlook

The analysis of plastic waste management policies in China, India, Japan, and Thailand reveals a shared commitment to addressing the plastic pollution crisis, driven by legislation that emphasizes reducing, reusing, and recycling to realize a circular economy and address plastic pollution. This study confirms that EPR is a crucial tool for enhancing plastic waste management by ensuring shared accountability among producers, government, and consumers. Japan's Resource Circulation Strategy for Plastics, with its foundational Plastic Resource Circulation Act, stands as a strong example of a holistic legislative approach. The effective management of plastic waste is directly linked to a nation's ecological sustainability, underscoring the urgency of this issue. The effective management of plastic waste is shown to significantly impact the ecological sustainability of nations, emphasizing the urgency of addressing this issue [9].

The findings highlight that a combination of the 3R Plus approach, circular economy principles, and the BCG economy model is vital for driving progress. These frameworks, supported by technological advancements and robust policy instruments, are crucial for fostering resource-efficient societies and stimulating new economic growth. Equally, the importance of fostering behavioural change through public awareness campaigns, integrating circular economy education into formal and non-formal curricula, and organising stakeholder engagement workshops cannot be overstated. These measures are essential for embedding a culture of innovation, resource efficiency, and long-term sustainable practice.

Based on this comparative analysis, the following recommendations are put forth to enhance policy effectiveness and promote sustainable practices:

i. Attempt Upstream Interventions to Decouple Growth from Plastic Consumption. The analysis of Japan's high plastic consumption despite advanced recycling and China's post-import ban success demonstrates that downstream measures alone are insufficient. Therefore, all nations should promote a circular economy model that emphasizes reusable and less-packaged products, as seen in Thailand's BCG model. This includes

incentivizing plastic recycling through buy-back programs and exploring innovative alternative packaging materials derived from agricultural waste, which can address both plastic production and issues like stubble burning in India.

ii. Move Beyond Single-Use Plastics Bans by Strengthening the Entire Plastic Waste Management Chain. While banning single-use plastics is a popular policy, its implementation often faces challenges, as seen in India and Thailand. A robust system for managing alternatives is crucial. The analysis shows that strengthening waste management practices—improving segregation, collection, and processing through material recovery facilities—is a necessary complement to bans, effectively reintegrating plastic waste into the circular economy.

iii. Ensure Rigorous Implementation and Monitoring of National EPR Schemes. India's experience with its online EPR portal, which enhances transparency and accountability, provides a model for other nations. To be effective, EPR schemes must move beyond mere policy and be supported by robust monitoring systems to guarantee that produced plastic waste is effectively returned to the recycling chain, enhancing producer responsibility and accountability.

iv. Invest in Formalizing the Informal Recycling Sector to Improve Efficiency. The analysis highlights that the informal recycling sector, particularly in India, handles a significant volume of waste but contributes to plastic leakage. Integrating this sector through training, formal recognition, and partnerships, as proposed in some of India's EPR rules, can significantly improve the efficiency of plastic waste collection and processing.

v. Embed Circular Economy Education to Bridge Gaps in Policy Implementation. The study found that a major gap in China and Thailand is a lack of understanding of circular economy principles at the local and industrial levels. Therefore, nations should embed circular economy education into national education systems—from primary school through professional training—to foster sustainable design, resource conservation, and a future workforce equipped to implement these policies effectively.

In conclusion, the transition towards a sustainable society in China, India, Japan, and Thailand hinges on closing the loop of resource flows, stimulating new economic growth, and effectively addressing climate change. The integration of the 3R Plus approach, robust EPR policies, the BCG economy model, and circular economy principles is crucial for driving progress towards the UN SDGs in these nations and beyond as shown in Figure 4.

The ongoing negotiations for a Global Plastics Treaty represent a historic opportunity to establish a legally binding international instrument on plastic pollution. At the fourth session of the Intergovernmental Negotiating Committee (INC-4) in April 2024, significant progress was made on a revised draft of the treaty text. Key areas of debate included whether the treaty should cap or reduce plastic production, and the extent of financial and technical support to be provided to developing nations [95]. The outcomes of fifth session, INC-5 in late 2024 are poised to be critical in shaping the final text. The treaty's provisions on shared responsibilities, trade controls, and financial mechanisms will directly influence national policies, reinforcing the urgency for all nations to strengthen their efforts toward preventing plastic waste and transitioning to a truly circular economy [96]. However, resumed session of fifth session, INC-5.2 still cannot reach consensuses for all key obligations even on plastic waste management, international society should wait for third session, INC5.3 to conclude possibly [97].

Author Contributions

A.K.: conceptualization, methodology, visualization, supervision, writing—original draft and writing—review & editing; N.Z.: resources, visualization, writing—original draft and writing—review & editing; S.P.: resources, visualization, writing—original draft, writing—review & editing. All authors have read and agreed to the published version of the manuscript.

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Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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