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Evaluating the Parameters Influencing Plastic Recycling

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Abstract. The long-term and excessive utilization of plastic significantly contribute to environmental degradation and potential contamination. Notably, plastic undergoes various degradation processes, including photodegradation, thermo-oxidative degradation, and mechanical fragmentation, ultimately resulting in the generation of microplastics (MPs). Recent studies pointed out that MPs could accumulate in multiple human organs, such as the lungs, liver, and pancreas, leading to oxidative stress and cellular toxicity. Our investigation with indicators such as GDP, education, pricing, and cultural attitudes revealed that price as the predominant factor influencing the recycling of plastic bags. We analyzed the relationship between price and recycling rates through a linear regression model with the R packages broom and dplyr, which aims to inform the formulation of new regulatory measures designed to enhance plastic reuse and plastic waste mitigation.

Keywords: plastics, recycle, rrice, Linear Regression Model

1. Introduction

Plastic pollution becomes one of the most serious forms of pollution on our planet at our times [1, 2]. With 30 million tons of garbage pollution produced every year worldwide, a significant portion of the trash is poured into the oceans, rivers, and landscapes [3]. This pollution is primarily driven by single-use plastics, for example, bottles, bags and straws, designed for convenience but often discarded after just one use. Notably, plastic can take up to 1,200 years to decompose in landfills, leading to a serious threat to biodiversity because of the increasing amount of plastic in our environment [4].

Aside ftom its effects on wildlife, plastic pollution also casts substantial risks to human health. Microplastics (MPs), resulting from the breakdown of larger plastic items, tiny plastic particles have been found in drinking water, seafood, and even the air we breathe [5]. Recent findings indicate that MPs exist in various human tissues and organs [6-9]. As plastic continues infiltrating our food chains, the long-term consequences for human health remain a critical concern [10].

Enhancing plastic waste management is imperative for reducing the negative environmental effects of plastic pollution, necessitating a combined strategy that engages individuals, communities, businesses, and government entities. One of the most effective strategies is the implementation of comprehensive recycling programs [11].

The recycling of plastic waste is affected by diverse indicators that can either promote or impede effective recycling process. Due to the distinct properties of various plastic types, the recycling process requires tailored techniques for each material. Additionally, various factors affect the recycling rate of plastic, including education, economic conditions, government regulations, and cultural attitudes. In this context, we investigated the roles of education, economic factors, plastic bag prices by country, and cultural perspectives to evaluate the key elements influencing plastic recycling rates. Our results showed a strong correlation between plastic bag prices and recycling rates. By increasing the price of plastic bags, we can enhance plastic recycling efforts and promote a more sustainable future.

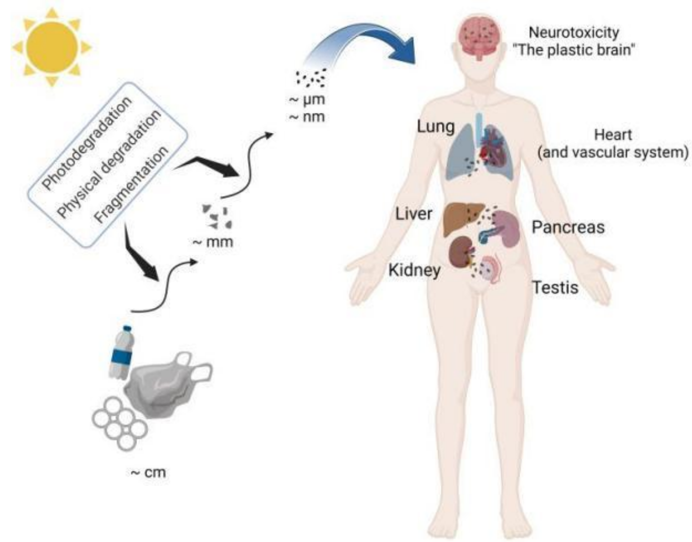

Figure 1. The generation of microplastics (MPs) and their toxicity to the human body. The disposed plastic wastes go through photodegradation, physical degradation, and fragmentation to form MPs. The existence of MPs in the brain, heart, lung, liver, kidney, pancreas, and testis was reported recently [6-9, 12].

2. Methodology

The summary of the MPs' generation from the environment and its effect on environmental sources and their effects on human health were related to toxicology research papers as cited [6-9, 12]. The MP's cellular toxicity was discussed in the section.

The data on education, economy, and plastic bag prices were obtained from government reports and NEWs. The cumulative factor model is a statistical approach that fits the plastic recycling calculation. We use it to analyze the relationships between multiple variables by identifying underlying factors that explain the observed correlations among them. We suppose there is an initial level of recycling rate, as a. Suppose the recycling rate as y, accumulates with several factors Xi, such as education, economic factors, and plastic bag price. The equation will follow the cumulative factor model, as below:

$$y = a + \sum_{i=1}^{n} biXi + c$$

The bi is the loading for factor i, Xi is the value of factor i, and c is the error term. The necessary of the error term parameter c was validated during model fitting.

The R package dplyr and broom were used to calculate the linear regression and prediction. The R packages ggplot2 and ggpubr were used to generate the figures.

3. Results and Discussion

3.1. MPs accumulate in the human body and cause cellular damage

Microplastics (MPs) have been identified in 15 different parts of the human body, with varying concentrations in specific areas, including the lungs [7], liver [8], and placenta. This suggests that MPs not only traverse the food chain but also have the potential to accumulate within the human body [6, 9, 12].

Microplastics inhibit cell proliferation and alter metabolism, and the combination of morphological changes and cell stress can lead to different changes in cell activity and affect the overall function of the cell [13]. This can lead to long-term problems such as irregular organ development, tissue degeneration, and even organ failure [14]. Therefore, long-term ingestion of microplastics may lead to chronic health conditions caused by changes in cell function, making them more susceptible to disease [15].

Tiny particles are dispersed throughout the body, influenced by blood circulation to all organs. Industrialization is thought to give rise to the decline in male fertility because of environmental pollution [16]. Over the past 50 years, semen quality among men worldwide has declined dramatically according to a new analysis of research. Much epidemiological evidence suggests that exposure to EDCs can lead to impaired reproductive health in human. While the exact causes of reduced semen quality in humans are unknown, environmental pollutants such as PM2.5, heavy metals, and endocrine-disrupting compounds (EDCs) play an important role. What's more, plasticizers such as BPAF and its analogues may be adsorbed by MP, which increase the total risk of human exposure to BPAF and the likelihood of human health effects [17].

Microplastics and nanoplastics can induce oxidative stress in nervous system cells, impacting various internal cellular processes due to uncontrolled reactive oxygen species by uncontrolled reactive oxygen species (ROS), such as nuclear DNA damage, protein oxidation, lipid peroxidation levels, membrane instability, mitochondrial protein damage, endoplasmic reticulum stress, and subsequent cell damage, including neuroinflammation and cell death [18]. Besides, inflammation of the central nervous system and oxidative stress have been linked to various neurodegenerative diseases such as Parkinson's disease, Alzheimer's disease, amyotrophic lateral sclerosis, and Huntington's disease, highlighting that exposure to microplastics and nanoplastics may contribute to the onset or exacerbation of neurodegenerative diseases [19].

3.2. Plastic bag price is the factor that affects the recycling rate

To elucidate different factors that affect the recycling rate of plastic, we analyzed the GDP, education, and plastic bag prices of 25 countries.

Initially, we investigated the relationship between Gross Domestic Product (GDP) and the recycling rate of plastic where the GDP as an indicator of a country's economic performance reflects the total value of goods and services produced within a specific time period. As economies grow, they tend to produce and consume more, leading to increased plastic usage. This surge in plastic consumption often results in higher rates of plastic waste. While countries with higher GDPs typically have greater access to resources and technology. Advanced regeneration technology and systems which can efficiently reduce plastic waste. In contrast, developing countries with lower GDPs may struggle with inadequate waste management infrastructure, resulting in lower recycling rates and higher levels of pollution. These factors make the relationship between GDP and recycling rates complicated. Our analysis showed the GDP and the recycling rate were not correlated (Pearson correlation coefficient $r = -0.123$).

On top of that, we hypothesized that education was essential to influence the recycling rate. Education levels also shape attitudes, behaviors, and awareness related to waste management, especially concerning plastic recycling. When individuals are educated about the harmful effects of plastic pollution on wildlife, human health, and ecosystems, they are more likely to adopt sustainable practices by reducing the usage and increasing the recycling of plastics. For example, schools that incorporate environmental education into their curricula often see students advocating for recycling programs in their communities, demonstrating how knowledge can lead to action. Moreover, local governments and organizations that implement educational campaigns about proper recycling practices can significantly impact recycling behaviours. In addition to formal education, informal education through media and social platforms can further enhance public awareness. Documentaries, social media campaigns, and public service announcements that focus on plastic pollution and recycling can reach a broad audience, fostering a culture of sustainability. By raising awareness, fostering responsibility, and promoting sustainable practices, education empowers individuals and communities to engage in recycling efforts actively. However, the data showed that education and plastic recycling rates have a relatively low positive correlation ($r = 0.2546$).

Subsequently, we investigated the relationship between plastic bag prices and the recycling rate. As concerns about plastic pollution increase, some local communities have enacted policies to reduce plastic consumption, including extra fees or bans on plastic bags. When the price of plastic bags increases—whether through direct fees, taxes, or the introduction of alternatives—consumer behaviour tends to shift. Higher costs often lead individuals to reconsider their reliance on single-use plastic bags, prompting them to seek reusable options. This behavioural change can result in a decrease in plastic bag consumption, ultimately leading to less plastic waste entering the environment. As consumers become more conscious of their plastic usage, they may also become more aware of the importance of recycling, thereby increasing participation in recycling programs. Moreover, when plastic bags are priced appropriately, it creates an economic incentive for consumers to recycle and a tax income to the government that can be used for plastic waste management. In regions where plastic bags are subject to a fee, studies have shown a corresponding increase in recycling rates as communities adapt to new norms regarding plastic usage. In contrast, in areas where plastic bags are provided for free, there tends to be a higher rate of consumption and, consequently, more plastic waste. From our analysis, the plastic bag price and the recycling rate have a relatively high positive correlation score of 0.4732. To conclude, the price of plastic bags is the major factor that affects the recycling rate.

Additionally, the relationship between cultural attitudes and the recycling rate of plastic are also worth exploring. Cultural attitudes encompass the values, beliefs, and behaviours that shape how individuals and communities perceive and interact with their environment. In cultures where environmental stewardship is deeply ingrained, recycling rates tend to be higher. For instance, countries like Germany and Sweden have strong cultural norms that prioritize sustainability and waste reduction. However, when separating the countries by continent, we did not observe any correlation between cultural attitudes and the recycling rate of plastic.

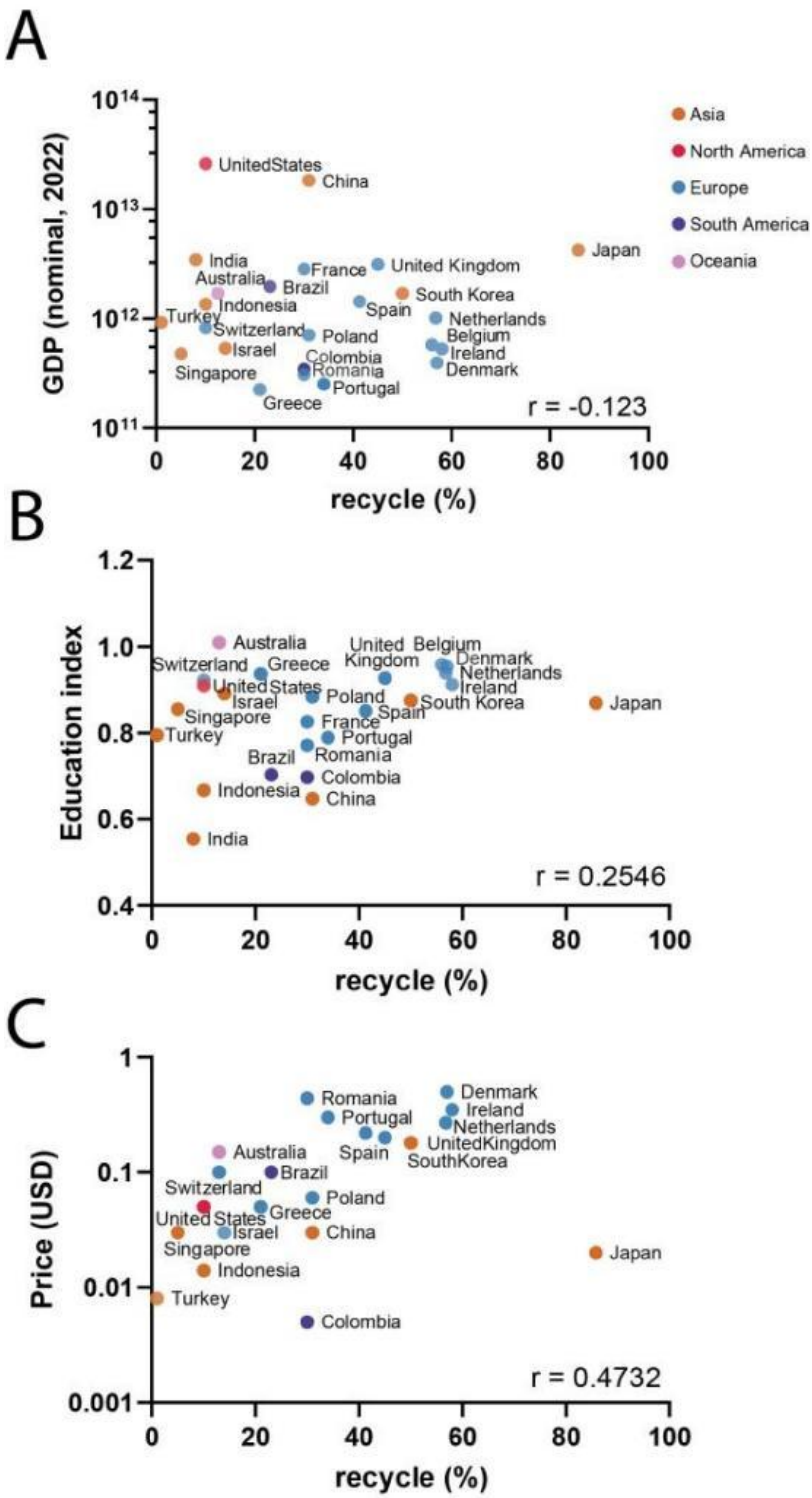

Figure 2. The correlation of (A) GDP, (B) education, and (C) price of plastic bags with the recycling rate by country. The selected countries were divided by the continents using different colours. Orange for Asia, Red for North America, Blue for Europe, Purple for South America, and Pink for Oceania. The R-value of the Pearson correlation coefficient was listed.

3.3. The equation of Plastic bags and the recycling rate

The residuals vs. fitted plot is a diagnostic tool used in linear regression analysis to assess the validity of the model. In this plot, the x-axis represents the fitted values (predicted values) from the regression model, while the y-axis displays the residuals, which are the differences between the observed values and the predicted values. Our residuals vs. fitted plot showed that the plastic bag price and the recycle rate exhibit a systematic pattern. It suggests that our model captures the relationship. The normal Q-Q plot is for validating the assumption of normality in regression analysis, helping researchers identify potential issues that could affect the reliability of their model's predictions and inferences. This alignment of our data indicates that the distribution of the residuals matches that of a normal distribution, which is a key assumption of linear regression. The scale-location plot is crucial for diagnosing potential issues in regression analysis, and guiding analysts in refining their models to ensure valid and reliable predictions. In our model, the points are randomly scattered around a horizontal line, indicating that the residuals are homoscedastic, meaning their variance is consistent across the range of fitted values. The residual vs. leverage plot is a diagnostic tool used in linear regression to identify influential data points that may disproportionately affect the model's estimates. In our model, most points cluster around zero, with only a few scattered points. The equation for the regression line showed that to get a recycling rate of around 80%, the price of a single-use plastic bag needs to be set between 0.152-0.486 US dollars.

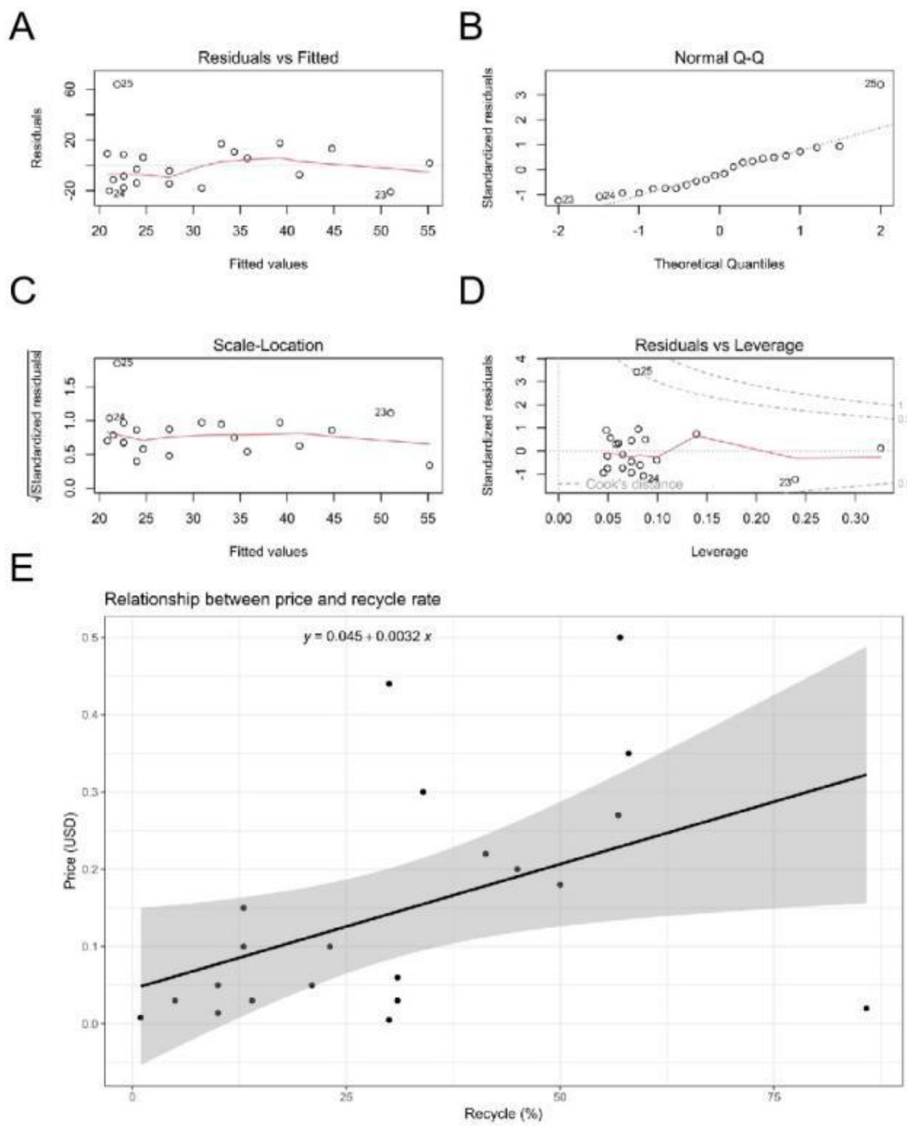

Figure 3. The linear regression of the price of plastic bags with the recycling rate by country. (A) The residuals vs Fitted plot, (B) the normal Q-Q plot, (C) the scale-location plot, and (D) the residuals vs leverage plot of the price of plastic bags with the recycling rate. (E) The equation for the regression line of price of plastic bags with the recycling rate.

4. Conclusion

Microplastics have been found to accumulate in various parts of the human body, such as the placenta, liver, and lungs, addressing that the contamination do not simply pass through the food chain but rather leaf in our body. This accumulation can cause cellular damage, disrupt metabolism, and potentially lead to serious health issues, including organ failure and increased susceptibility to diseases. In examining factors affecting plastic recycling rates, our analysis across 25 countries found no significant correlation between GDP and recycling rates, suggesting that economic performance alone does not dictate recycling success. However, education shows a positive correlation, indicating that higher awareness and understanding of plastic pollution can lead to better recycling practices. The most substantial impact comes from the cost of plastic bags; higher prices strongly correlate with increased recycling rates, suggesting economic measures could significantly enhance recycling efforts. Additionally, cultural attitudes towards environmental stewardship also play a crucial role in recycling behaviors, though this varies significantly across different regions. Our regression analyses, including various diagnostic plots, indicate that a price range of $0.152-$0.486 per plastic bag could potentially achieve an 80% recycling rate, highlighting the importance of economic incentives in promoting recycling behaviors.

The plastic recycling rate is affected by numerous factors, thus a comprehensive approach that encompasses these interconnected elements is crucial to improve recycling rates effectively. By fostering a culture of recycling, investing in technology and infrastructure, implementing supportive policies, and encouraging community engagement, societies can work toward reducing plastic waste and promoting environmental sustainability. As the global community continues to grapple with the challenges posed by plastic pollution, understanding and addressing these multifunctional influences will be crucial for creating a more sustainable future.

Developed nations, such as Japan and Switzerland, displayed high plastic recycling rates whilst maintaining relatively low prices for plastic bags. This study aims to conduct an in-depth analysis of the factors influencing Japan's effective plastic recycling practices. Our initial model, which is relatively straightforward, correlates the total volume of plastic waste with its recycling rate. By enhancing this model, we aim to provide a more comprehensive understanding that could inform policy decisions and encourage sustainable practices globally. Additionally, insights drawn from this study could help in developing strategies that other countries might adopt to improve their recycling efficiencies and reduce plastic waste, thereby mitigating environmental impacts and promoting economic sustainability.

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