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Governance and Innovation in Plastic Waste Management: The Case of Japan

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Abstract

This study investigates plastic waste management, focusing on Japan. The volume of plastic waste in Japan is more than eight million tons, and less than a quarter of the plastic waste is subjected to recycling. Considering that Japan is an archipelago consisting of a combination of four large islands and numerous smaller ones, plastic waste that enters the ocean poses significant threats to marine life, birds, other living beings, and beach pollution. This research explores the underlying factors that have made Japan one of the highest users of plastic. In addition, this study evaluates different strategies that are utilized in Japan to deal with the reduction in plastic utilization and plastic waste. The final section of the study proposes strategies that can reduce utilization of plastic and production of plastic waste and the new and future outlook for replacement of plastic.

Keywords: waste management; Japan; strategies to deal with plastic waste; alternatives to using plastic

1. Introduction

The focus of this research is Japan, one of the highest plastic waste-producing countries. The volume of plastic waste in Japan reached approximately 8.23 million tons in 2022 [1]. In 2020, only 21% of plastic waste was subjected to material recycling [2]. Plastic waste is damaging the bodies of water, and it has a harmful impact on marine life, birds, and all other living beings across the globe [3–9]. In addition to the destructive environmental impact of plastic waste, plastic is manufactured from crude oil, which is another source of carbon emissions [10,11].

According to the Organization for Economic Co-operation and Development (OECD), the manufacturing and utilization of plastic have increased from 234 million tons to 435 million tons in a span of twenty years, from 2000 to 2020 [12]. OECD predicts that by the year 2040, manufacturing and utilization of plastic will increase by 70% from the year 2020 [12]. According to the OECD, economic development in emerging countries and also the OECD country members will contribute to an increase in plastic use that will have a great impact on increasing global carbon emissions [12].

Following the literature review, the study explores the underlying reasons why there is so much plastic utilization in Japan. The study examines several strategies that have been implemented in Japan to deal with plastic utilization and plastic waste. The Plastic Resource Circulation Strategy, adopted in May 2019 by Japan's Ministry of the Environment, set ambitious goals, including a 25% reduction in single-use plastics and a 60% recycling rate for plastic packaging by the year 2030 [7].

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The final parts of the study propose public–private partnership and the utilization of blockchain technology as a resource-recycling platform, in addition to exploring the development of innovative sustainable materials that can replace plastic.

2. Literature Review

As mentioned above, based on the OECD's prediction, the production and utilization of plastic will have a tremendous increase by the year 2040, with a major impact on increasing greenhouse gases (GHGs) globally [12]. Several studies have explored the impact of microplastics on marine life and birds and how microplastics in the oceans contribute to the death of sea animals and birds [5,6,13]. According to Susanti et al. [5], microplastics in the oceans contribute to the death of sea animals and birds. The study by Li et al. [6] discusses plastic waste and marine life. Concurrently, some researchers state that plastic does not degrade for a very long time means that plastic waste is transportable and enters the bodies of water and the oceans across the globe [3,6]. Li et al. also propose that plastic industries need to be accountable, and different countries have to pass rules and regulations to address this issue [6]. Schwarz et al. [13] conducted a study of the types of plastic waste in marine environments, such as rivers and oceans. They found that the plastic waste in the rivers included mostly the plastic wrappings of products used by consumers that stayed in the rivers or washed to the beaches, while the fishing equipment was mostly found in the oceans. Schwarz et al. suggest that understanding the transportation and accumulation of plastic waste is an important factor to consider the environmental damage of plastic waste [13]. Pilapitiya and Ratanayake [3], in their study reviewing plastic waste and its environmental impacts, discuss how plastic has revolutionized the way we deal with different products. According to the authors, the properties of plastic, such as being lightweight, easy to handle, and convenient for wrapping different products and transporting them, have made a tremendous impact on the production and utilization of plastic. The authors emphasize the importance of global cooperation in 6 dealing with plastic waste [3].

Rafey and Siddiqui [4], in their study of plastic waste in India, discuss the challenges that encompass plastic waste recycling and the need for comprehensive strategies that provide solutions to deal with the production and sustainable waste management of both plastic and bioplastic.

Vuk et al. [7] investigated waste management and plastic waste recycling in Japan, South Korea, Singapore, and China. Among the studied countries, Japan and China indicate reductions in plastic waste, 11% for Japan and 8% for China. Japan has set rules and regulations for the reduction in plastic utilization and recycling, such as the 2019 Resource Circulation Strategy for Plastics [7]. However, South Korea and Japan, which used to send their plastic waste to China, cannot do it anymore since China banned importing the plastic waste [7]. The authors predict that Japan cannot achieve its goals of reducing single-use plastic and recycling by the year 2030, and there is a need to establish policies, such as a circular economy, and implement them through public–private partnerships to deal with the plastic waste and its impact on the environment in and around Japan [7].

Gazeau et al. [8] conducted a systematic review on tracing plastic recycling and concluded that blockchain technology is the most capable tool for ensuring accurate tracking. They noted, however, that significant challenges such as integration and standardization must be overcome by establishing high, cross-industry standards for recycling practices. Other researchers likewise emphasize that robust digital traceability frameworks are essential to advancing a circular plastic economy [8].

Torkelis et al. [9] discussed the increase in usage of plastic packaging, while there is no indication of meeting the set goal for recycling plastic waste. They argue that multiple

factors, including economic, political, environmental, technological, cultural, and legal dimensions, must be addressed in tandem to improve plastic utilization and waste management. This broad perspective aligns with an OECD analysis [12], which stresses that recycling goals cannot be met without concurrently tackling such diverse influences.

This study focuses on Japan and explores the underlying reasons for Japan's high volume of plastic waste and the ways that Japan deals with recycling plastic waste and its efficiency. The last part of the study explores the most effective ways of dealing with plastic waste in Japan and globally and proposes strategies that can best deal with plastic waste. The goals of this study are delineated below:

a. Investigating the different practices dealing with plastic waste in Japan.
b. Exploring the advantages and disadvantages of the current practices dealing with plastic waste that are currently used in Japan.
c. Proposing strategies to best deal with Japan's plastic utilization and plastic waste with the potential of global impact.

3. Plastic Waste in Japan

Japan's cultural emphasis on hygiene and aesthetics has deep historical roots [14–16]. Brown's analysis of Japanese cultural practices [14] notes that packaging is not merely functional but symbolic, representing respect and care in both personal and commercial contexts. This cultural inclination results in high levels of single-use plastics, such as individually wrapped produce and elaborate packaging for gifts. The research by Gamaralalage et al. [15] emphasizes that such practices significantly contribute to Japan's position as one of the largest producers of plastic waste. According to the study by Li et al. [16], Japan's cultural emphasis on hygiene and aesthetics significantly influences the high consumption of single-use plastics. The tradition of meticulous packaging reflects a societal value placed on cleanliness and presentation. A survey conducted by the Japan Ministry of the Environment reveals that 60% of household waste in Japan consists of packaging materials, underlining the cultural priority placed on cleanliness and presentation [17].

An emerging area of research involves behavioral interventions to reduce plastic consumption. A study by Ohtomo and Ohnuma [18] shows that financial incentives, such as discounts for reusable containers, significantly influence consumer habits. Their study further indicates that public awareness campaigns emphasizing the environmental impact of single-use plastic have also proven effective, particularly among the younger generation, and integrating such interventions with existing policy frameworks can accelerate the shift towards a circular economy. In addition, concentrating on industries that heavily use plastic can also assist in reducing the usage of plastic. Nakatani et al. [19] investigated plastic waste in Japan and how it could effectively be recycled and reused. Their finding suggest that the concentration should be on industries that use plastic, such as the food industry, in addition to the collection of plastic waste from households.

Furthermore, Japan's economic strength supports its capacity for technological innovation in waste management. However, heavy reliance on imports for raw materials intensifies its plastic dependency. Policies, such as the Plastic Resource Circulation Strategy and incentives for reducing single-use plastics, represent attempts to balance economic growth with environmental sustainability. Luk [20] argues that these policies, while progressive, require stronger enforcement mechanisms and broader public participation.

As a result, in addition to national policies, regional efforts also play a role. Jones [21] highlights case studies of municipal programs, such as Yokohama's "Smart Resource Recycling" initiative, which combines citizen engagement with advanced sorting technologies to achieve higher recycling rates. Such localized efforts often serve as models for nationwide implementation but require significant funding and community involvement.

Currently, Japan's traditional methods, such as incineration and mechanical recycling, which is the process of converting plastic waste into new products through physical reprocessing (e.g., sorting, melting, and remolding) without altering the polymer's chemical structure [22,23], dominate the waste management strategies in Japan. While incineration is efficient for reducing waste volume, it contributes to greenhouse gas (GHG) emissions and raises environmental concerns. According to Ma et al. [23], recent advancements in chemical recycling, including the HiCOP method and blockchain-based tracking systems for resource recycling, have attracted academic and industrial interest. As highlighted by Mitsui Chemicals [24], blockchain technology, in particular, has been identified as a transformative tool for ensuring transparency and accountability in recycling practices.

Another solution to decrease plastic waste is the technological advancements focusing on material innovations as alternatives to the utilization of plastic [25]. Satti and Shah [26] discuss the development of plant-based biodegradable plastics that aim to replace conventional polymers. Plant-based biodegradable plastics are materials derived from renewable biological resources (e.g., corn-based polylactic acid) that can be broken down by microorganisms into natural substances like water and carbon dioxide [26]. These materials are designed to decompose in natural environments, reducing the environmental hazards of plastic waste [26].

Xu et al. [27] propose that international cooperation is vital for addressing transboundary plastic pollution. Japan's participation in global initiatives, such as the G20 Osaka Blue Ocean Vision, demonstrates its commitment to reducing marine plastic litter. The G20 Osaka Blue Ocean Vision is an international initiative launched under Japan's G20 presidency in 2019 that aims to eliminate new marine plastic litter pollution by 2050 [28]. However, more concrete actions, including stricter regulations on plastic exports and increased investment in regional waste management infrastructures, are needed to deal with plastic waste in Japan.

This research examines different methods that are used to recycle plastic waste and highlights the benefits and issues of these methods. This study proposes strategies that can be effective in dealing with plastic pollution. The proposed strategies concentrate on Japan, one of the most plastic waste-producing countries in the world, with the potential for global impact.

4. Problem Identification

According to Alves [29], the worst mismanagement of plastic waste happens in Asia, which produces 65% of plastic waste globally. Table 1 presents the top 10 plastic waste-producing countries in the world [30].

The Plastic Management Index (PMI) was originated by Economic Impact and The Nippon Foundation as part of the "Back to Blue" initiatives [31]. PMI includes 25 selected countries that are compared based on how they manage their plastic waste from production to recycling. PMI, in combination with the "Decade of Ocean Science" that was 157 started by the United Nations in 2021, assists in developing strategies for countries to deal with plastic production, utilization, and waste management [31].

Table 1. Plastic Pollution by Country 2024.

Country	Plastic Waste (M Tons)
China	37.6
United States	22.9
India	7.4
Brazil	4.9
Mexico	4.0
Japan	3.8
Germany	3.6
Indonesia	3.4
Thailand	3.4
Italy	3.3

Plastic Waste Challenges

A major issue with plastic waste is that it is not biodegradable, causing plastic residues to persist in the environment for centuries. Over time, larger plastic items degrade into microplastics, which can be ingested by humans through water and seafood, posing potential health risks [6,7]. Additionally, the impact on marine life and birds and the tainting of the seafood are inevitable [4,6].

The plastic waste degradation process occurs globally, but it is particularly visible in countries like Japan, where high plastic usage meets extensive coastal areas [1,7]. As incineration is used in Japan to deal with plastic waste, an equally important concern is air pollution and greenhouse gas emissions from the incineration of plastic waste, Japan's most widely employed plastic disposal method [8]. While incineration effectively reduces plastic waste volume, it also releases CO_2, nitrogen oxides, and other pollutants [8]. If recycling of plastic waste through incineration is not properly regulated in Japan, toxic substances, such as dioxins, can be emitted, which causes long-term environmental harm and potential health hazards for nearby communities [8]. As China and other Southeast Asian nations have stopped plastic waste imports [32], Japan must handle a larger share of its plastic domestically, leading to an increased reliance on incineration that raises additional environmental and public health concerns [7,32].

Moreover, the high cost of recycling plastic waste presents a significant barrier. Collecting, sorting, and processing different types of plastics, ranging from PET (polyethyleneterephthalate) bottles to more complex multilayer packaging, requires sophisticated infrastructure and specialized technology [10,25]. The complexity of recycling plastic and its high cost not only discourage the adoption of advanced recycling methods but also drive local governments to select less expensive, yet more polluting, options, such as incineration and landfill disposal [8,22].

Compounding this challenge for Japan is Japan's cultural emphasis on hygiene and elaborate packaging, which leads to extensive use of single-use plastics, from individually wrapped produce to disposable cutlery, thereby inflating the overall volume of plastic waste [15,17].

Finally, the increasing prevalence of marine plastic pollution is a reminder that plastic waste is not confined to terrestrial systems but also affects global oceans. Studies show that plastic debris, especially from coastal regions, often ends up in marine environments, harming coral reefs, fish populations, and seabird colonies [6,7,14]. As an island nation, Japan faces heightened vulnerability to marine pollution, and cleaning up plastic debris along its coastlines imposes additional economic and labor burdens on local governments and

non-governmental organizations (NGOs) [1]. Consequently, addressing these challenges calls for comprehensive solutions. The strategies that Japan is using to deal with plastic waste are as below:

1. Incineration.
2. Chemical Recycling.
3. Extensive public engagement.
4. International collaborations.
5. Policy intervention.
6. Reducing plastic utilization.
7. Circular Economy.
8. Blockchain Technology.

5. Current Strategies Utilized in Japan to Deal with Plastic Waste

1. Incineration: Incineration remains Japan's dominant strategy due to its capacity to handle large quantities of waste efficiently [8,33]. Yet, as discussed above, this method contributes significantly to greenhouse gas emissions and air pollution [8,33].
2. Chemical Recycling: Chemical recycling approaches have gained attention, converting plastic waste into raw materials or fuels. While promising in principle, these processes demand high energy inputs and cost-intensive facilities, limiting their widespread adoption [10,23].
3. Stakeholders' Engagement: Along with coming up with technological solutions to plastic waste recycling, the engagement of stakeholders has become crucial. Governments, businesses, and NGOs need to collaborate on awareness campaigns and community-driven initiatives, such as local plastic collection events and educational programs on sorting protocols [15,17]. Beyond raising public consciousness, such engagements can contribute to policy changes at multiple levels, local, regional, and national, to promote both innovative recycling methods and a reduction in the utilization of plastic [16,19,29].
4. International Collaborations: International agreements also play a significant role in shaping Japan's approach to plastic utilization and plastic waste recycling. Initiatives, such as the G20 Osaka Blue Ocean Vision and the United Nations "Decade of Ocean Science", have encouraged Japan to align its policies with global standards on marine conservation and plastic pollution control [29]. There is a need for robust international collaboration mechanisms since cross-border collaborations can be hindered by inconsistent regulations and varying economic interests [29].
5. Policy Intervention: Improving plastic waste collection efficiency is another strategic focus, as better sorting and retrieval of plastic waste can greatly enhance recycling rates [17,27]. Advanced AI-driven sorting systems, developed by companies like Nippon Electric Corporation in Japan, are increasingly used to identify and separate various plastic polymers, thereby reducing contamination and boosting material recovery [8,23]. However, these technologies require substantial financial investments and reliance on public compliance with sorting guidelines [27].
6. Reducing Plastic Utilization: A more transformative approach involves reducing plastic utilization outright, particularly single-use plastics. Japan has introduced multiple legal and policy measures, such as discouraging the free distribution of plastic bags and utensils in retail and dining establishments, to curb plastic dependency [20,32]. These measures are complemented by industry-level shifts toward biodegradable or bioplastic alternatives, which can assist in diminishing fossil-based plastic production in the long term [11,26,34].

7. Circular Economy Model: Closely related to reducing plastic usage is the pursuit of a circular economy model. Through this approach, products are designed and manufactured with reuse, repair, and remanufacturing in mind, thereby minimizing waste over the product life cycle [8,10,27]. To implement such a paradigm shift effectively, the Japanese government has enacted policies like the 2019 Plastic Resource Circulation Strategy, incentivizing manufacturers to adopt design-for-recycling principles and to create markets for secondary raw materials [8].
8. Blockchain Technology: Blockchain technology has emerged as a compelling tool for ensuring transparency and traceability in the entire recycling chain [9,24]. When deployed effectively, blockchain systems can track the journey of plastic from production to disposal, reducing fraud and guaranteeing that materials labeled "recycled" are genuinely recycled. Yet, implementing blockchain comes with challenges, including high setup costs, the need for regulatory frameworks, and collaboration issues among diverse stakeholders [9,24].

Table 2 presents the discussed strategies that Japan has adopted to deal with plastic waste and the advantages and disadvantages of these strategies.

Table 2. Japan's strategies in dealing with plastic waste.

Strategies	Advantages	Disadvantages
Incineration	• Inexpensive and quick • Reduction in waste volume rapidly	• Increasing CO_2 emissions and air pollution • Potential release of toxins
Chemical Recycling	• Conversion of plastics into valuable chemical feedstock • Reduction in the need for virgin materials	• Energy-intensive process • High operational costs
Engagement of Stakeholders	• Raising awareness of plastic pollution • Encouraging collaborations among Government agencies, industries, and Consumers	• Requiring consistent long-term funding • May face resistance if cultural and economic interests are not aligned
International Collaborations	• Enhancing global cooperation and knowledge exchange • Harmonizing regulations across borders	• Enforcement can be inconsistent • International political tensions can impede progress
Policy Intervention	• Improving sorting and lowering contamination • Efficiency in collection and enhancing recycling rates	• Requiring advanced infrastructure and technology • Depending on public participation and adherence to sorting rules
Reducing Plastic Utilization	• Reducing plastic waste at the source • Encouraging the use of alternative Materials	• Cultural preference for over-packaging remains strong • May lead to higher costs for Businesses and consumers
Circular Economy	• Extending product life cycle through Reuse and remanufacturing • Potential reduction in resource depletion and pollution	• Complex to implement at scale • Requiring alignment of policy, technology, and social values
Blockchain	• Enhancing traceability of recycled Materials • Reduction in risk of data tampering and fraud in waste management systems	• High initial costs for the system implementations • Requiring digital standardization across stakeholders

In sum, incineration remains popular due to its lower costs and efficiency in reducing waste volume, yet it contributes significantly to air pollution and greenhouse gas emissions. By contrast, chemical recycling offers a pathway to reclaim valuable raw materials but

remains capital-intensive. Engagement of stakeholders, including policymakers, corporations, and citizens, serves as a critical means of raising awareness and instituting broader reforms. Similarly, international collaborations, agreements, and policy interventions by efficient collection systems can ease logistical challenges and enhance recycling outcomes. Efforts to reduce plastic utilization, particularly in single-use applications, necessitate shifts in consumer behavior and business practices, which may be facilitated by circular economy initiatives. Finally, blockchain technologies present a novel solution for improving accountability and transparency in waste management operations.

The complexities outlined in Table 2 indicate the need for a systematic investigation of the factors driving plastic waste generation and management. In light of these diverse strategies, such as incineration, chemical recycling, engagement of stakeholders, international agreements, circular economy initiatives, and blockchain-based traceability of recycled materials, this study investigates several strategies to pinpoint the most vital strategic model to deal with plastic utilization and plastic waste in Japan. This research evaluates a combination of policy measures, technological innovations, and cultural shifts to identify the most effective comprehensive approach. Prior research has called for public cooperative strategies (e.g., combining circular economy policies with stakeholder engagement) as essential to tackling Japan's plastic waste problem [7].

6. Strategies to Deal with Plastic Utilization and Waste in Japan

This section examines several strategies aiming to clarify and explain the interplay among policy measures, technological innovations, and socio-cultural norms in shaping plastic waste recycling outcomes. Recent studies [8,15,33] emphasize that simple correlations, such as those between environmental policy stringency and reduced plastic consumption, may be confounded by broader economic structures, consumer behavior, and supply chain dynamics. Likewise, while the Plastics Management Index (PMI) serves as a robust measure of policy efficacy and infrastructural readiness, its predictive power for actual waste outcomes can be moderated by nation-specific conditions, such as Japan's 291 cultural norms that determine single-use plastic packaging practices across different industries [17,32]. To determine the most effective strategy to deal with plastic waste in 293 Japan, the subsequent strategies are explored to highlight the best one that can shape the 294 ultimate reduction in plastic waste.

1. Strategy 1

Countries with higher PMI scores demonstrate a lower per capita plastic waste generation rate. This proposition suggests that nations scoring favorably on the PMI, reflecting strong policies, infrastructure, and stakeholder engagement, will exhibit a reduced per capita plastic waste output.

2. Strategy 2

In Japan, implementing circular economy approaches, such as chemical recycling and design for recyclability, and drawing upon Japan's recent policy framework, the 2019 Plastic Resource Circulation Strategy, the goal is to reduce single-use plastics by 25% by 2030 [35]. This study proposes that by integrating advanced recycling processes with product redesign principles, these circular economy measures can yield a demonstrable and measurable reduction in aggregate plastic waste.

3. Strategy 3

The adoption of advanced incineration technologies in Japan, such as gasification and pyrolysis, correlates with a net decrease in carbon dioxide (CO_2) emissions compared to conventional incineration methods [36]. These technologies also achieve higher energy

recovery efficiency, which can further reduce net emissions by offsetting the use of fossil fuels [36]. Although incineration remains Japan's principal disposal technique, modern thermal processes, such as gasification and pyrolysis, may ease some environmental impacts by lowering net CO_2 outputs, assuming strict emission controls and efficient energy recovery.

4. Strategy 4

Blockchain-based traceability solutions increase the accuracy of reported recycling rates, resulting in a smaller discrepancy between reported and independently verified plastic recycling data. This study proposes that digital traceability systems can reduce inconsistencies in official recycling figures. Blockchain provides an undisputable record of each transaction in the recycling process, making it difficult to falsify or double-count recycled material and thereby helping to align reported figures with actual outcomes [8]. For example, a Japanese pilot project using SAP's Green Token blockchain system to track recycled plastic inputs has shown that such technology can substantiate environmental claims and improve transparency in the plastics supply chain [37].

7. Investigating the Strategies for Dealing with Plastic Waste in Japan

To evaluate the above strategies, data were compiled from multiple sources, including the Plastics Management Index [38], OECD environmental databases [12], Japan's Ministry of the Environment [35], academic research on advanced incineration processes [8,23], and blockchain-based waste management implementations [9,24]. Figure 1 indicates the PMI scores for the listed countries [38] and their per capita plastic waste in kilograms per year [31].

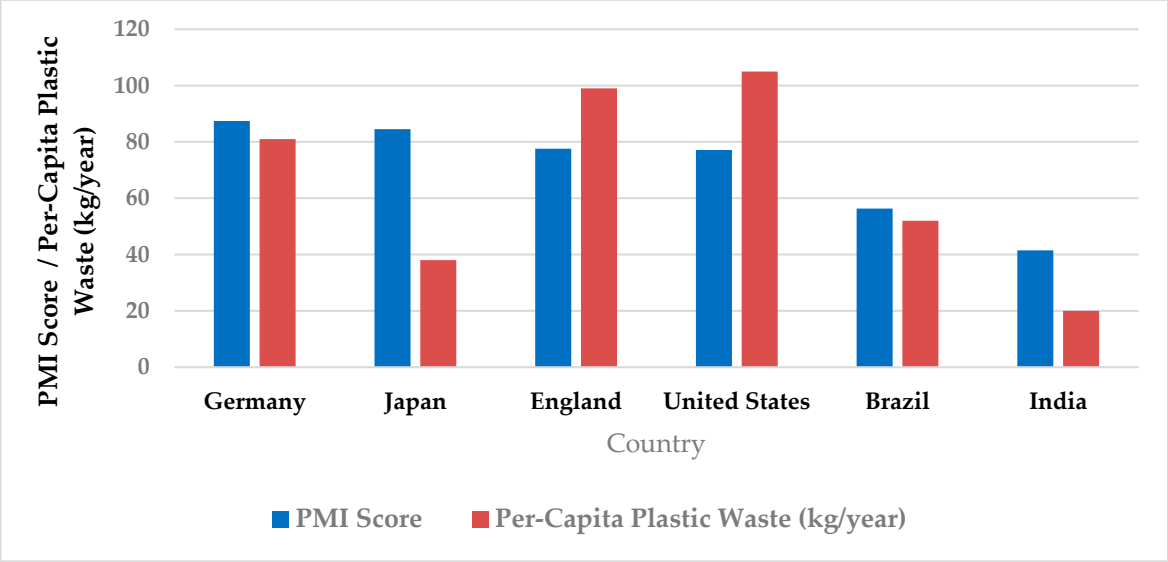


Figure 1. PMI score versus per capita plastic waste (2021, 2016).

As illustrated in Figure 1, countries with relatively high Plastics Management Index (PMI) scores, such as Germany (87.4) and Japan (84.5), exhibit lower per capita plastic waste (Germany = 81, Japan = 38) than England (99) and the U.S. (105), with lower PMI. However, as indicated in Figure 1, countries with low PMI scores, such as Brazil (56.3) and India (41.5), exhibit a lower volume of per capita plastic waste, 52 kg/year for Brazil and 20 kg/year for India. As a result, data does not support the assumption in Strategy 1 that countries with higher PMI scores demonstrate a lower per capita plastic waste generation rate.

To evaluate Strategy 2, Japan's approach to decreasing plastic waste by implementing a circular economy is examined. Japan's implementation of a circular economy, such as

chemical recycling and design for recyclability, is to significantly decrease overall plastic waste disposal by at least 15% within five years [31]. Figure 2 presents the estimated reduction in plastic waste after the implementation of circular economy strategies in Japan from 2019 through 2021 [33,34].

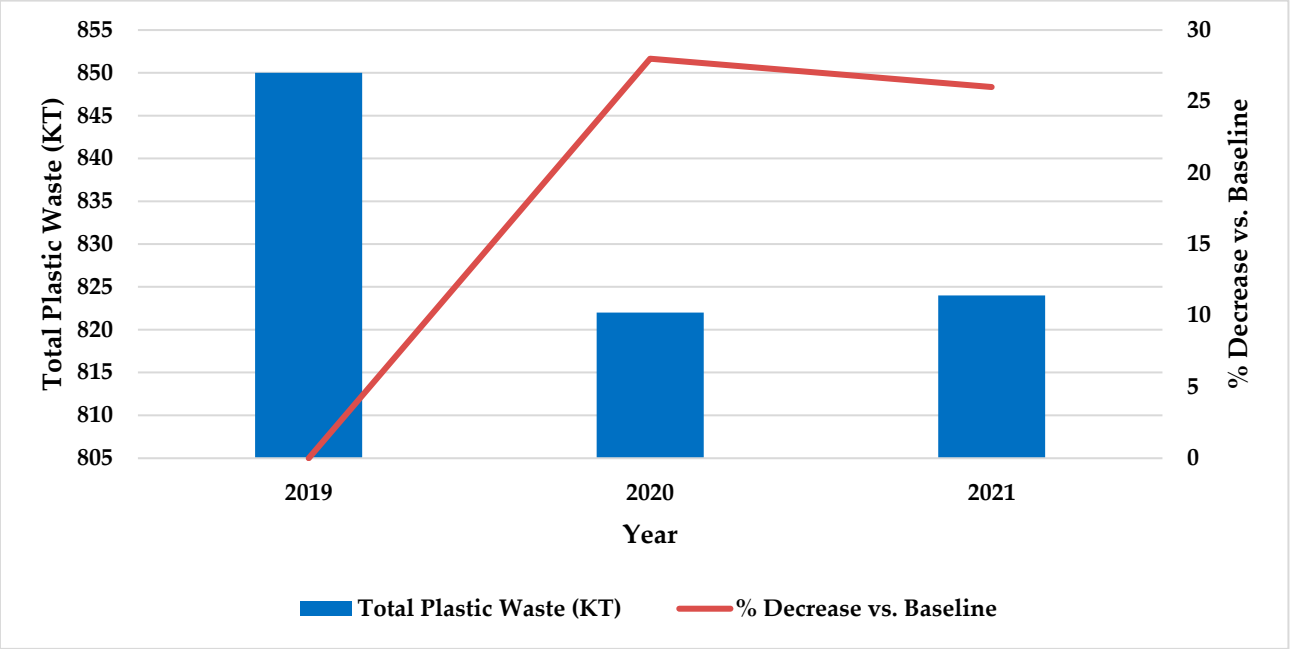


Figure 2. Estimated reduction in Japan's plastic waste with circular economy strategies.

As indicated in Figure 2, the plastic waste was reduced by 28% in 2020 and 26% in 2021 compared to 2019. However, the percentage of plastic waste in 2021 increased by 4 kT when compared to 2020. These discrepancies indicate the need for more assertive policy measures or faster technological adoption to achieve significant plastic waste reduction.

Strategy 3, incineration, remains Japan's principal disposal technique through modern thermal processes. Figure 3 presents the results of the examination of this strategy by comparison of missions created from different incineration techniques in Japan for 2021 [39].

Figure 3 provides information and compares the average CO_2 emissions (CO_2 kg/plastic kg) and the percentage of energy recovery efficiencies among different incineration methods used in Japan: pyrolysis, gasification with ammonia or combustion, and conventional methods. As indicated in Figure 3 [39], incineration with different methods exhibits high CO_2 emission. The conventional incineration methods indicate a lower CO_2 emission, but the energy efficiency ranges between 25% and 40%. Higher energy recovery ratios, which may contribute to a more sustainable waste-to-energy conversion if scaled nationally. However, economic and infrastructural barriers remain critical to the widespread adoption of different efficient incineration methods.

The last strategy to explore, Strategy 4, blockchain-based traceability, has the potential of increasing the accuracy of reported recycling rates. In order to examine the accuracy of reported plastic recycling versus the actual verified plastic recycling rates, Figure 4 presents the results of this investigation. As indicated in Figure 4, there are discrepancies between reported versus verified plastic recycling rates in the countries below from 2020 to 2021. The data for the selected countries in Figure 4 were from different sources: Japan [39–41], Germany [41], South Korea [41,42], Singapore [41], and India [43–45].

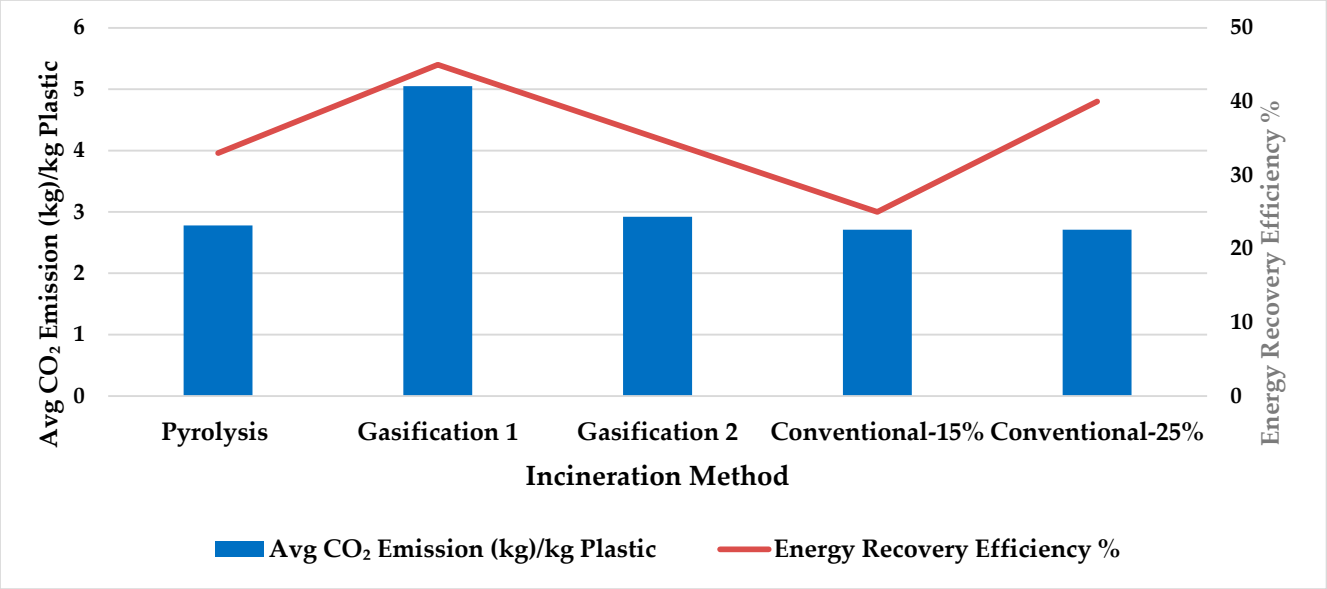


Figure 3. Comparison of CO_2 emissions utilizing different plastic incineration techniques in Japan (2021).

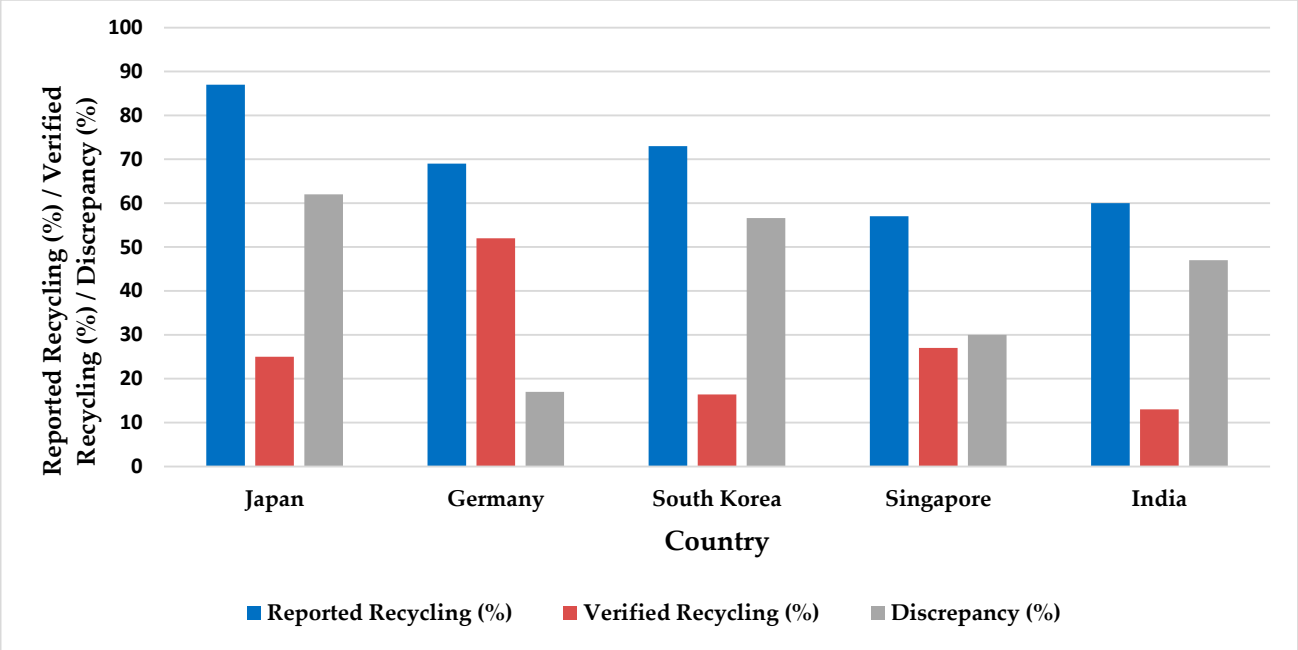


Figure 4. The discrepancy between reported versus verified plastic recycling rates in the selected. countries (2020, 2021).

As presented in Figure 4, there are discrepancies between the reported recycling of plastic waste and the verified recycling of plastic waste in the above nations. As a result, there is a need for robust digital transparency that can improve accuracy in reported recycled plastic waste [8,37]. Utilization of blockchain traceability that follows the life cycle of a product can enhance the records of recycling of plastic waste across the globe.

8. Discussion

Based on the presented tables and figures, the strategies that are implemented to lower plastic waste all demonstrate positive and negative points. The PMI and per capita plastic waste and implementing policies, infrastructure, and stakeholder engagement show

a general trend toward lower waste generation in countries with high PMI, with notable exceptions, such as Japan, as depicted in Figure 1. That means strong policy frameworks alone may not reduce consumption if cultural or economic factors drive single-use plastic demand, as the PMI and per capita plastic waste data indicate that it is the situation in Japan.

Circular economy efforts in Japan have led to very modest decreases in total waste as depicted in Figure 2 [33,34], which falls short of the goal of a 25% reduction in plastic waste [35]. Strengthening policy implementation and accelerating innovation could help bridge this gap.

Utilization of different incineration techniques for plastic waste, as presented in Figure 3, shows that all these techniques produce CO_2 ranging from 27.1 to 50.5 kg per kg of plastic waste, and energy recovery is between 25% and a maximum of 45%. 50.5 kg. The conventional method of incineration with a power generation rate of 25% produces less CO_2 (27.1 kg/kg plastic waste) and an energy recovery efficiency of 40%. However, national-scale implementation of better techniques remains limited due to high costs and infrastructure constraints.

The blockchain strategy and the results of recycling rates depicted in Figure 4 highlight discrepancies between self-reported versus verified recycling rates, which vary from 17% (Germany) to 62% (Japan).

Collectively, the findings of our study highlight the complexity of plastic waste management, which hinges on a combination of policy frameworks (PMI), technological innovation (advanced incineration, blockchain), and socio-cultural factors (packaging norms, consumer habits). Japan's experience with simultaneously high PMI and relatively high per capita plastic usage demonstrates that even advanced systems must continually adapt to new challenges if significant reductions in plastic pollution are to be 443 achieved.

In light of the observed shortcomings and successes, we argue that Japan should pursue an integrative model of plastic waste governance. This includes implementing blockchain-based traceability systems alongside public–private partnerships to improve accountability, investing in R&D and infrastructure to upscale advanced recycling and waste-to-energy technologies, and promoting cultural shifts through education and incentives. By interpreting the empirical findings in this manner, our discussion bridges to the subsequent recommendations, which outline concrete steps to govern plastic waste for policymakers and stakeholders. Additionally, it lays out a future outlook wherein continuous innovation and international cooperation will be vital. Japan's case exemplifies a broader lesson. Achieving significant plastic waste reduction will require not only national efforts but also alignment with global initiatives and treaties, ensuring that domestic actions contribute to and are reinforced by worldwide progress.

9. Recommendation

Based on the results of our research, we recommend a blockchain traceability strategy along with public–private partnerships and interdisciplinary research combining behavioral science, design innovation, and governmental policies that have the potential of yielding effective educational frameworks to deal with plastic utilization and plastic waste recycling.

Studies examining Japan's cultural hygiene for plastic packaging, such as Brown [14] and Nakatani et al. [19], highlight how deeply rooted norms can drive persistent single-use plastic consumption despite robust policy interventions. These analyses confirm that any successful waste reduction strategy must be culturally responsive rather than merely legislatively driven.

Changing the hygiene cultural aspect of Japan through focusing on introducing early environmental literacy in school curricula needs to be the starting point. Involv-

ing academia and scientists to create consumer awareness is essential in encouraging the decrease in the utilization of plastic. Devising government policies to promote incentives for different industries to implement eco-packaging alternatives can positively influence national cultural values.

In addition, considering Japan is a country surrounded by water, international alliances to assure ecological safety for living beings and marine life are imperative. Discussions of strategies regarding the reduction in plastic utilization and proper plastic waste management in organizations, such as the G20 [39], are imperative for the successful implementation of global strategies. The study by Gamaralalage et al. [15] emphasizes the critical role of international alliances in addressing transboundary plastic pollution. As a result, multilateral agreements, shared monitoring platforms, and standardized data collection protocols are beneficial in aligning stakeholders' interests. Moving forward, comprehensive inquiries are necessary to develop and test more scalable models of global collaboration regarding plastic utilization and plastic waste.

Studies by Torkelis et al. [9] and Jones [21] investigating advanced incineration and recycling technologies reveal that while methods such as pyrolysis or gasification have promise, the operational complexities and financial costs can hinder large-scale implementation.

Recent research on life-cycle assessments of bio-based plastics by Khoo et al. [10] and biodegradable polymers by Satti and Shah [24] illustrates both the potential and pitfalls of new material innovations. Although emerging solutions can diminish reliance on fossil-based plastics, trade-offs in land use, water consumption, and cost-effectiveness must be thoroughly examined.

Multi-criteria decision-making (MCDM), as discussed by Taherdoost and Madanchian [36], is a sound approach to systematically evaluate the ecological and socioeconomic dimensions of novel materials. Interdisciplinary teams, combining polymer science, environmental economics, and industrial design, can be positioned to explore, prototype, and pilot alternatives to plastic utilization and plastic waste recycling at various stages of the supply chain. These efforts can also address questions of recyclability, consumer acceptance, and policies resulting in widespread adoption.

Furthermore, the emerging research on blockchain-based traceability and digital reporting, as explored by Gazeau et al. [8] and Mitsui Chemicals [24], highlighting how technology can revolutionize plastic recycling accountability, signifies that utilization of evolving blockchain technology and digital reporting will have a major impact on decreasing and ultimately eliminating plastic utilization and plastic waste in Japan.

10. Future Outlook

Future studies should concentrate on methods that can reshape public perceptions and cultural hygiene around plastic packaging in Japan by changing the hygiene culture, which is a major contributing factor to plastic utilization. As mentioned above, educating the public, starting with the young generation, is imperative to understand the impact on Japan's coastlines, bodies of water, marine life, and the health and welfare of all living beings.

In addition, the impacts on the environment at the national and municipal levels, comparing different waste-treatment scenarios, need to be explored. Furthermore, real-world pilot programs, accompanied by longitudinal data collection, can validate these novel approaches to plastic utilization and plastic waste recycling.

By integrating findings from pilot-scale successes and failures, government entities and private-sector stakeholders can refine best practices for broader deployment, especially in urban areas with high waste-generation rates. To effectively deal with plastic utilization and plastic waste recycling, public–private partnerships can be the underlying dynamic for

the elimination of plastic utilization across the globe. In addition, international alliances are very important to deal with the hazards of plastic utilization and plastic waste.

In addition, further research is needed to explore the replacement of plastic with other safe and easily degradable materials in the near future. As a result, it is imperative for future studies to concentrate on developing effective, safe, and affordable techniques to replace and recycle plastic waste across the globe.

11. Conclusions

The present study makes scientific contributions by examining Japan's plastic waste management through both governance and innovation lenses. It provides an integrated analysis of how policy measures, cultural factors, and technological innovations interact in the context of plastic waste, offering a comprehensive case study for nations grappling with similar issues. Academically, our work highlights the importance of cultural context in waste management outcomes. For example, Japan's ingrained single-use packaging norms were shown to reduce the effectiveness of otherwise strong policies. This finding contributes to the literature by empirically demonstrating that technological or policy solutions alone are insufficient without societal engagement. Additionally, the study's evaluation of advanced recycling technologies, such as improved incineration techniques and blockchain traceability, sheds light on both their potential and limitations in a real-world national setting, thus providing a perspective that bridges engineering and policy disciplines.

Looking forward, the challenges identified in this research point to several future directions. One key direction is the need for longitudinal studies to assess how behavioral interventions, such as education campaigns or incentive programs, can gradually shift consumption patterns in cultures with high plastic dependency. Another is the development of cross-sector pilot projects. For instance, collaborations between municipal authorities, industry, and technology developers to implement circular economic initiatives can be used to test integrated solutions at scale. Our findings also suggest that international cooperation will be critical. Therefore, establishing unified metrics and data-sharing protocols for plastic waste, building tools like PMI, could be an important step, enabling researchers and policymakers to track progress and learn from each other's experiences. In conclusion, by combining insights from policy analysis, cultural examination, and technological evaluation, this study underscores that tackling plastic waste is a multifaceted challenge. It calls for sustained interdisciplinary efforts and international collaboration to drive the systemic changes required for a more sustainable and circular plastic economy in Japan and beyond.

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References

1. Klein, C. Volume of Plastic Waste Japan 2013–2022. Statista. 2 August 2024. Available online: https://www.statista.com/statistics/695382/japan-plas-tic-waste-disposal-volume/ (accessed on 1 June 2025).
2. Neils. Global Plastic Watch: Using AI to Prevent Plastic Flowing in the Oceans. 21 June 2024. Available online: https://nelisglobal.org/4revs/global-plastic-watch-using-ai-to-prevent-plastic-flowing-in-the-oceans/#:~:text=According%20to%20the%20To-524kyo%2Dbased,while%206%25%20went%20to%20landfills (accessed on 1 June 2025).
3. Pilapitiya, N.T.; Ratnayake, A.S. The world of plastic waste: A review. *Clean. Mater.* **2024**, *11*, 100220. [CrossRef]
4. Rafey, A.; Siddiqui, F.Z. A review of Plastic Waste Management in India—Challenges and opportunities. *Int. J. Environ. Anal. Chem.* **2023**, *103*, 3971–3987. [CrossRef]
5. Susanti, N.K.; Mardiastuti, A.; Wardiatno, Y. Microplastics and the impact of plastic on wildlife: A literature review. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *528*, 012013. [CrossRef]
6. Li, C.; Tse, H.F.; Fok, L. Plastic waste in the marine environment: A review of sources, occurrence and effects. *Sci. Total Environ. J.* **2016**, *566–567*, 333–349. [CrossRef]
7. Vuk, A.; Szűcsp, I.; Bauerné Gáthy, A. Waste management and plastic waste recycling in Japan, China, Singapore and South Korea—What trends can be observed under different regulations. *Int. Rev. Appl. Sci. Eng.* **2025**, *16*, 118–131. [CrossRef]
8. Gazeau, B.; Zaman, A.; Minunno, R.; Shaikh, F. Developing traceability systems for effective circular economy of plastic: A sys-tematic review and meta-analysis. *Sustainability* **2024**, *16*, 9973. [CrossRef]
9. Torkelis, A.; Jolanta Dvarionienė, J.; Denafas, G. The Factors Influencing the Recycling of Plastic and Composite Packaging Waste. *Sustainability* **2024**, *16*, 9515. [CrossRef]
10. Khoo, H.H.; Tan, R.B.H.; Chng, K.W.I. Environmental impacts of conventional plastic and bio-based carrier bags. *Int. J. Life Cycle Assess.* **2010**, *15*, 284–293. [CrossRef]
11. Panda, A.K.; Singh, R.K.; Mishra, D.K. Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and manufacture of value added products—A world prospective. *Renew. Sustain. Energy Rev.* **2010**, *14*, 233–248. [CrossRef]
12. OECD. Plastics. 2020. Available online: https://www.oecd.org/en/topics/sub-issues/plastics.html (accessed on 1 June 2025).
13. Schwarz, A.E.; Ligthart, T.N.; Boukris, E.; van Harmelen, T. Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. *Mar. Pollut. Bull.* **2019**, *143*, 92–100. [CrossRef]
14. Brown, A. *Just Enough: Lessons from Japan for Sustainable Living, Architecture, and Design*; Tuttle Publishing: North Clarendon, VT, USA, 2022.
15. Gamaralalage, P.J.; Abeynayaka, A.; Hayashi, M. *Japan's Plastic Waste Management—Challenges and Potential Solutions*; Institute for Global Environmental Strategies: Hayama, Japan, 2022; pp. 1–2. Available online: https://www.iges.or.jp/en/pub/japans-plastic-waste-management/en (accessed on 1 June 2025).
16. Li, B.; Li, Q.; Xing, Y.; Kondo, Y. Integrated Assessment of Environmental, Economic, and Social Impacts of Waste Plastic Recycling in Japan. *Jpn. J. Life Cycle Assess.* **2023**, *19*, 169–186.
17. Ministry of the Environment, Government of Japan, Separate Collection by Municipalities and Re-Cycling Under the Containers and Packaging Recycling Law. Available online: https://www.env.go.jp/press/103766.html (accessed on 1 June 2025). (In Japanese).
18. Ohtomo, S.; Ohnuma, S. Psychological interventional approach for reduce resource consumption: Reducing plastic bag usage at supermarkets. *Resour. Conserv. Recycl.* **2014**, *84*, 57–65. [CrossRef]
19. Nakatani, J.; Maruyama, T.; Moriguchi, Y. Revealing the intersectoral material flow of plastic containers and packaging in Japan. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 19844–19853. [CrossRef]
20. Luk, K. How Strict Waste Management in Japan Alleviated Its Environmental Impact. 13 September 2021, pp. 1–6. Available online: https://earth.org/japan-waste-management/ (accessed on 1 June 2025).
21. Jones, T. Japanese Solid Waste Management (SWM): A Case Study of Yokohama's G30 Waste Policy. In Proceedings of the International Conference of Technology, Management and Social Sciences (ICTMS-15), London, UK, 29–30 December 2015.
22. Plastic Waste Management Institute. An Introduction to Plastic Recycling. 2022. Available online: https://www.pwmi.or.jp/ei/plastic_recycling_2022.pdf (accessed on 1 June 2025).
23. Ma, Y.; Zhou, H.; Jiang, X.; Polaczyk, P.; Xiao, R.; Zhang, M.; Huang, B. The utilization of waste plastics in asphalt pavements: A review. *Clean. Mater.* **2021**, *2*, 100031. [CrossRef]
24. Mitsui Chemicals. Endeavor to Create a Circular Economy, the Website of Mitsui Chemicals. 2023. Available online: https://jp.mitsuichemicals.com/en/sustainability/mci_sustainability/circular_economy/recycle/index.htm (accessed on 1 June 2025).
25. Japan Gov. New Biodegradable Material Reduces Plastic Waste. 2019. Available online: https://www.japan.go.jp/tomodachi/2019/winter2019/new_biodegradable_material_reduces.html (accessed on 1 June 2025).
26. Satti, S.M.; Shah, A.A. Polyester-based biodegradable plastics: An approach towards sustainable development. *Lett. Appl. Microbiol.* **2020**, *70*, 413–430. [CrossRef]

27. Xu, Q.; Zhang, M.; Guo, P. Reflections on Japan's participation in negotiations of the global plastic pollution instrument under international environmental law. *Front. Mar. Sci.* **2023**, *10*, 1323748. [CrossRef]
28. Ministry of Foreign Affairs of Japan. Japan's "MARINE Initiative" Toward Realization of the Osaka Blue Ocean Vision. 2019. Available online: https://www.mofa.go.jp/ic/ge/page25e_000317.html (accessed on 1 June 2025).
29. Alves, B. Mismanages Plastic Waste Shares Worldwide, Select Country. Statista. 15 June 2024. Available online: https://www.statista.com/statistics/1270965/mismanaged-plastic-waste-worldwide-bycountry/#:~:text=India%20and%20China%20accounted%20for,misman-aged%20plastic%20waste%20that%20year (accessed on 1 June 2025).
30. Plastic Pollution by Country. World Population. 2024. Available online: https://worldpopulationreview.com/country-rankings/plastic-pollution-by-country (accessed on 1 June 2025).
31. Plastics Management Index. Evaluating Effective Management and Sustainable Use of Plastics. Back to Blue. An Initiative of Economic Impact and The Nippon Foundation. September 2021. Available online: https://backtoblueinitiative.com/wp-content/uploads/2021/09/Plastics-Management-Index-Whitepaper_sep29.pdf (accessed on 1 June 2025).
32. Japan's Plastic Waste Management—Challenges and Potential Solutions. Plastic Atlas Asia. 2022. Available online: https://www.iges.or.jp/en/publication_documents/pub/reportchapter/en/12341/PlasticAtlasAsia2022_en_WEB_1.pdf (accessed on 1 June 2025).
33. Bertone, M.; Stabile, L.; Cortellessa, G.; Arpino, F.; Buonanno, G. Techno-economic assessment of amine-based carbon capture in waste-to-energy incineration plant retrofit. *Sustainability* **2024**, *16*, 8468. [CrossRef]
34. Yuan, T.; Han, M.; Gu, D.; Bi, Z.; Gu, Z.; Hu, T.; Li, G.; Zhang, N.; Lu, J. PVC dechlorination for facilitating plastic chemical recycling: A systematic literature review of technical advances, modeling and assessment. *Sustainability* **2024**, *16*, 8331. [CrossRef]
35. Ministry of the Environment, Japan. *Japan's Resource Circulation Strategy for Plastics*; Government of Japan: Tokyo, Japan, 2019. Available online: https://www.env.go.jp/content/000050297.pdf (accessed on 1 June 2025).
36. Jeswani, H.; Krüger, C.; Russ, M.; Horlacher, M.; Antony, F.; Hann, S.; Azapagic, A. Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. *Sci. Total Environ.* **2021**, *769*, 144483. [CrossRef] [PubMed]
37. Ledger Insights. GreenToken by SAP in Blockchain Recycling Pilot with Japan's DIC Group. Ledger Insights (News). 21 July 2022. Available online: https://www.ledgerinsights.com/greentoken-by-sap-in-blockchain-recycling-pilot-with-japans-dic-group/ (accessed on 1 June 2025).
38. Back to Blue. Plastics Management Index White Paper. September 2021. Available online: https://backtoblueinitiative.com/plastics-management-index-whitepaper/ (accessed on 1 June 2025).
39. GreenMatch. 10 Countries Producing Most Plastic Waste. 2023. Available online: https://www.greenmatch.co.uk/blog/10-countries-producing-most-plastic-waste (accessed on 1 June 2025).
40. Eunomia Research & Consulting Ltd. Global Recycling League Table: Phase 1 Report. 2024. Available online: https://www.tomra.com/-/media/project/tomra/tomra/about-tomra/documentation/global-recycling-league-table-phase-1-report.pdf (accessed on 1 June 2025).
41. Surfrider Foundation. New Report Reveals U.S. Recycling Rate Has Fallen to 5~6%. 2022. Available online: https://www.surfrider.org/news/new-report-reveals-u.s-recycling-rate-has-fallen-to-5-6-percent (accessed on 1 June 2025).
42. Custom Market Insights. India Plastic Recycling Market Size, Trends, Share 2033. 2024. Available online: https://www.custommarketinsights.com/report/india-plastic-recycling-market/ (accessed on 1 June 2025).
43. Climake, & Aspen Network of Development Entrepreneurs (ANDE). Plastic Waste and Circularity Guide: Investing in the Waste and Circularity Sector in India. 2025. Available online: https://andeglobal.org/wp-content/uploads/2025/01/Plastics-Investment-Guide-Publishing-Clean.pdf (accessed on 1 June 2025).
44. Sun, N.; Tabata, T. Environmental impact assessment of China's waste import ban policies: An empirical analysis of waste plastics importation from Japan. *J. Clean. Prod.* **2021**, *329*, 129606. [CrossRef]
45. Bhubalan, K.; Tamothran, A.M.; Kee, S.H.; Foong, S.Y.; Lam, S.S.; Ganeson, K.; Vigneswari, S.; Amirul, A.A.; Ramakrishna, S. Leveraging blockchain concepts as watermarkers of plastics for sustainable waste management in progressing circular economy. *Environ. Res.* **2022**, *213*, 113631. [CrossRef] [PubMed]

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