Closing the Waste Loop: Converting Single-Use Plastics Into a Sustainable Resource

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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STS Research Paper

Introduction to the Plastics Paradox and their Role in Modern Society

One of the most pressing environmental challenges facing the world in the 21st century is the accumulation of plastic pollution, which has significant long-term impacts on ecosystems that are comparable to those of radioactive waste. The abundant use of plastics in our daily lives is inherent from water bottles to medical instruments in the emergency room to the point where the human and plastics life cycles became intertwined and cannot be separated from cradle to end-of-life phases. The negative impacts of plastic pollution on human health in the form of microplastics, the imbalance that plastics introduce to ecosystems due to the plastics' inability to decompose organically and biodegrade have led many individuals, organizations, and countries around the world to start thinking about finding alternative solutions that are more sustainable and environmentally conscious (OECD, 2022). Plastics are an essential part of modern society, providing numerous benefits and conveniences. However, their use has also led to significant environmental and societal costs, including pollution and waste. To address this paradox, we need to examine the changes in plastic industry and consumption and what are the suggested ways to mitigate the negative impact of plastics while preserving their benefits. This requires a fundamental shift in the way we design, produce, and consume plastics, as well as collaboration between stakeholders to create a more sustainable and circular plastics economy.

The paradigm shift theory proposed by Thomas Kuhn argues that the scientific truth remains constant and accepted uncritically till a new paradigm emerges and offers a better holistic explanation for gathered data that does not fit the old scientific narrative (Bird, 2018). Applying Kuhn's STS framework in a resource-constrained world, plastic waste management systems in countries such as United States, Germany, and Japan can adopt resource recovery strategies and alter consumption patterns to transition towards a circular economy.

Methodology

How has the plastic industry experienced a paradigm shift from the 1950's to the present?

Throughout this paper, I will view the complex socioeconomic and technoeconomic issues surrounding plastic waste management using a combination of case studies in OECD countries such as United States, Germany, and Japan. The research will be guided by the paradigm shift framework and will include an analysis of current recycling methods, disposal options, and the potential for redesigning products to reduce plastic waste. Data sources will include peer-reviewed articles, government reports, and industry publications. The analysis of each case study will involve a synthesis of the findings from the literature to provide a comprehensive conclusion of each country's stance in terms of the Kuhn cycle.

Background: A brief synopsis of the current plastic waste conditions

The Organization for Economic Co-operation and Development (OECD) estimates that" the current use of plastics is far from circular. Wherein, of the 353 million tons of global plastic waste generated globally in 2019, only an estimated 55 million tons were collected for recycling, 22 million tons of which were disposed" (OECD, 2022). The projected world population growth, estimated to reach 9.9 billion by 2050 according to the United States Census Bureau, coupled with the increasing trend of globalization of goods and services, has led to a significant rise in the usage and reliance on plastics compared to other synthetic materials such as cement or steel (United States Census Bureau, 2022). The world's projected economic growth is driving the growth of plastic production and implementation in consumer goods to be tripled from 460 million tons in 2019 to 1.321 billion tons in 2060 while the projected plastic waste under the current industry standards and modeled growth of SUP's consumer market is raising the current total waste from 353 million tons in 2019 to 1.014 billion tons in 2060 (OECD, 2022). Globally, only 9% of plastic waste is recycled while 22% is mismanaged with 84% of the expected population growth being distributed across middle to low-income countries in Asia and Africa where poor waste management policies are prevalent in governing their infrastructures and resource recovery through recycling is severely lacking (OECD, 2022). The end-of-life phase of plastic waste varies from one region to another, but the key destinations are recycling, incineration, landfilling, mismanagement which leads to leakage causing pollution. (Wilson, 2015)

The growing concern about the environmental impact of plastics began to emerge since the commemoration of the first Earth Day in 1970. The United States government passed the Resource Conservation and Recovery Act in 1976, which regulated the disposal of hazardous waste, including plastics. Coincidentally, similar environmental concerns also emerged in Germany and Japan. As a result, the plastic industry in the United States, Germany, and Japan began to shift towards more sustainable practices in the 1990s. The concept of the circular economy gained traction, and companies began to focus more on reducing waste and increasing recycling.

According to the United Nations Environment Program (UNEP), Single-Use Plastic (SUP) bags and Styrofoam containers pose environmental hazards as they slowly degrade, leaching harmful chemicals into the soil and water can in a process that may take up to 1,000 years to for SUP to decompose. The health impacts of single-use plastics (SUPs) are concerning, as they contain carcinogens such as benzene and styrene. When SUP waste is mismanaged and incinerated in low-income regions, these carcinogens can be released, posing a risk to human health. Additionally, SUP waste leakage into the ecosystem can enter the local food chain, leading to human ingestion of these harmful substances in the form of microplastics (UNEP, 2018).

The growing trend of single-use plastics utilized in packaging, textiles, and personal protection equipment (PPE) has led to massive accumulation of the short-lived plastic products in the waste stream due to poor waste management, single-use consumption, low price of virgin fossil fuel feedstock relative to bioplastic feedstock. “In the early 2000’s, the amount of plastic waste we generated rose more in a single decade than it had in the previous 40 years combined. Today, we produce about 400 million tons of plastic waste every year” (UNEP, 2022). For example, during the COVID-19 pandemic, “the World Health Organization (WHO) requested a 40 per cent increase in disposable PPE production in view of monthly global consumption and waste of 129 billion face masks and 65 billion gloves; in the case of PPE use in the United States this would mean that an entire year’s worth of medical waste would be generated in just two months” (Adyel. 2020). We often hear the words ‘sustainable’, ‘carbon footprint’, ‘bio-degradable’, ‘recyclable’ a lot in our daily lives from news media outlets to small conversations in waiting lines in the coffee shops but what do they mean?

STS Framework

Considering the ever-increasing plastic waste accumulation, it is important to understand the socioeconomic and sociotechnical factors contributing to plastic pollution and how the mitigating solution can be explored via series of analyses focusing on existing regulations, future legislations, anticipating the perspectives of plastic industry’s advocates, waste management systems, life cycle analyses of different plastic feedstocks and their recyclability potential. In the context of Science, Technology, and Sustainability (STS) the paradigm shift theory focuses on the change articulated by the most novel transformation to what are universally recognized as scientific achievements that for a time provide model problems and solutions to a community of practitioners (Kuhn, 1962). The technological advancements in biobased feedstock, effective waste management systems and resource recovery combined with changes in societal consumption perspective towards plastics can be analyzed via Kuhn's paradigm shift theory.

One of the major contributors to the application of Kuhn's theory to the plastic industry is Susan Freinkel. In her book, "Plastic: A Toxic Love Story," Freinkel applies Kuhn's theory to the history of the plastic industry, arguing that there have been several paradigm shifts in the way we think about and use plastic. Other scholars, such as Jennifer Gabrys and Rebecca Altman, have also applied Kuhn's theory to the history of plastics and the environmental implications of plastic waste. While these scholars generally agree on the applicability of Kuhn's theory to the plastic industry, there are some areas of debate and disagreement. For example, some scholars like Gay Hawkins in his book "*The Ethics of Waste: How We Relate to Rubbish*", argue that the plastic industry is characterized by a complex web of social, economic, and political factors that cannot be reduced to a simple model of scientific progress and paradigm shifts.

While these scholars may have reservations about the applicability of Kuhn's theory to the study of plastics, it is worth noting that many others have found it to be a useful framework for understanding the historical and cultural factors that have shaped the plastic industry and its relationship to waste. Ultimately, the usefulness of Kuhn's theory will depend on the specific economic progress for each country being examined and the societal context in which the relationship between producers and consumer is developed.

Plastic Waste Case Study in the United States of America

In the United States, 73% of plastic waste is landfilled, 19% is incinerated, 4% is mismanaged or not collected while only 4% is recycled (OECD, 2022). The plastic industry in the United States uses virgin feedstock derived from crude oil and natural gas refinery byproducts as it is perceived as the most feasible source for low-cost raw materials. However, the Environmental Protection Agency (EPA) has developed a quantitative approach to analyze the plastic segment in the annually generated municipal solid waste. EPA's Sustainable Materials Management (SMM) focuses on the use and reuse possibilities for the lifecycle of the plastic's component of the municipal solid waste (EPA, 2020). Prior to the 2018 Chinese ban on plastic waste imports, the United States had been exporting a significant amount of its plastic waste to China. However, the ban disrupted the global plastic waste trade, leading to a backlog of plastic waste in the U.S. and other countries. As global consumption of plastic goods per capita continues to rise, the accumulation of plastic waste is expected to accelerate, exacerbating the plastic waste crisis (Brooks, 2018).

The United States government is making plans to address the growing plastic fraction in municipal solid waste by introducing potential avenues for reuse in other industries via legislation such as Recycled Plastic Asphalt Act in 2022 that aims to secure funding and develop a research program to review and evaluate the use of recycled plastics in asphalt pavement applications (recycled plastic asphalt act, 2022). Also, President Biden announced an initiative to phase-out SUPs in national parks and other public lands managed by the Department of the Interior by 2032 and encouraging for rapid advancements over the next decades in bio-based plastics as part of the federal sustainability strategy (Executive Order No. 14057, 2021).

The plastic industry in the United States is undergoing the early stages of a paradigm shift in terms of new innovations in product design, technical advancements in resource recovery, environment-friendly government policies, and sustainability-conscious brands and markets that are exploring the viability of recycled plastics. One example of such a commercial product shift is Coca Cola’s implementation of new sustainable paper packaging that plans to remove 75,000 pounds of plastic packaging per year. The Coca Cola step may not have the biggest impact in the short-term, but it is a promising start to encourage other food and beverage giant corporations to follow their lead and collaborate for a better packaging practice.

The plastic revolution that once propelled plastics into every facet of everyday life seems to be on the cusp of a new industrial revolution. The timing is no coincidence, as all stakeholders can now benefit from revamping existing policies and procedures due to the easy accessibility of technological advancements brought on by globalization. The driving force behind this new revolution is sustainability, motivated by ecological concerns and the successful lobbying efforts of natural habitat conservationists who have persuaded governments to implement better strategies for mitigating plastic waste generation. However, the lack of an extensive network for collecting and transporting plastic waste from end-users to recycling facilities presents a significant challenge that requires further mechanization and automation of collection and sorting infrastructure.

Plastic Waste Case Study in Japan

According to the OECD, the plastic waste generated annually per capita in Japan was 69 kilograms. Such plastic waste is generated due to improper disposal and insufficient collection from the plastic product’s final phase in the consumer’s trash cannisters. Japan had done considerable work assessing the plastic waste via using Material Flow Accounting (MFA) framework that seeks to quantify the final waste disposal rate to better implement the resource recovery strategies for the global plastic waste recycling documentation (Wilson, 2015). There is an interesting case study in the town of Oki in the Kyushu region of Japan regarding the microscale paradigm shift from waste management to resource management to attain zero waste status with a recycling rate of 65.3% and 56% reduction in waste incineration (Liu, 2018). Moreover, the government of Japan has implemented various policies and regulations to reduce plastic waste, such as the Containers and Packaging Recycling Law, which requires businesses to either recycle or pay a fee for their plastic waste disposal (Ishimura, 2022). The Japanese government's policy sought to make the plastic producers improve the eco-design of their products and has also set a goal to increase the recycling rate of plastic waste to 60% by 2030 (Ministry of the Environment, 2021). In 2019, the Japanese government implemented the Plastic Resource Circulation Strategy, which is based on the principles of the 3Rs (reduce, reuse, and recycle) plus Renewables, with the goal of transitioning to a circular economy through plastic waste management. The strategy outlines three milestones: first, the implementation of fees to discourage the use of single-use plastics; second, the enforcement of waste sorting at the point of collection to promote efficient resource use; and third, the promotion of renewable materials, such as paper and bioplastics, as well as other alternatives to plastic (Plastic Atlas Asia,2022).

following the Chinese ban on importing plastic waste in 2018, Japan underwent the same circumstances as other plastic waste exporting nations such as the United States, according to the plastic management index (PMI), a metric for comparing countries' performances on plastic waste management from various angles, Japan is ranked second after Germany out of 25 countries. Moreover, Japan is among the top countries in the world when it comes to managing PET bottles, with a collection rate of 93% and a recycling rate of 85.8% (as of 2019). As for collection channels, 46% rely on local governments and organizations, while 54% rely on businesses, including PET bottle-specific trash cans installed beside vending machines and other collection boxes (Plastic Atlas Asia, 2022). Based on the Kuhn cycle, the status quo suggests that Japan has reached the stage of "normal science" in plastic waste management, where there is a widely accepted paradigm of plastic waste reduction, reuse, and recycling. The Plastic Resource Circulation Strategy established by the Japanese government in 2019 reflects this paradigm shift towards a circular economy approach to plastic waste management. Japan's high rankings on the plastic management index and its effective management of PET bottles indicate that the country has successfully implemented this paradigm through various collection channels and achieved significant progress in plastic waste management.

While Japan is ranked second in the world in plastic waste management, especially in managing PET bottles, there are still limitations to its current approach as significant amount of plastic waste is still being incinerated, leading to increased air pollution and greenhouse gas emissions. To address these limitations, future research could focus on exploring alternative approaches to plastic waste management, such as reducing plastic usage and developing biodegradable plastics. Additionally, interdisciplinary research could be conducted to better understand the social and cultural factors that contribute to plastic waste generation and disposal, in order to develop more effective and sustainable solutions.

Plastic Waste Case Study in Germany

In 2019, Germany generated 6.3 million tons of plastic waste, exported 1.1 million and imported 0.5 million tons, yielding an export surplus of 0.6 million tons of plastic waste, most of which is post-consumer packaging to be recycled in non-EU states (Conversio Market & Strategy GmbH, 2020). On a global scale and based on trade value, Germany is the sixth largest importer of plastic waste, and the second largest exporter. As a result of the landfill ban in Germany, over 99% of plastic waste is either recycled or recovered, although the percentage of recycling varies significantly between post-consumer and post-industrial plastic waste (D’Amato, 2023). The management of plastic waste in Germany is part of the European Union (EU) implemented strategy for the Packaging and Packaging Waste Directive (PPWD) based on extended producer responsibility in 1994, achieving a recycling rate of 42% for plastic packaging waste as of 2018. However, in contrast to Japan's CPRL, the PPWD allows plastic packaging waste to be exported outside the EU for recycling purposes. The exported plastic packaging waste outside the EU accounts for 34% of the total recycling volume (Ishimura, 2022).

The increasing recycling capacity in the EU is a significant challenge, especially considering the forthcoming implementation of the ‘Basel Convention' which imposes stricter conditions on shipping plastic waste abroad to non-EU states. Many EU member states heavily rely on non-EU countries to manage their plastic packaging waste so that they can achieve their recycling targets. In fact, almost one-third of the EU's reported plastic packaging recycling rate is achieved through routing the waste to non-EU countries for processing. However, beginning in January 2021, most plastic waste shipments will be banned. The EU's limited capacity to treat such waste within its borders compounds this issue, posing a significant risk to meeting the new recycling targets, according to auditors. The potential result could be an increase in illegal shipping and waste crime, which the current EU framework is too weak to address.(European Court of Auditors, 2020). The export of plastic packaging waste plays an important role in achieving the 99% recovery rate for recycling recovered in 2013 via either mechanically recycled 41% or energetically recovered 57% (UBA, 2017). However, the aftermath of the Chinese plastic waste import ban and other countries following suit by restricting waste permits such as Malaysia. The circular economy in Germany aims to eliminate waste and pollution by redesigning the entire life cycle of plastic products, from production to consumption and disposal. This approach seeks to create a closed-loop system where resources are used efficiently, and waste is minimized. The transition towards circular economy by employing resource recovery that is facilitated by patented environmental plastics technologies that have increased more than threefold between 1990 and 2017. The fundamental shift in plastic industry can be supplemented by social and business model innovation (European Environment Agency, 2021). Thus, "The Circular Plastics Alliance (CPA) initiative was established by the European Commission under the Strategy for plastics (2018) to boost the EU market for recycled plastics to 10 million tons a year by 2025. The Alliance covers the whole plastics value chain and comprises 311 signatories representing industry, academia, Non-Government Organizations (NGOs) and public authorities, who have signed a declaration committing to the Alliance's shared vision and contributing to its operational work (Arnold, 2023).

Numerous business strategies prioritize closed material loops for plastic-containing products that are standardized and widely used. Some companies offer take-back services for their products at the end of their life phase, enabling high-quality recycling and even reuse in certain cases, as they possess complete traceability of the materials and components. Other companies establish partnerships with relevant stakeholders to develop specific collection and recycling schemes for a particular product category such as the European Faerch packaging and container manufacturing group's sustainable food packaging solutions by completely recycling the PET packaging and reuse it to manufacture products of the same quality without alteration of the PET material's properties (Arnold, 2023).

The noticeable paradigm shift in plastic industry in Germany and overall, the EU is evident in the current 26% production capacity of the global bio-based and biodegradable plastic. Although the current global share of bio-based plastics is less than 1 % of total plastics produced annually but the production of bio-based plastics is expected to continue to grow beyond 2 % of total plastics produced annually by 2026 (European Bioplastics, 2021). The environmental benefits of bio-based plastics lie in its sustainable sourcing from renewable raw materials – mainly carbohydrate-rich, agriculturally-based sources, such as maize or starch, and non-edible lignocellulosic feedstock from wood-based sources. Bio-based plastics can be either: 1) non-biodegradable – for example, bio-polyethylene and bio-polypropylene; or 2) biodegradable – for example, polyhydroxy alkanoates and starch blends. It is important to note that bio-based is not a synonym for biodegradable. Biodegradation is a complex process that can either be industrial compostable or home compostable. In both cases, biodegradation occurs only under very specific conditions. However, this pathway focuses on bio-based, non-fossil feedstock and not biodegradable plastics. Alternative plastic feedstocks are generally divided into first-, second- and third-generation ones: first generation feedstock, such as maize and sugar cane, is also suitable for food and feed applications; second generation feedstocks, such as non-food-crop cellulose or side streams from such first-generation feedstock as maize stover, are not (yet) suitable for food or feed applications; third-generation feedstocks come from such sources as algae and different waste streams (Arnold, 2023).

Since the EU and Germany in particular has recognized the negative impact of plastic waste accumulation on the environment, the increased public pressure and regulatory actions to reduce plastic use and waste has presented a potential opportunity to transform the plastic waste into a recovered resource. Applying Kuhn’s cycle to the EU and Germany's plastic industry, we can say that they are currently in the crisis stage. As a result, the plastic industry is facing significant challenges, such as finding sustainable alternatives to fossil fuel-based plastic and developing new business models that prioritize circularity and resource efficiency. In response to the plastic waste crisis, the industry is investing heavily in research and development of new materials and technologies, such as bioplastics and recycling innovations. However, it is not yet clear whether this crisis will lead to a revolution and a fundamental transformation of the plastic industry, or whether it will eventually lead to a new normal that is characterized by incremental changes and improvements. Future research will examine how the plastic industry will evolve in response to the current crisis.

Conclusion

This paper focused on the current state of plastic waste in OECD countries as they possessed the most up-to-date datasets on plastic waste management as well as the existence of current environmental policies that drive the legislation for more sustainable practices and regulations on the plastic industry as a whole to invest in more efficient manufacturing methods. Due to the lack of literature on underdeveloped parts of the world where plastic waste is accumulating at an alarming rate, this study focused solely on the OECD regions with the most advanced plastic waste management systems. The findings of these case studies can serve as a framework for other countries to follow and adapt to their existing socio-economic conditions. With the plastic industry's transition towards more efficient and sustainable plastic production and consumption, it is hoped that this paper contributes to the global efforts in mitigating the negative impact of plastic waste on the environment.

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