Analysis of Socioeconomic, Geography, and Political Determinants of Municipal Solid Waste Generation in OECD Countries (1997-2021)

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EE516: Multivariate Analysis for Geographers

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December 10, 2024

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Introduction

Signed in 1992 and entering into force in 1994, The United Nations Framework Convention on Climate Change (UNFCCC) is the UN's entity that aims to support and enhance the global response to anthropogenic climate change (LSE, 2022; UNFCCC, n.d.-a). This convention has provided an important basis for international climate negotiations and led to a historical breakthrough when the Paris Agreement was formed in 2015 (UNFCCC. n.d.-b). Over the last decade, the Paris Agreement has often been at the center of climate change discussions, and famously saw the US pull out of and reenter the agreement (Cho, 2021). However, despite what critics and supporters believe of the Paris Agreement, anthropogenic climate change is an undeniable fact with a plethora of evidence which proves it is a serious threat to humanity (NASA, n.d.).

In 2023, The UNFCCC came out with a statement that insufficient progress is being made to meet the goals of the Paris Agreement, and immediate action is required by the states that signed the agreement in 2015 (UNFCCC, 2023). The agreement's main goal is to stop the global temperature from rising to dangerously high levels, which is primarily achieved by reducing GHG emissions and eventually reaching carbon neutrality (Schleussner, et al., 2022). While the bulk of responsibility of reaching these goals lies with the nations that signed the treaty, citizens play an important role in reaching these goals as well. Citizens can reduce their carbon footprint through different actions such as switching to electric vehicles or using less electricity and gas, but an important action every citizen should take is reevaluation their consumption behavior (UCAR, 2020).

Consumption directly leads to waste generation, as products that are created for consumption, are discarded by consumers when they have no more use for them (Environment America, 2021). On top of that, excessive consumption poses a serious threat to the environment (Environment America, 2021; UCAR, 2020; UNFCCC, 2021). Waste is responsible for 20% of anthropogenic methane emissions and with rapid global industrialization and urbanization, the future is not looking much better (Lama, 2024). In the US alone, waste generation has increased significantly between 1960 and 2018 (Figure 1).

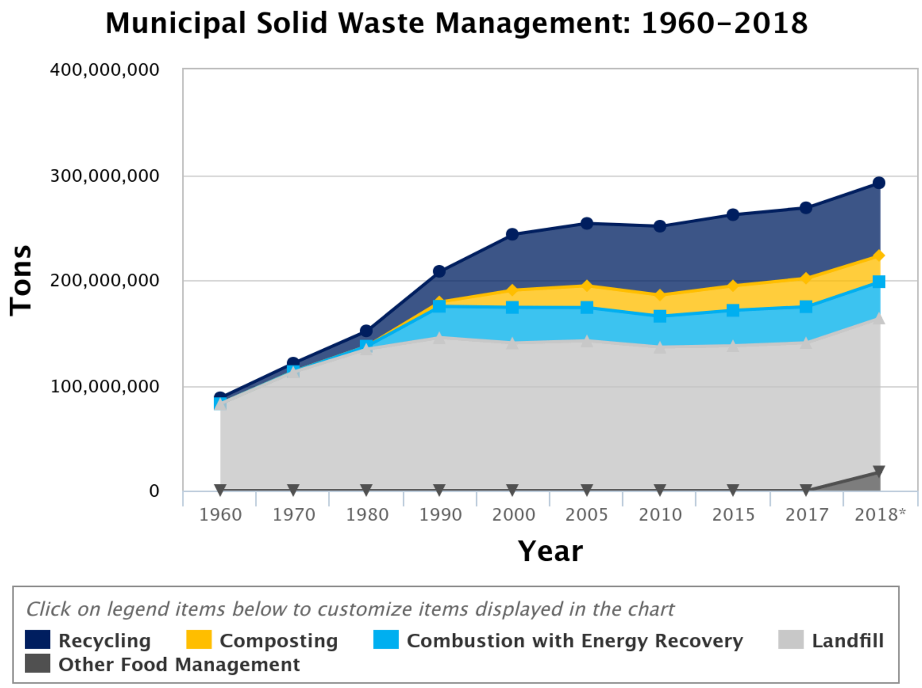

Figure 1*: MSW Management USA 1960-2918, [EPA](), 2023*

Additionally, research by Agamuthu and Babel (2023), indicates that consumer consumption, production and the volume of waste management have increased significantly since the last century. While the increase in waste management processes is a positive sign, a reduction in consumption and production would arguably be more effective (Ritchie, 2023). Furthermore, these increases present a worrisome trend, as the environmental impact of waste is significant. Both waste incineration and landfills have been linked to soil, water and air pollution that will harm present and future generations of communities and ecosystems (Environment America, 2021). Innovative waste collection and valorization processes could provide countries with the solution to this problem, but may take decades to be fully developed (Lama, 2024). Therefore, understanding and ultimately reducing waste generation could provide a faster solution.

This statistical research study aims to do exactly that: understanding which factors influence waste generation per household. For this study, waste is defined as Municipal Solid Waste (hereinafter referred to as MSW). According to EPA (2016), MSW is: “more commonly known as trash or garbage—consists of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries.” As there are a plethora of factors that influence MSW generation per household, three categories of factors have been identified: socioeconomic factors, geographical factors and political factors. In the next chapter, the specific variables that are observed within each category are discussed in more detail. Furthermore, this study aims to observe MSW generation per household in different countries over a span of 25 years. As collecting consistent data from a multitude of countries over decades can be a challenging task, this study focuses solely on states that are part of the OECD. The OECD provides an array of data on many different topics such as education, economics and waste generation, and is often used as the basis for forming public policies (OECD, n.d.-a). As the goal is to analyze waste generation over 25 years, this study focuses only on member states that joined prior to 1996. Furthermore, any data that is not available on OECD will be supplemented with local and international sources that provide data regarding the statistical variables that are determined. Finally, different case studies are conducted on countries that present interesting trends in MSW generation. These chapters contain statistical models that differ from the main statistical models, and aim to understand the regional differences in MSW generation.

With the societal relevance described, the aim of this research study discussed and considering all other arguments thus far, this study aims to answer the following research question: *To what extent is municipal solid waste (MSW) generation per household influenced by socioeconomic, geographical and political factors in OECD countries from 1997 to 2021?*

Literature Review

2.1 Socioeconomic Factors

The relationship between affluence, economic activity and MSW generation has been researched substantially. Malouf and Mavropoulos (2022) highlight that industrialized countries generate roughly 34% of global MSW while developing nations only account for 5% of global MSW generation. This indicates that affluence may directly influence MSW generation. Research by Ichinose et al. (2014) shows that this is also present on a national scale in Japan. When the income level of Japanese households increases, their economic activity increases as well, which as a result positively impacts MSW generation in households and local businesses. Cohen (2019) draws on this relationship and adds that lifestyle and consumption behavior in general are main drivers for the high levels of waste generation in the U.S. In addition, research by Magazzino et al. (2021) indicates that wealth and MSW generation are positively correlated in Denmark. Thus, the body of research indicates that wealth and economic activity are correlated with MSW generation.

For these reasons, different variables that aim to capture wealth and economic activity in OECD countries are included in the scope of this research. The first of which is: “Household spending”, and is defined by the OECD as: “Household spending is the amount of final consumption expenditure made by resident households to meet their everyday needs, such as food, clothing, housing (rent), energy, transport, durable goods (notably cars), health costs, leisure, and miscellaneous services.” (OECD, n.d.-b). While this is a rather broad definition and covers a lot of expenditures, it does provide an insight into how much households are able and willing to spend. Furthermore, the dataset contains both total household spending in a country, as well as household spending per capita. The next variable that captures wealth in OECD countries and is included in the scope of this research is Gross National Income (GNI). The observations of this variable are adjusted to the Purchasing Power Parity (PPP) of the USD in 2017. PPP is a metric that explains the purchasing power of citizens in a country, accounting for the different exchange rates and is adjusted to a baseline value (OECD, n.d.-c). This creates an equitable observation that considers the relative wealth of citizens, rather than their absolute wealth. For this reason, GNI adjusted to PPP will provide a value that captures the ‘average’ income of citizens in a country.

Besides affluence and economic activity, there are other socioeconomic factors that may explain variance in MSW generation in OECD countries. The first factor that is considered is the Human Development Index (HDI). According to the United Nations Development Program, a high HDI value is associated with better health, social services and the education of citizens in a country (UNDP, n.d.). Furthermore, based on research by Blagoev et al. (2023) in Bulgaria, HDI was a statistically significant predictor of MSW generation providing a negative correlation with MSW generation, meaning that MSW generation decreased for each unit of increase in HDI in Bulgaria. However, the HDI is an index that captures different factors such as life expectancy, income, standard of living and mean years of education. For this reason, this index is broken up and specific factors are included in this study. As mentioned earlier, Income is included in the scope of this research. Besides income, this study will also aim to capture the effects of life expectancy and mean years of schooling on MSW generation in OECD countries.

With regards to education, different studies indicate that education may be negatively correlated with MSW generation. Noufal et al. (2020) state that citizens in Syria that completed tertiary education (College level and higher) produce less MSW than citizens who possess lower levels of education. Research by Halkos et al. (2020) provides similar results and shows that education negatively impacts MSW generation in OECD countries. Furthermore, Halkos et al. (2020) add that education can be used as an effective tool to enhance environmental friendly behavior, stating that environmental education should be a staple in educational systems in OECD countries. However, while these insights are beneficial, education has also been linked to enhancing economic growth (Hanushek & Wößmann, 2010). For this reason, education may help reduce MSW generation in specific cases, but it may also indirectly increase MSW generation as wealth is positively correlated with MSW generation. Considering these different variables and arguments, it is important to understand which socioeconomic factors influence MSW generation per household in OECD countries. Thus, sub question 1 is formulated as:

SQ1: Which socioeconomic variables influence MSW generation per household?

2.2 Demographic/Geographic Factors

Demographic factors, such as population size, population density, urbanization level, and household size, are widely recognized as foundational predictors of municipal solid waste (MSW) generation. Numerous studies including Cheng et al. (2020), Shapiro-Bengtsen et al. (2020), Xiao et al. (2020), and Malav et al. (2020) have established that population size and urbanization level are directly related to the amount of MSW produced. Furthermore, MSW generation correlated positively to population density and urbanization level. Dangi et al. (2011) found a strong correlation, 0.94, between waste generated in Kathmandu, Nepal and number of people. Higher population density often results in more waste per unit area due to greater consumption and production activities in dense urban settings (Brown 2015).

"…the data from the 105 countries analyzed clearly suggest what we already intuitively know – that holding all other factors equal, as populations rise, so too does waste generation "(49 Brown).

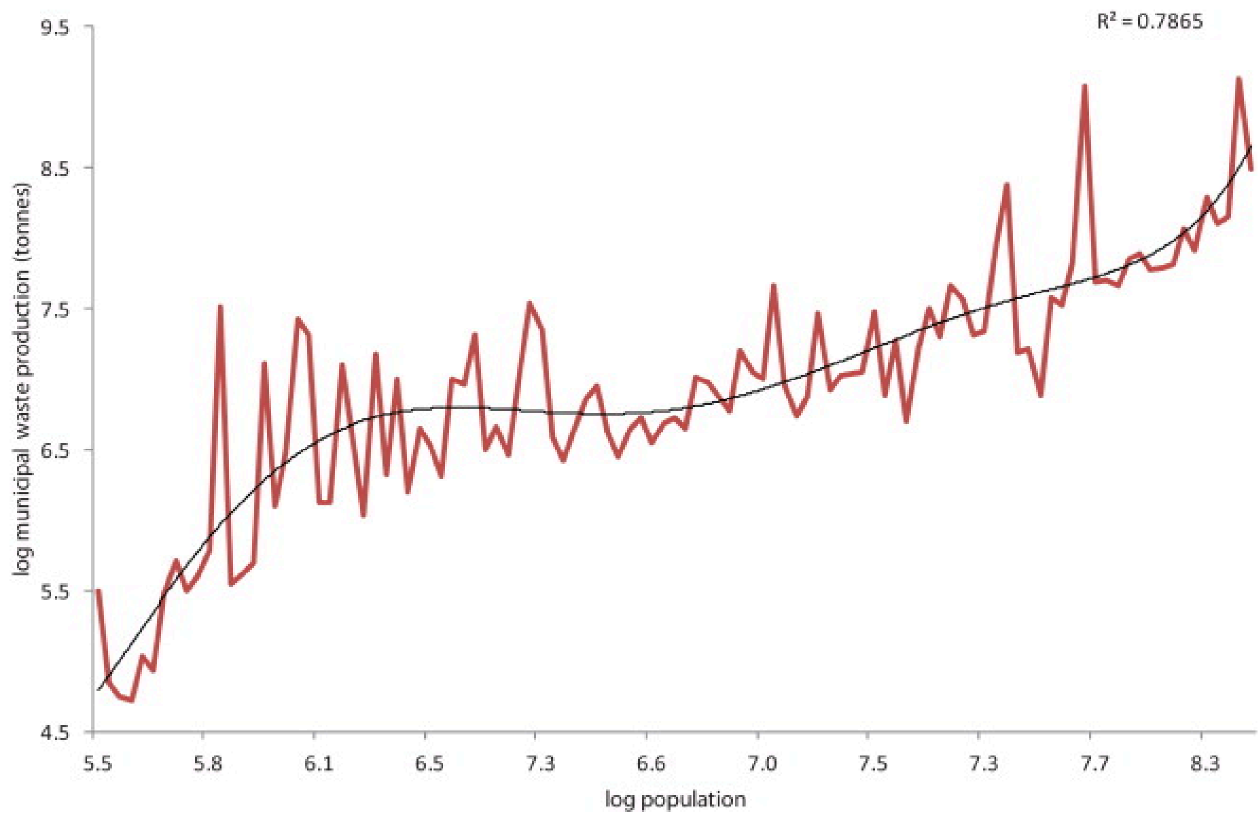

Figure 2: *Relationship between MSW and Population of 105 countries in 2019 (Brown, 2015)*

Similarly, the urbanization level is another determinant factor in generation of MSW in that consumption patterns are shifted as urbanization rate changes. The findings show that higher levels of urbanization are associated with increased generation of paper, plastic, and food waste. In Taipei City and other urban regions in Taiwan, the volume of paper waste has significantly increased as local business grows and the use of paper in commercial centers increases (Chen 2018). While there are various indicators to show urbanization level, given our goal of identifying what factors influence MSW the most in OECD countries, percentage of urban population is considered to be most appropriate since it can effectively capture the degree of urbanization and is relatively consistent across different contexts, where each OECD country has unique local characteristics. The single standardized metric would allow for more reliable cross-country comparisons and more general insights for all OECD countries without the complexity of accounting for each country's unique features.

Household size also plays a significant role, as smaller household sizes tend to generate more waste per person due to less efficient resource use and packaging waste (Masebinu et al., 2017). Lebersorger, Beigl (2011) also shows that larger household sized produce lower per capita waste compared to smaller households, where they utilized a regression model that explains coefficient of determination value of 74.3 % in several provinces of Styria and Austria, indicating household size is very effective at explaining the variation for MSW. Another finding from the study is that variations in household structure influence waste composition. Households with a higher proportion of young children tend to generate more disposable products and organic waste, while households with a higher proportion of elderly members may produce less food waste but more recycles such as paper and glass. Given the fact that numerous past research includes those variables and its clear relationship with MSW, it is essential to include these demographic factors in the project.

However, it is challenging and time consuming to collect historical data about households across 26 countries. In light of that, one of the variables that are considered to be as good to replace household size is fertility rate. Changes in fertility rates significantly influence household size, with higher fertility rates typically associated with larger households, and lower fertility rates linked to smaller households (Estive et al., 2024). For instance, countries with fertility rates below 1 often have smaller household sizes, while those with rates of 3 or 4 tend to have larger households. Bradshaw et al. used regression trees to test whether there is any relationship between household size and fertility rate across 64 countries and found that there is a significant positive relationship between them (Bradshaw et al., 2023). Given this relationship, the fertility rate can reflect the household size effectively and serve as a great indicator for household size when actual household data is difficult to obtain.

Geographic factors, such as climate, have also been shown to influence MSW generation. Climate variations can affect the quantity and composition of waste generated in a region. For instance, areas with warmer climates may produce more organic waste during certain times of the year. It is revealed that organic waste, paper, and metal content showed significant variations across seasons. Also, it has been shown that warmer seasons can lead to higher organic waste production due to an increase in consumption of perishable goods (Denafas et al., 2014). Other than seasonal variation, higher temperatures accelerate the decomposition of organic waste, leading to rapid decay and more frequent waste collection (Vergara & Tchobanoglous, 2021). In addition, extreme weather events like heavy rainfall can negatively impact on infrastructures in landfills, resulting in landslides and contaminants in MSW dissolving into nearby water bodies (Fei et al., 2021). Considering methane emission from landfills contribute to greenhouse gasses globally, the impact of waste management on climate change is significant (Magazzino & Falcone, 2022).

While there exists multiple climate-related indicators, average annual temperature has been selected to be the most suitable indicator that measures and reflects impacts of climate on MSW most. It can effectively represent the influence of temperature on waste generation and decomposition since the variation of temperature reflects seasonal variation that can significantly affect consuming patterns. Furthermore, it is a consistent variable across regions and time periods, which is beneficial to our project where we have to compare all OECD countries, as temperature is used as a core variable to reflect climate's impact on MSW for multiple countries in Gnonlonfin et al. (2017), By using average annual temperature, we expect to be able to capture the essential climate impact on MSW generation while maintaining simplicity and consistency in our analysis.

It is crucial to include population size, population density, urbanization rate, and household size as core demographic variables for analyzing MSW generation, as several similar past researches show their clear and strong relationship with MSW. Also, the reviewed literature is often limited to specific local areas or a small number of countries. Including these variables in our project is meaningful as we expect to gain insights from the global view as to global and common factors that contribute to the generation of MSW. Meanwhile, climate change, including seasonal variation and weather events, is another crucial factor that should be taken into account regarding MSW due to its direct and indirect influence on waste composition. While growth-related variables and green areas offer valuable insights, we decided to exclude them from the primary analysis in order to maintain focus on variables with more immediate and profound effects on MSW generation. Furthermore, those growth-related variables such as population growth rate and urbanization rate are more suitable for studies focused on urban areas with high economic growth potential, such as Dyson and Chang (2005), which differs from our objective to identify what factors influence MSW across all OECD countries.

SQ2: *Which geographic/Demographic? variables/factors influence MSW generation per household?*

2.3 Political Factors

Political factors are another determinant factor in solid waste generation. According to the World Bank, 1.6 billion tonnes of greenhouse gas emissions were generated from the process of solid waste treatment and disposal in 2016, accounting for 5 percent of global emissions. As a matter of fact, MSW decomposition is known to be a significant source of global warming, due to decomposition of organic wastes which produces greenhouse gasses (Su et al., 2023). Therefore, it is essential to delve into how the process is regulated and managed between each country and how differences in the process and regulations direct the amount of waste generated.

A numerous factors may influence MSW. Many studies have analyzed the concept of environmental policy stringency (EPS) (Rufael, 2020; Su et al., 2023; Cecere, 2016), defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior (OECD, 2024). While EPS offers an examination of the regulatory structure and the degree of devotion to tackling environmental issues (Fatima et al., 2024) the index is not a direct proxy of stringency of regulation within the scope of waste. As stated in OECD report from 2022 and can be seen in figure 3, the index disregards waste management domain as data is unavailable in a large cross-country panel. However, this study hypothesizes that nations with stricter environmental restrictions would have more stringent regulations in regards to waste management and disposal. Therefore, waste stringency may not be observed directly from the index, but it can still be inferred from the environmental behavior of countries from policies (Corrocher & Cecere, 2018). For the degree that political factors and policy are concerned, many studies have employed a series of internal and external indicators to explore stringency.

One factor of environmental behavior of countries is innovation. One study studied correlation between environmental efficiency technology gaps in European countries (quantified in the form of patents and trademarks in European Countries) and regulation in terms of ratification of Kyoto protocol, finding a positive relationship between them (Kounetas, 2015). Moreover, Mazzanti and Nicolli (2011) also found a positive effect of policies on environmental innovation on packaging waste and compost waste for OECD nations. These results indicate that technological innovation and regulatory framework promoted in countries stimulate development of waste management technologies and may lead to more effective waste reduction. This variable will be measured in terms of the number of parents on environmental technologies by each country (OECD).

Another way to quantify environmental behavior would be through financial policies that promote more efficient waste management. Based on the case study in Milwaukee, WI, Tominac (2021) suggests that economic strategies such as environmental tax, incentive, and green budgeting encourage sustainable municipal organic waste management. On the other hand, Lafolla (2010) claims that environmental taxation has not produced a decrease in the waste generation levels. However, it is worth noting that the study dates back to 2010, and doesn’t account for potential changes in patterns of municipal solid waste generation afterwards. In addition, the data employed for corresponding inquiry only involved EU 15 countries and does not capture waste production trends and policies in nations outside of the scope. Therefore, we found it beneficial to include financial instruments as a variable for inquiry. Having discussed about political/policy related variables, our sub question would be:

SQ3: *Which political variables/factors influence MSW generation per household?*

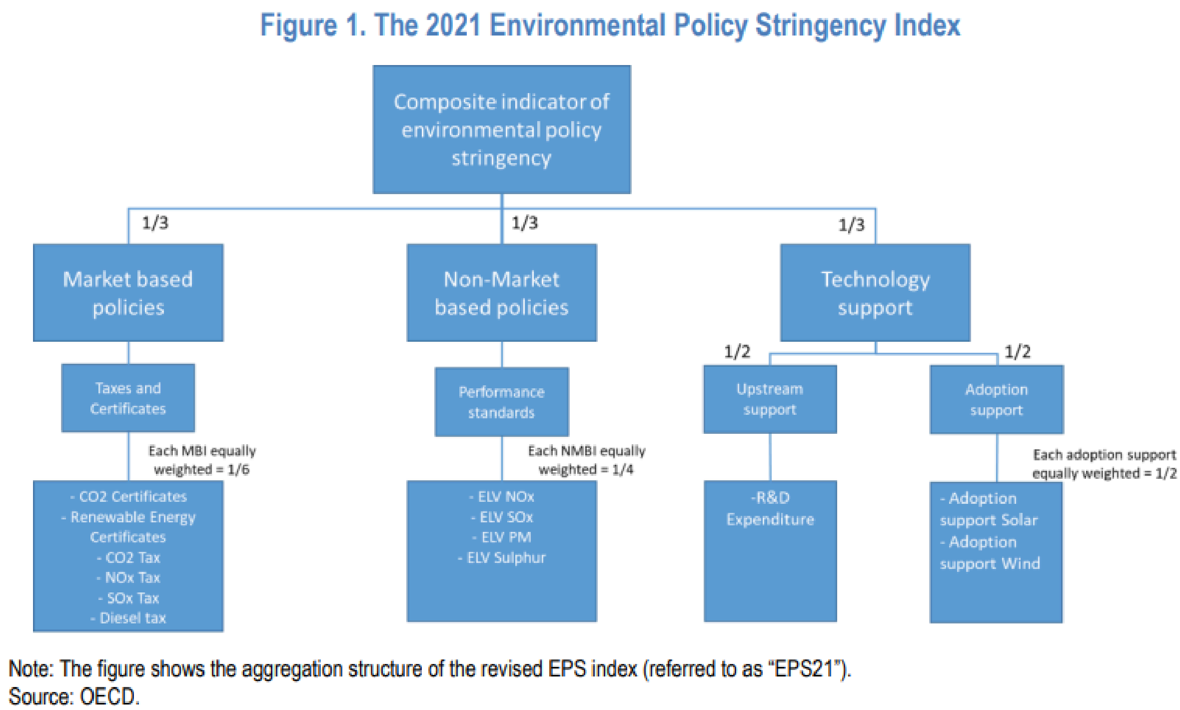

Figure 3*: Composition of OECD's Environmental Policy Stringency Index in 2021*

2.4 MSW generation in OECD countries

According to the IMF (2020), MSW generation in affluent countries, many of whom are part of OECD, is much higher than in developing nations. Much of the body of research points at affluence and economic activity being positively correlated with MSW generation (Magazzino et al., 2021; Cohen, 2019; Malouf & Mavropoulos, 2022). Furthermore, many of the goods and services these affluent consumers purchase use a lot of non biodegradable packaging. Furthermore, many of these products are so durable that they present a risk for the environment (IMF, 2020). Affluent countries also have a history of exporting a lot of this waste to developing nations (Winters, 2023). This waste, which includes textiles, plastics and e-waste, ends up in landfills located in developing countries that contaminate the soil and pollute the environment, creating severe health risks for the locals that live near these landfills (Winters, 2023).

Considering the high levels of waste generation in industrialized countries and the inequality present in the management of this waste, much of the responsibility to reduce waste lies with industrialized countries. Certain countries like Korea and Japan have taken a strong lead in this, showing a declining trend in waste generation and an increase in sustainable waste management processes (Agamuthu & Babel, 2023). However, most industrialized countries are still lagging behind. This study aims to see which industrialized countries produce the most MSW per household and what factors influence this. Therefore, the fourth sub question is:

SQ4: *Which countries that are part of the OECD generate the most MSW per household?*

Besides answering this research question, different case studies are conducted on countries that present interesting trends in MSW generation. These case studies contain individual statistical models and are linked to the body of research on MSW generation in these countries.

Data Sources & Description

The panel data consists of 25 OECD member countries, including Austria, Belgium, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Türkiye, United Kingdom, and United States. The timeframe of the study will be from 1997 to 2021. Such broad geographic coverage of study areas and a wide range of years would enable holistic analysis of the topic. The variables collected for the study are described below on table 1. The summary of the data is shown in table 2.

Label	Description	Classification	Source
mswpp	MSW PP (KG)	Dependent Variable	Organization for Economic Cooperation and Development (OECD)
envtax	Environmental tax (million dollars)	Political	Organization for Economic Cooperation and Development (OECD)
envtech	Environmental Related Patents (count)	Political	Organization for Economic Cooperation and Development (OECD)
string	Environmental Stringency Index	Political	Organization for Economic Cooperation and Development (OECD)
waste_recovery_ops_pp	Waste Recover Operations per Person including recycling (tonnes)	Political	Organization for Economic Cooperation and Development (OECD)
gni	Gross National Income	Socioeconomic	Organization for Economic Cooperation and Development (OECD)
meanschool	Mean schooling in years	Socioeconomic	United Nations Development Program (UNDP)
lifeexp	Life expectancy	Socioeconomic	United Nations Development Program (UNDP)
gdi	Gross Domestic Income Growth (%)	Socioeconomic	World Bank
hhspendmil	Household spending (millions)	Socioeconomic	Organization for Economic Cooperation and Development (OECD)
hhspendpp	Household Spending Per Person	Socioeconomic	Organization for Economic Cooperation and Development (OECD)
temperature	Temperature	Demographic/Geographic	Global Data Lab
urpop	Urban Population	Demographic/Geographic	World Bank
pop	Population Size	Demographic/Geographic	Organization for Economic Cooperation and Development (OECD)
dens	Population Density (per sq.km)	Demographic/Geographic	World Bank and OECD
fer	Fertility Rate	Demographic/Geographic	Organization for Economic Cooperation and Development (OECD)

***Table 1**. Labels, description and data sources for variables used as part of analysis.*

All of the data is sourced from reputable international institutions, such as Organization for Economic Cooperation and Development (OECD), World Bank, National Climatic Data

Center (NCDC), and National Centers for Environmental Information (NCEI). Most of the data is pulled from OECD to ensure consistency across multiple datasets. Due to the high variability in the data in terms of size (ex. population), some variables (Environmental tax, patents, household spending, recycling) had to be normalized by the total population. The dependent variable of the study is Municipal Solid Waste generation. The descriptive statistics (table 2) indicates that MSW generation across selected OECD countries ranges from 256 to 883.8 kg per person, with an average of 525 kg per person.

Name	Variable	Mean	Standard Deviation	Min	Max
Referencearea	Referencearea				
Country	Country_code				
Year	year				
Environmental Tax	envtax	24701.47	30434.17	231.5631	155106.2
Environmental Related Patents	envtech	1083.364	2240.444	0.5	10805.97
Environmental Stringency Index	string	2.557622	0.9891937	0	4.888889
Gross National Income	gni	37558.64	15435.18	8530	94500
Life Expectancy	lifeexp	79.53914	2.66455	70.57	84.784
Mean Years Schooling	meanschool	11.41202	1.74828	5.018	14.256
Gross Domestic Income Growth%	gdi	2.28304	3.318663	-11.2	24.5
Household spending (mil)	hhspendmil	892603.8	2067706	3786	1.59E+07
MSW PP (KG)	msw	525.9567	131.8329	256	883.7793
Household Spending Per Person	hhspendpp	18439.29	6724.9	4891.028	47894.77
Temperature	temp	10.05422	3.540119	0.992	16.81
Urban Population	urpop	77.27882	10.46788	52.428	98.117
Population Size	pop	4.08E+07	6.28E+07	271130	3.32E+08
Population Density	dens	162.3084	136.4316	2.704519	531.109
Fertility Rate	fer	1.601291	0.2857706	0.808	2.716
Waste Recovery Operations	waste_recovery_ops	12218.26	22548.56	0	132666
Waste Recovery Operations per Person	waste_recovery_ops_pp	.0003184	.0002069	0	.0008405
Environmental Related Patents Per Person	envtechpp	.0000221	.0000219	4.47e-08	.000128
Environmental Tax Per Person	envtaxpp	.000907	0005719	.0000727	.0029873

***Table 2**: Descriptive statistics of Variables*

Given the data gaps in certain variables in certain years, some OECD members (Mexico, Canada, Australia and New Zealand) had to be excluded from the study. Remaining nations with spots of missing data values were interpolated using a 3 point moving average.

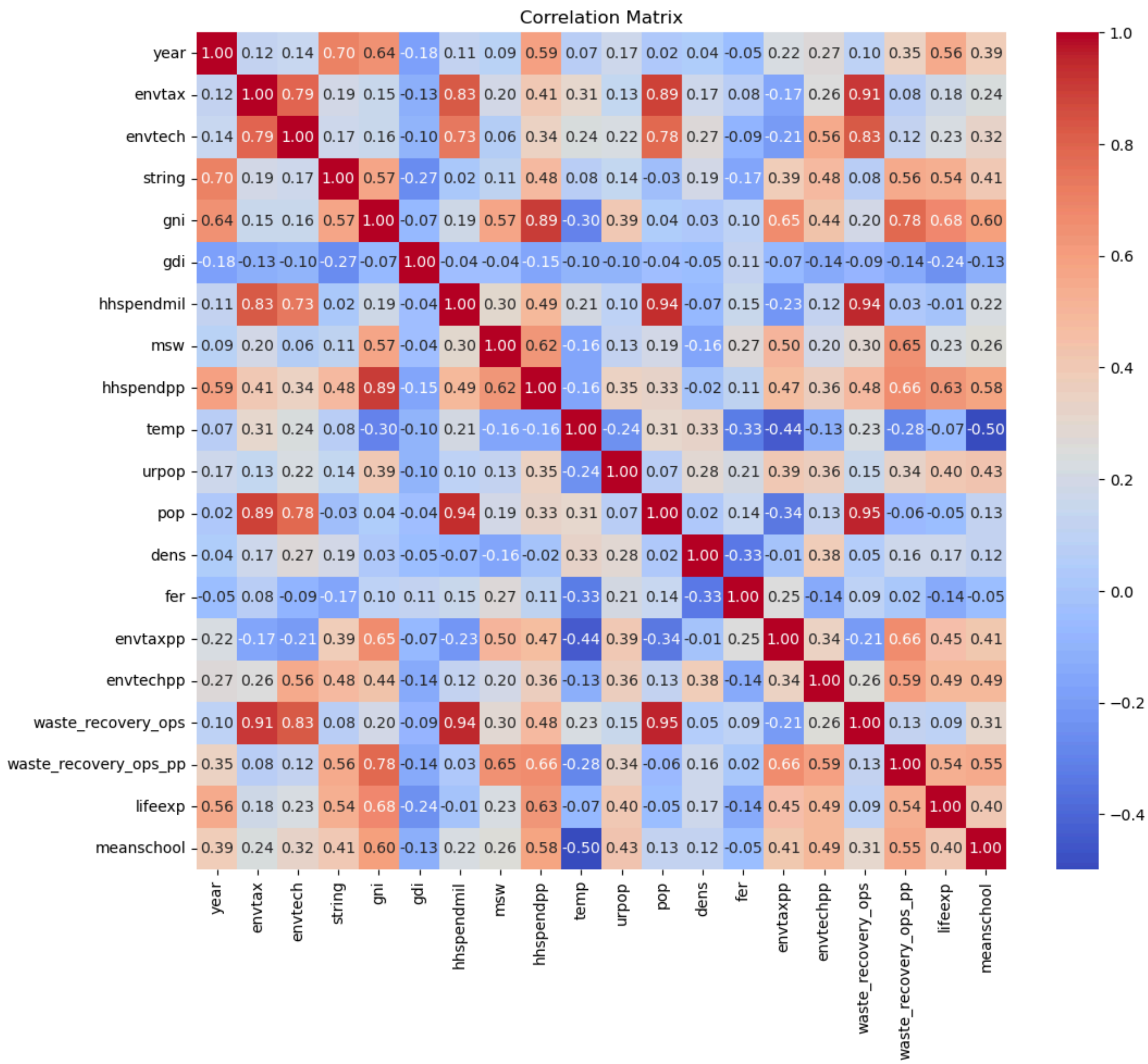

Figure 4: *Correlation matrix of all variables*

The data was tested for correlation (Figure 4). There are noticeable correlations among some independent variables: household spending and GNI, population and environmental tax, population and householding spending, waste recovery operations and environmental tax, waste recovery operations and environmental tech, waste recovery operations and householding spending, and waste recovery operations and population. The correlations between householding spending and GNI, as well as household spending to population and, can be explained by the fact that larger total spending would have larger GNI as well as other factors. The strong correlation between Environmental Tax and Waste Recovery Operation is logical, as taxing individuals for not recycling likely encourages more recycling behavior.

Similarly, the high correlation between Environmental Tax and Population Size, suggests that larger populations lead to increased spending and greater tax revenue for governments. This aligns with the idea that a higher population generates more tax payers, resulting in increased tax collection. One notable relationship to consider is between HH spend and Waste recovery operations. Previous research indicates that larger households tend to produce less waste, as they are more likely to use recyclable materials over the long term. Larger households also tend to have higher spending, which explains the strong correlation between household spending and recycling in this context.

One important consideration in this correlation test is the presence of multicollinearity among the independent variables since this can give incorrect results and misleading insights that potentially bias our interpretation of the relationship between dependent variables and independent variables. In light of the fact that they are strongly considered to have multicollinearity, the independent variables are tested for multicollinearity with the VIF (Variance Inflation Factor) test (Table 3). It is a statistical measure used to detect multicollinearity in a set of regression variables where VIF larger than 10 is considered to be extremely correlated that we need to address for multicollinearity.

Variable	VIF
waste_recovery_operations	52.67
pop	30.72
hhspendmil	25.75
hhspendpp	17.56
gni	14.53
envtax	12.7
envtech	9.6
waste_recovery_operations_pp	5.97
envtechpp	5.06
meanschool	5.04
lifeexp	4.37
temp	4.11
envtaxpp	3.89
string	3.33
dens	2.38
fer	2.04
urpop	1.93
gdi	1.24

Table 3*: variance inflation factor (VIF) test*

It turns out that population size (pop), waste recovery operations, Household spending(hhspendmil), Household spending per person (hhspendpp), environmental tax (envtax) and gross national income(gni) need to be addressed for multicollinearity issue, showing greater than VIF value of 10. To address this issue, some variables are dropped, including population and household spending. The population variable is dropped as it is already accounted for in normalized variables. Therefore, having population as a variable seems redundant. The household spending is dropped as household spending per person exists in the model.

Data Transformation

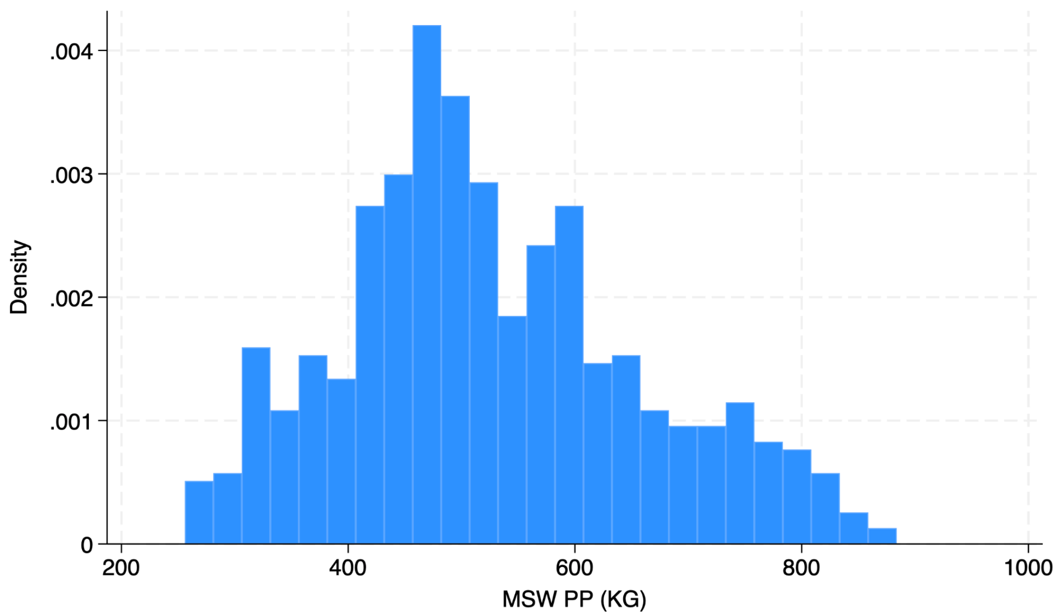

Figure 05*: histogram of MSW per capita*

Looking at the distribution of our dependent variable (figure 05), MSW PP, the distribution is slightly skewed to the right. We considered some transformations including log transformations and power transformation to address this.The log-transformed MSW data (figure 06) is no longer skewed to the right but now shows slight left skewness. Additionally, the power-transformed MSW data on figure 07 exhibits even stronger positive skewness. Since these transformations do not effectively resolve the skewness issue and the degree of skewness in MSW is minor, we decided not to apply any transformations. We expect that this weak skewness will not significantly bias our predictions. Furthermore, our primary focus is on understanding the relationships and quantifying the impact of various factors on MSW rather than perfecting the change in MSW in the future, so this minor degree of skewness would not be important in the context of our research..

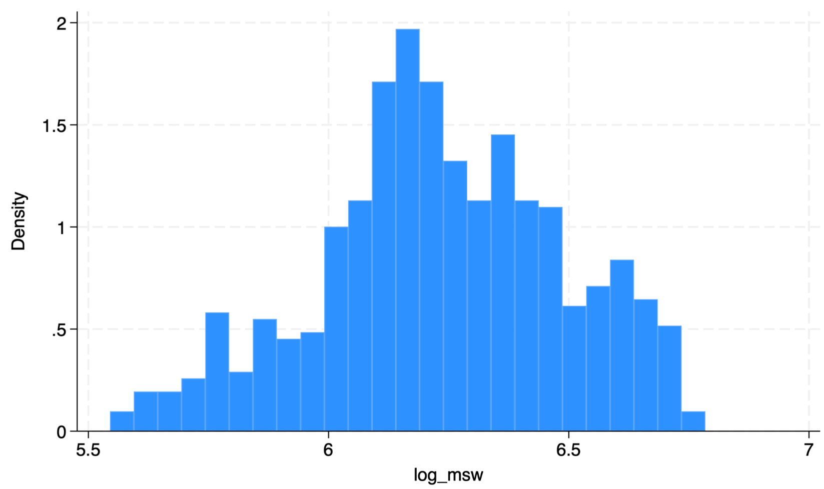

Figure 06: *histogram of log-transformed MSW per capita*

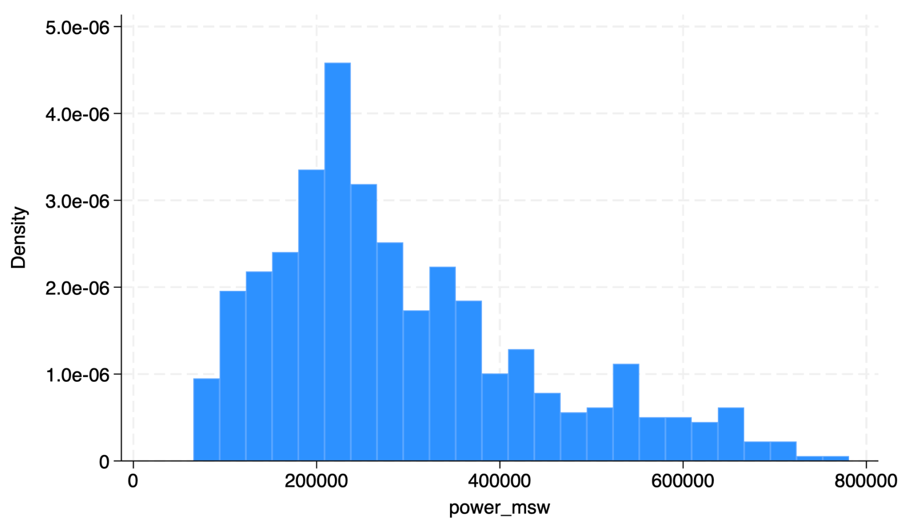

Figure 07*: histogram of power-transformed MSW per capita*

Another data transformation applied is taking the first differences and incorporating lagged values for both dependent and independent variables. Since the study involves time series data, time-variant variables are expected. If not properly addressed, this can result in temporal autocorrelation and spurious regression, leading to misinterpretation of results and inaccurate insights. Additionally, lagged values not only address non-stationary variables, but also capture delayed effects of the factors. Hence, it is important to do those transformations in time series analysis for capturing past effects, addressing temporal autocorrelation, and ensuring accurate and meaningful results.

Methodology

The study aims to explore the effect of socioeconomic, geographical and political factors on production of municipal solid waste in OECD countries from 1997 to 2021. To approach the issue, the study would invoke construction of models that incorporate variables identified in each factor.

Given that the project is involved with multiple categorical values, countries and time series data, panel regression analysis is found to be appropriate. Panel regression is a method used to analyze datasets where observations are collected over time for the same multiple entities. Not only this reason, but also some other past research associated with MSW made use of panel regression, and ended up finding meaningful insights. For example, Mazzanti et al. (2009) uses panel regression analysis on a dataset where there are 103 different provinces of Italy from 2001 to 2004. Using the provinces as cross sectional dimension and years as time series dimension, they were able to find evidence that strongly supports their hypothesis. In q2Ercolano et al. (2017), the research includes Lombardy regions in Italy as a cross-sectional variable, using daily per capita waste generation as a target variable over a 7 years period from 2005 to 2011.The study aimed to explore the relationship between economic wealth and waste production, as described by the Waste Kuznets Curve (WKC). Using a panel data approach, the researchers achieved meaningful results, demonstrating a robust, reliable, and well-fitting model. Not only this research, but also other research associated with MSW involved cross-sectional variables with time period (Cecere,, 2016; Banacu et al., 2019; Mance et al., 2020) employed panel data analysis and they were effective. Based on the review, the model for panel regression can be outlined as:

$$Y_{i\,t} = \beta_0 + \beta_1 X_{1,it} + \beta_2 X_{2,it} + \beta_3 X_{3,it} + \beta_1 X_{1,it} + \alpha_i + \epsilon_{it}$$

- $Y_{i\,t}$ - dependent variable for observed i at time t
- $X_{i\,t}$ - independent variables
- α_i - unobserved effects capturing time-constant individual heterogeneity
- ϵ_{it} - error that varies across time
- β_0 - intercept
- $\beta_{1,2,3\ldots n}$ - coefficient

Before conducting panel analysis, the data would be tested for collinearity as some independent variables might be intercorrelated, which could cause large standard errors and may lead to inaccurate results. Additionally, it must be determined whether a fixed effects model or random effects model is most appropriate. A fixed effects model assumes there are differences between panels that can not be included in the model (i.e.: missing data or different calculation methods), and that may influence the coefficient of the variables within the panel (Zulfikar, 2018). Whereas the random effects model assumes that the differences between panel data is random and uncorrelated with the independent and dependent variables (Zulfikar, 2018). Furthermore, the random effects model is often used to eliminate heteroscedasticity (Zulfikar, 2018). However, as visible in Appendix B, the variance of results do not indicate that there is heteroscedasticity present in this research study. To test whether a fixed effects model or random effects model is most appropriate, one should conduct the Hausman test (Zulfikar, 2018). The null hypothesis of this test states that a random effects model is most appropriate, whereas the alternative hypothesis states that the fixed effects model should be used. Therefore, if the P value of the test exceeds the alpha level of 0.05, a random effects model should be chosen. After conducting this test, the P value of the Hausman test was 0.0003, meaning that a fixed effects model is most appropriate for this study.

The panel regression model provided interesting insights into MSW generation, but does not paint the full picture. After conducting unit root tests, it seemed that most independent variables are nonstationary (Appendix A). Therefore, based on the significant variables of the Panel Regression Model, an OLS Regression Model was created that controls for time and space. Such application of OLS regression is also observable in past research. For example, Aguilar et al. (2020) used multiple linear regression models to forecast the rate of MSW in Mexico. The model was effective, showing that MAPE, MAD and RMSE, the values of 7.70, 0.16 and 0.19, respectively, indicate a high precision since the values of these tests are close to 0. Furthermore, Multiple Linear Regression appears to be the commonly used analysis method for analyzing municipal solid waste and what factors influence MSW, as employed in numerous past researches including Wei et al. (2013), Popli et al. (2021), and Khajevand Tehrani (2019) Vivekananda, Nema. (2014). The external validation by R3 jackknife presented a value of 97.44%, indicating high forecasting capacity. Furthermore, another study by (Khajevand & Tehrani. 2019) performs multiple different analyses on MSW generation, and multiple linear regression-OLS ended up having the most precision on MSW generation prediction. Despite its simplicity, the widespread use of the OLS highlights its effectiveness in analyzing the relationship between MSW and other factors, especially when the research is scoped to single countries or regional scales. The purpose of MSW is to present general trends in the data, while accounting for the strong influence of time in this study. The equation of this model is presented below:

$$y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + \ldots + \varepsilon$$

where $B_{0,1,2,3}$ are the parameters, $X_{1,2,3}$ are explanatory variable, y is an outcome (dependent variable), and ɛ is an error term.

In addition, the study will involve the use of Analysis of variance (ANOVA) to test statistically significant differences across countries or defined groups. For this part of the study, dependent variables will be selected and aggregated into specific categories. Similar to the way ANOVA was used to evaluate the seasonal variations in MSW generations in previous studies (Ayeleru et al., 2018, Likando & Chipandwe, 2024), the ANOVA will be used to capture the between and in group variance of individuals variables in MSW generation.

The final part of analysis would focus on case studies of specific countries, as latter results from ANOVA indicate differences exist within countries in terms of demographic, social, economical and political factors, which may vary spatially and may influence MSW. The dataset would be divided by individual countries, and regression analysis would then be performed for each country to understand MSW production variability across OECD countries.

5. Results

As explained in the methodology, the two main statistical methods of this study are the Panel Regression with fixed effects, and the OLS Regression controlling for time and space. This chapter presents the data from these tests.

5.1 Panel Regression

As certain predictors were correlated, a few independent variables were omitted prior to the development of this statistical model. Firstly, Gross National Income and household spend per capita had a correlation coefficient of 0.89, meaning that the values of these variables are influenced by each other. Because of this, Gross National Income was omitted. Furthermore, population size was used to generate new independent variables such as environmental tax per capita and household spending per capita. Because of this, population size had numerous high correlation coefficients and was thus excluded from the model. Furthermore, based on the highest P value, insignificant predictors were omitted one at a time. This backward variable selection ceased after the R2 value would stop increasing and important variables were next to be removed. Additionally, considering the influence of time in this study, lags were administered to different variables. This was done to see how the impact of certain predictors would influence MSW generation over time. Finally, the Panel Regression was conducted with fixed effects as a result from the Hausman test. The low P value of this test can be attributed to the differences in methods and calculations between countries.

After considering these different aspects and all processes were conducted, the final panel regression model was developed. This model is expressed with the following equation and is presented in table 4 and 5.

$$MSW_{i\,t} = \beta_0 + \beta_1\, EnvTech_{i\,t\text{-}4} + \beta_2\, EnvTaxPP_{i\,t\text{-}4} + \beta_3\, Lifeexp_{i\,t} + \beta_4\, Meanschool_{i\,t} + \beta_5\, HHSpendPP_{i\,t} + \beta_6\, Urpop_{i\,t} + \beta_7\, Fer_{i\,t\text{-}5} + \beta_8\, WasteRecoveryOperationsPP_{i\,t} + \alpha_i + \epsilon_{i\,t}$$

Observations	500
Panels	25
F Statistic (8, 467)	44.82
P value	0.000
R^2 Within	0.4343
R^2 Between	0.2163
R^2 Overall	0.2373

***Table 4**: Panel Regression Model Summary*

Independent Variable	Lags	Coefficient	Standard error	P value
Environmental tech	4	-.004664	.0033505	0.165
Environmental tax per capita	4	-23322.12	11100.52	0.036
Life expectancy	0	-19.60994	3.885764	0.000
Mean years of schooling	0	-4.141283	6.948685	0.551
Household spending per capita	0	0.0072164	0.001315	0.000
Urban population	0	-7.623324	1.609276	0.000
Fertility rate	5	-92.73108	22.21411	0.000
Waste recovery operations per capita	0	481394.1	37789.33	0.000
Constant	0	2610.416	259.9396	0.00

***Table 5**: Panel Regression Variables Summary*

The model is deemed statistically significant due to the F statistic (8, 467) exceeding 2.5 and the P value of the model being lower than the alpha level of 0.05 that was determined for this study. Therefore, it can be assumed that this model explains a degree of variance in MSW generation between OECD countries over 21 years. The R^2 Within of this model is 0.4343 indicates that within the panels, the predictors in this model are able to explain 43.43% of variance in MSW. While important for this study, this model deemed environmental tax and mean years of schooling to be statistically insignificant predictors in MSW. The other variables have P values that are lower than the alpha level of 0.05, meaning those are significant predictors. The coefficients are adjusted to the value of individual predictors, to see the influence of these coefficients, it is helpful to increase the value of the variable and observe the influence.

There are some socioeconomic factors that strongly affect MSW generation. As the coefficient of household spending per capita is 0.0072164, an increase of 1000 dollars in household spending would result in 7.21 kg more MSW to be generated. Given that a scale of values in the feature is extremely large, this positive relationship suggests that higher household spending leads to more waste generation likely due to increased consumption and disposal of goods. Since it is a household spending at per capita level, we need to focus on individual-level consumption behaviors. It would be more effective to target high spending households since they are likely to contribute to waste generation more than low spending households. Strategies such as promoting sustainable consumption, encouraging recycling, and incentivizing less wasteful purchasing behaviors could also help mitigate this effect. Life expectancy is also an important socioeconomic factor. It has a coefficient of -19.660994 with a p-value of 0.000, meaning one year increase in life expectancy leads to approximately 20 kg reduction in MSW generation. A longer life expectancy negatively correlates with MSW, possibly due to environmentally aware populations or stricter regulations in regions with longer life spans. And, This is a valid assumption that longer life span is often associated with the developed countries whose population are more aware of environmental importance. That is, This could imply that countries or regions with higher life expectancy may adopt more sustainable consumption habits or advanced waste management systems, leading to less waste generation.

As to political factors, waste recovery operations per capita and environmental tax per capita play a significant role in increasing and reducing MSW generation. For waste recovery operations per capita, the coefficient has a high value of 481394.1. However, the value of the observation is very low, so an increase of 0.00001 in this variable would result in 4.81 kg more MSW to be generated. Despite the fact that values are low in those features, we can not deny that waste recovery operations per capita has a positive association with MSW. This result may indicate that increasing operations does not directly translate to reduced waste generation. As MSW generation increases, more waste recovery operations are implemented, leading to a feedback loop rather than a direct reduction in waste, leading to a great inefficiencies in the system. This emphasizes that simply increasing the number of waste recovery operations may not be sufficient to reduce waste generation, but need to employ more effective deployment strategies. Additionally, the positive relationship between them might simply indicate that large overall MSW generation. Hence, this shows large recovery operations as they have a large MSW generation. Environmental tax per capita has a coefficient of -23332.12. It has an extremely large coefficient due to scaling issues. However, considering that its value ranges from 0.0000727 to 0.00298732, environmental tax per capita is crucial for managing MSW generation, which means the minor changes in this variable can lead to large changes in MSW generation. A negative relationship indicates that higher environmental taxes per capita lead to a reduction in MSW per capita as expected. This suggests that taxes may incentivize waste reduction behaviors or investment in waste management systems. As current environmental tax shows a great impact on reduction in MSW generation, we should consider maintaining or increasing environmental tax rates. Taxation has a notable deterrent effect on waste generation at the individual level, likely incentivizing less wasteful behaviors.

Lastly, urban population has a coefficient of -7.623324 and its p-value is 0.000, indicating that this variable is statistically significant. Unexpectedly, the urban population is negatively associated with MSW generation while urban populations are often positively correlated with MSW generation due to high consumption patterns around urban areas. However, since urban populations are more environmentally aware and have better access to strict regulations, these negative coefficients could be reasonable. Also, considering the scope of the research is limited to OECD countries with high development, this could indicate that urban areas in the sampled OECD countries have better waste management systems, which mitigate waste generation. Alternatively, sampled OECD countries have more urbanized structure of populations across their territories and urban population might play a role counterintutivtively.. In this case, we need further research about their dynamics and structures of population to better understand how they are correlated. Fertility Rate has a coefficient of -92.73108 with p-value of 0.000. There is a high negative relationship between fertility rate and MSW where one unit increase in fertility rate leads to approximately 92 kg reduction in MSW. Countries with higher fertility are often less industrialized with consumption patterns where they use less disposable productions. Furthermore, Fertility rate represents the household size in this research. Past research finds that large household sizes often have lower per capita waste generation. This is because large households tend to utilize resources more effectively such as using recyclable products instead of single-use items, which reduces the MSW. Encouraging family-based consumption patterns across households could improve reduction in MSW.

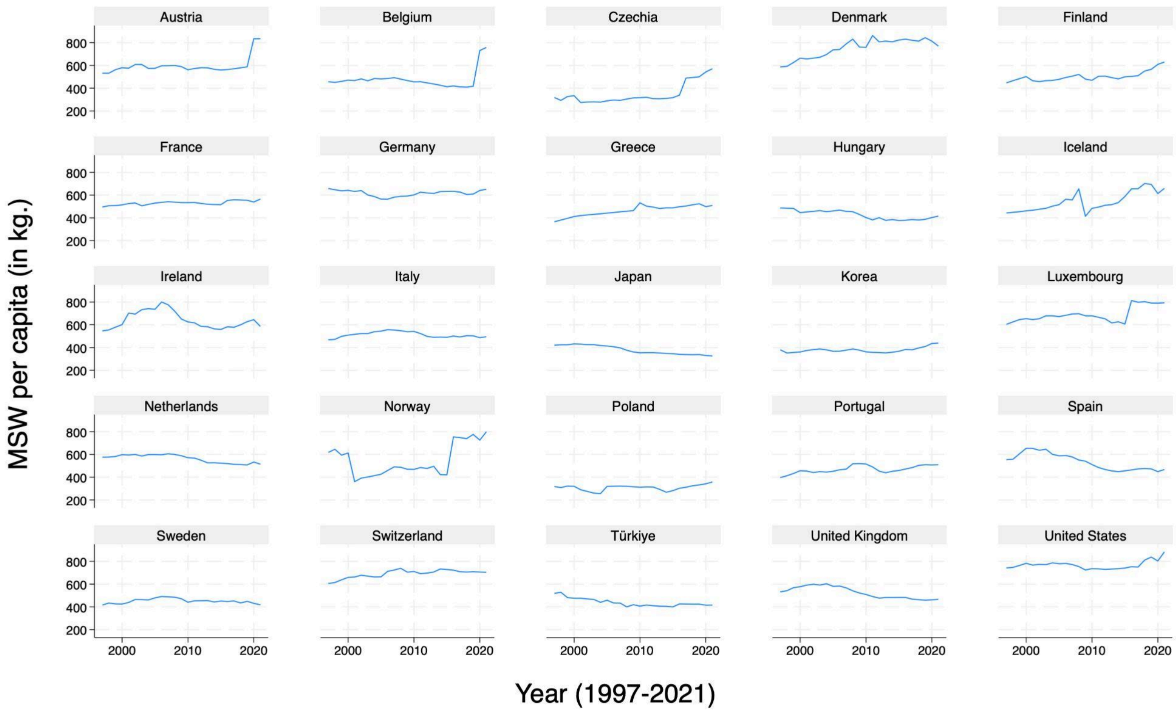

***Figure 8**: Trends in MSW generation in different countries.*

5.2 OLS Regression

The Panel Regression Model provided interesting insights into MSW generation, but does not paint the full picture. After conducting unit root tests, it seemed that most independent variables are nonstationary (Appendix A). The OLS Regression Model was created that controls time and space in order that we can primarily focus on the true and inherent relationship between MSW and other factors, while accounting for unobserved factors that can vary across regions and time. This presents general trends in the data, while accounting for the strong influence of time in this study. The equation of this model is presented below and the findings of this model are presented in images x and y. Independent variables used in the model are selected by backward selection in order to mitigate multicollinearity issues and reduce the dimensionality for better interpretation.

$$MSW = \beta_0 + \beta_1\, EnvTech + \beta_2\, EnvTechPP + \beta_3\, Gross\ National\ Income + \beta_4\, Lifeexp + \beta_5\, Meanschool + \beta_6\, HHSpendPP + \beta_7\, HHspend(mil) + \beta_8\, Urban\ Population + \beta_9\, WasteRecoveryOperationsPP + \beta_{10}\, WasteRecoveryOperationsPP + \beta_{11}\, Year + \beta_{12}\, Country + \epsilon$$

Observations	625
F Statistic (40, 584)	141.47
P value	0.000
R^2 Value	0.8992
Adjusted R^2 Value	0.8928
Root MSE	43.162

***Table 6**: OLS model summary*

Independent Variable	Coefficient	Standard error	P value
Environmental tech	--0.0088242	0.0030912	0.004
Environmental tech per capita	1451932	216866.7	0.000
Gross National Income	-.0033926	.0005481	0.000
Life expectancy	-24.32864	2.705928	0.000
Mean years of schooling	18.53911	4.182077	0.000
Household spending per capita	0.0111428	0.0017099	0.000
Household Spending(mil)	0.0000333	6.13e-06	0.000
Population Size	-8.15e-07	3.02e-07	0.007
Urban population	-6.306629	1.897413	0.000
Waste recovery operations per capita	634866.9	40360.11	0.000
Waste recovery operations	-0.0084614	0.0007683	0.000
Constant	2221.648	193.1427	0.000

Table 7: *OLS regression variables summary*

The p-value of 0.000 for F-statistics of this model indicates that our model has a great fit overall. Approximately 90% of variations in the dependent variable are explained by the independent variables. Additionally, the adjusted R-Squared value of 89% accounts for the number of predictors, indicating great overall fit of the model.

According to this model, both political, demographic, and socioeconomic factors complicatedly affect the amount of generation in MSW. As for political factors, environmental tech has a coefficient of -0.008842 with p-value of 0.004, indicating statistical significance. This negative association might imply that the advance in environmental technology contributes to the reduction in MSW. The magnitude of coefficient is very small, close to zero due to scaling issues, where the values in environmental tech range from 0.5 to 10805.97. Even taking that into account, the 8kg reduction in MSW requires approximately 1000 unit increase in environmental technology, indicating that environmental technology, in its current form, might not significantly affect MSW reduction at a systemic level. In contrast, when examining environmental technology on a per capita basis, its coefficient is 1451932, which is positive and extremely larger than total environmental tech unlike aggregated environmental technology. Environmental technology per person range is from 4.47e-08 to 0.000128, which means 6.89e-07 increase in environmental energy leads to 1 kg increase in MSW generation. This indicates that, unlike the aggregated measure, the individual-level environment technology significantly increases MSW with greater magnitude, suggesting it is more sensitive to changes at the per capita level. This disparity suggests that environmental technology shows some effectiveness broadly, but might not be effectively utilized evenly across populations. That is, it slightly reduces MSW at a broad scale but may have localized or uneven effects Additionally, in light of the fact that the values of environmental tax per capita are extremely low, scaling the variable per capita was exaggerating its magnitude, making it appear more influential than it is at the systemic level.

In terms of socioeconomic factors, the main variables that stand out from the model are household spending, household spending per capita, gross national income, life expectancy, mean years of schooling. Out of 22 features, 10 were selected, with 5 representing socioeconomic factors, underscoring their various impacts on MSW generation. Household spending has a coefficient of 0.000333 and a p-value of 0.000, indicating that this variable is statistically significant. However, the magnitude of this coefficient is relatively small due to the large scale of household spending values, which range from 3,786 to 15,900,000 (in millions). To put this in perspective, a 1 million unit increase in household spending corresponds to a 333 kg increase in MSW, suggesting that aggregate national spending does have an impact but is somewhat moderate in magnitude. Also, scoping to per capita level of household spending, its coefficient is 0.011428, with a p value of 0.001. While this value appears larger than the aggregate household spending coefficient, it is essential to account for the per capita spending range from 4,891.03 to 47,894.77. This means that a 1,000-unit increase in per capita household spending leads to approximately 11.4 kg of additional MSW generation. Therefore, per capita household spending has a larger impact than aggregate household spending, suggesting that waste generation is influenced more by individual-level consumption patterns than aggregate national-level spending since per capita level analysis reflects the direct influence of individual consumption patterns on MSW. This could imply consumption behaviors are key drivers of MSW generation. It underscores the need for targeted interventions, such as encouraging sustainable consumption practices.

Next variable to focus on is a gross national income with a coefficient of -0.0033926 and p value of 0.001. A small negative effect suggests that higher GNI might be associated with better waste management or investment in waste reduction programs. However, the magnitude of the effect is too small to draw strong conclusions. Life expectancy has a coefficient of -24.32864 with a p-value of 0.001. That is, a one-year increase in life expectancy is associated with a reduction of approximately 24.33 kg of MSW. This possibly reflects better waste management policies in countries as countries with better waste management policies tend to have longer life spans, or possibly older populations generate less waste with low consumption rate than younger populations. With respect to mean years of schooling, it is positively related to MSW with a coefficient of 18.53911 and a p-value of 0.000. This suggests that higher educational levels might correspond to the increase of MSW. Higher education is often associated with increased income levels and urban areas, so populations with higher education are likely to have more consumption-driven lifestyles that generate more MSW. Life expectancy and mean years of schooling reflect complex socioeconomic dynamics and require multidimensional waste reduction strategies. It needs further research on how life expectancy, education level and MSW generation are related along with the investigation into the consumption behaviors associated with higher education and the systems in waste management seen in countries with higher life expectancy.

Lastly, demographics factors also account for MSW according to the model. As for Population size, it shows the coefficient of -8.15e-07 with a p-value of 0.007, indicating statistical significance at the common alpha level of 0.05. Its coefficient is extremely small, indicating that population size has a negligible direct effect on MSW. Specifically, a one-unit increase in population size (in millions) corresponds to a reduction of only 0.000815 kg of MSW. Considering the population range in the dataset 271,130 to 332,000,000, this effect is practically insignificant. This could mean that other factors such as socioeconomic behaviors, waste management policies, or technological advancements may obscure the influence of population size on MSW. This underscores the complexity of MSW generation and suggests that systemic and behavioral factors are more critical determinants. However, Urban population has a coefficient of -6.306629 with a p-value of 0.000. This negative association between urban population and MSW is counterintuitive as urban areas are often associated with higher waste generation due to greater consumption and economic activities. However, this could reflect that urban areas have more advanced waste management systems to reduce MSW. It is also possible that the countries in this research are OECD countries with higher levels of development where they have a better infrastructure, stricter waste reduction policies, and more widespread adoption of recycling and waste recovery technologies. These factors might explain why urban populations contribute less to MSW than expected.

5.3 ANOVA

Both Panel and OLS regression provided insights on factors that influenced the MSW generation controlling for time, space and heterogeneity. However, this analysis does not formally address the differences between the MSW across countries or other categories.To understand if there are significant differences between groups of observation, ANOVA was adapted.

Observations	25
R^2 Value	0.5749
Adjusted R^2 Value	0.5363
Root MSE	24.214

Table 8: *Summary table of ANOVA on Netherlands*

Independent Variable	Sum of Squares	Degrees of Freedom	Mean Square	F	P value
stringency	17445.998	2	8722.9992	14.88	0.0001
Residual	12899.042	22	586.32008		
Total	30345.04	24	1264.3767		

Table 9*: Summary table of Variables*

The initial analysis (table 8 and 9) focused on understanding differences in MSW generation between levels of environmental stringency, when controlled for a state. The dataset above has been adjusted to control for the country, only including data from the Netherlands. The P value of 0.0001 demonstrates that stringency index alone does affect the solid waste. The adjusted R squared value is .5363, suggesting about 53% of variation in MSW is explained by the stringency categories (from 1 = low to 3 high).

When the ANOVA is run on the entire dataset (table 10 and 11), the result is quite different. Consistent with the previous reasoning, the p value is significant at the 0.05 level of significance, demonstrating that there is significant difference between stringency levels. However, the low overall and adjusted R value mean that stringency only accounts for around 5 to 6 percent of variation in MSW. The results appear to indicate that political factors are a big factor in solid waste generation in some countries but not as whole.

Observations	625
R^2 Value	0.0612
Adjusted R^2 Value	0.0551
Root MSE	128.147

Table 10*: Summary table of ANOVA for all countries combined*

Independent Variable	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F**	**P value**
stringency	663706.92	4	165926.73	10.10	0.0000
Residual	10181360	620	16421.549		
Total	10845067	624	17379.916		

Table 11*: Summary table of variables*

6. Case Studies

The maps in figures 9 and 10 present MSW generation in the OECD countries that are in the scope of this research. These images are rather telling, as some nations show significant positive or negative change, while other nations stayed consistent between 1997 and 2021. Based on these images and the trend lines in Figure 8, different case studies are conducted to understand the trends and behavior in waste generation. Firstly, MSW generation in Denmark is analyzed, as this country shows high levels of MSW and moderate levels of fluctuation between the years. Secondly, Japan is analyzed, as this country presents consistently low MSW generation between 1997 and 2021. Finally, the United States is discussed, as this economic superpower has some of the the largest MSW generation per capita in the world.

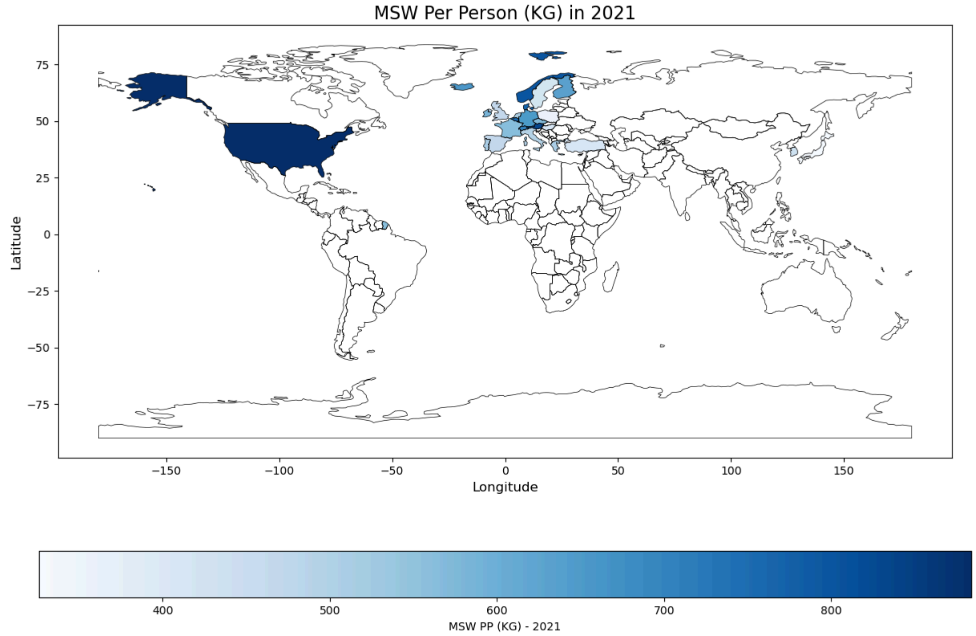

Figure 9: *MSW per capita (2021)*

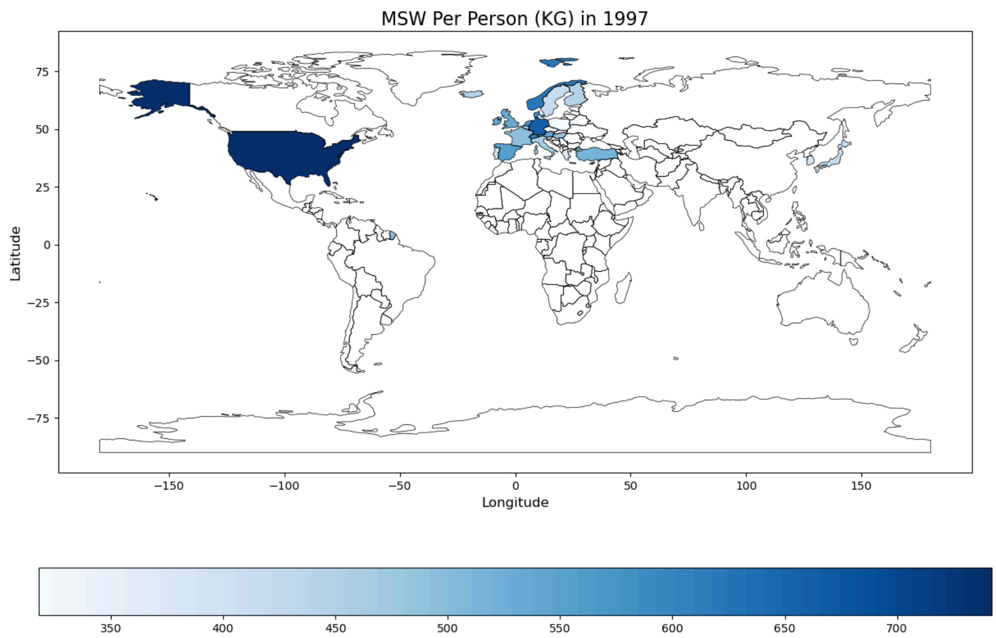

Figure 10: *MSW per capita (1997)*

6.1 Denmark and Waste Incineration

The mean MSW generation per capita between 1997 and 2021 for OECD countries within the scope of this research was 523 kg. and 2021. However in Denmark, the mean MSW generation per capita is significantly higher, sitting at 754.4 kg. Furthermore, while the growth is now stagnating, MSW generation has grown consistently over the last 25 years in Denmark. This growth has been visualized in Figure 11. These were interesting discoveries, as Denmark is often considered one of the most sustainable countries on Earth (State of Green, 2022).

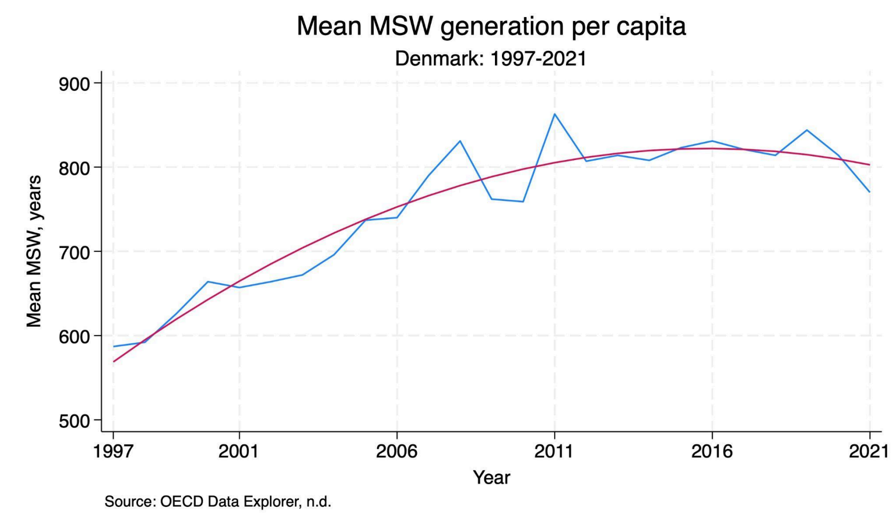

Figure 11*: MSW generation per capita in Denmark*

After investigating the potential reasons behind Denmark's relatively high MSW generation, different research and arguments were discovered. According to Paolino (2022), Denmark compensates for its high levels of waste generation by excelling in waste management, ranking only second to Korea. Magazzino et al. (2021) concur and add "Since Denmark displays one of the world's highest income per capita, this economy may have reached a turning point of economic development after which, wealth enhances waste generation while it reduces emissions from the waste sector (p. 13)." These findings indicate that while Danish people generate a lot of MSW, the government compensates for this by heavily investing in waste management processes and technology. One of these processes is waste-to-energy incineration processes.

Using advanced waste incineration processes that are able to remove toxic pollutants, electricity is able to be generated from municipal waste (Schaar, 2020). Waste incineration is a growing trend in all Scandinavian countries, many of which are motivated to substitute landfills with waste incineration plants (Mattson et al., 2024). However, this process considers waste to be a resource, and there is a linear relationship between the amount of waste and the amount of electricity that is generated (Mattson et al., 2024). Because of this, the Danes are forced to import much of this from other countries (Schaar, 2020). Furthermore, while modern waste-to-energy processes are able to remove many toxic pollutants, numerous negative effects on human health remain (Tait et al., 2020). According to Tait et al. (2020) numerous studies in Australia have found causality between waste incineration and different negative effects on human health, including: reproductive outcomes (such as miscarriages and infertility) and certain forms of cancer. However, it is important to mention that Tait et al. (2020) were able to debunk other health claims regarding waste incineration related to mental health, cardiovascularity and respiratory systems. Still, empirical evidence exists that indicates that waste incineration is unable to remove all toxic pollutants (Magazzino et al., 2021; Tait et al., 2020).

Besides health concerns, many organizations and scholars believe that waste generation and GHG emissions are correlated. Because of this, these actors advise that countries focus on reducing overconsumption and waste generation, rather than betting on waste valorization and recycling Paolino, 2022; EPA, 2016). Relying on waste-to-energy processes for final energy, will result in countries becoming dependent on these energy systems, making it counterproductive to reduce consumption and waste generation (Schaar, 2020). Considering these arguments, Denmark faces a paradoxical dilemma: Will it reduce MSW generation and lose a reliable electricity source, or increase MSW generation which could lead to a dependency on this *resource* and potentially harm its citizens?

Despite waste incineration falling out of the scope of this research, this variable was added for this case study and is expressed in tonnes, thousands (kg.). Furthermore, there seems to be evidence that there is a relationship between wealth, environmental technology, policies and MSW generation in Denmark. To test if these variables could explain variance in MSW generation in Denmark, an OLS regression was conducted, starting with the following independent variables: Gross national income, waste-to-energy incineration, environmental tax, environmental tech and environmental stringency. Due to the high correlation between waste recovery operations and MSW generation, this variable was not used in this particular OLS regression model. Furthermore, using backwards variable selection, stringency was omitted due to its high P value. Therefore, the final model used environmental tax, waste-to-energy incineration, environmental tech and gross national income to explain variance in MSW generation per capita. This OLS Regression model has a F statistic (4, 20) of 118.41 and a P value of 0.000. Therefore, the null hypothesis is rejected, meaning this model explains a degree of variance in MSW generation in Denmark. According to the adjusted R2 value, this model captures 95.14% of variance in MSW generation per capita. A detailed breakdown of the predictors is visible in table 12. The equation of this model is as follows:

$$MSW = \beta_0 + \beta_1 EnvTech + \beta_2 WasteInc + \beta_3 EnvTax + \beta_4 GNI + \epsilon$$

Independent Variable	Coefficient	Standardized Coefficient	Standard error	P value
Environmental tech	0.1399941	0.254276	0.0585573	0.027
Waste incineration	0.12223501	0.4167135	0.219205	0.000
Environmental tax	.0131689	0.0090282	0.0024644	0.002
Gross national income	0.0013093	0.2109794	0.0005244	0.021
Constant	281.4285	N/A	40.70469	0.000

Table 12: *OLS Regression Model - MSW generated in Denmark between 1997 and 2021*

To test the relative effects of these variables, each variable's value from 2021 is increased by 10% and this growth is subsequently multiplied by the coefficient of the variable. 10% growth in wealth, expressed in gross national income, increases MSW generation per capita by 9.51 kilograms. Furthermore, an 10% increase in environmental tech increases MSW generation per capita by 5.5 kilograms and an 10% increase in environmental tax from 2021 increases MSW generation per capita by 15.12 kilograms. Finally a 10% in waste incineration increases MSW generation by 23.98 kilograms. These statistical findings concur with the body of research on MSW generation in Denmark and based on these findings, a number of conclusions can be drawn.

All of the predictors in this model have a positive relationship with MSW generation, indicating that MSW generation is not slowing down in Denmark. Furthermore, concurring with research by Magazzino et al. (2021), the relationship between wealth and MSW generation is visible in this OLS regression model. However, more interestingly is that while the sustainability of Denmark is undeniable, the Danes are highly dependent on MSW for electricity generation (State of Green, 2022; Magazzino et al., 2021; Mattson et al., 2024). The body of research indicates that much of the environmental technology that Denmark possesses, is geared towards developing a circular economy, mainly centered around waste-to-energy processes (Schaar, 2020). However, if the country becomes dependent on waste incineration for final energy, it becomes counterproductive to reduce consumer consumption, as this would decrease the resources required for waste incineration (Magazzino et al. 2021). According to Magazzino et al. (2021), if Denmark wishes to commit to developing a circular economy, the solution may lie in material efficiency. These materials would result in less pollutants entering the atmosphere and using materials effective for waste incineration would improve energy efficiency as well.

However, this would leave the consumption issue unaddressed. According to Malouf and Mavropoulos (2022), industrialized countries generate 34% of global MSW, which has a direct negative impact on developing nations. If Denmark increases its consumption level to fuel waste incineration plants, it will exacerbate the inequality issue that is present in this matter. Furthermore, Mattson et al. (2024) state that waste incineration is a popular trend in Scandinavia and other European countries, indicating that the reduction of MSW generation is not prioritized in these regions. This stance by Mattson et al. (2024) concurs with the findings of this study, as most European countries exceed the mean MSW generation of countries within the scope of this research. This is visualized in figure 12, which shows that many European countries generate more MSW per capita than the mean of 523 kg.

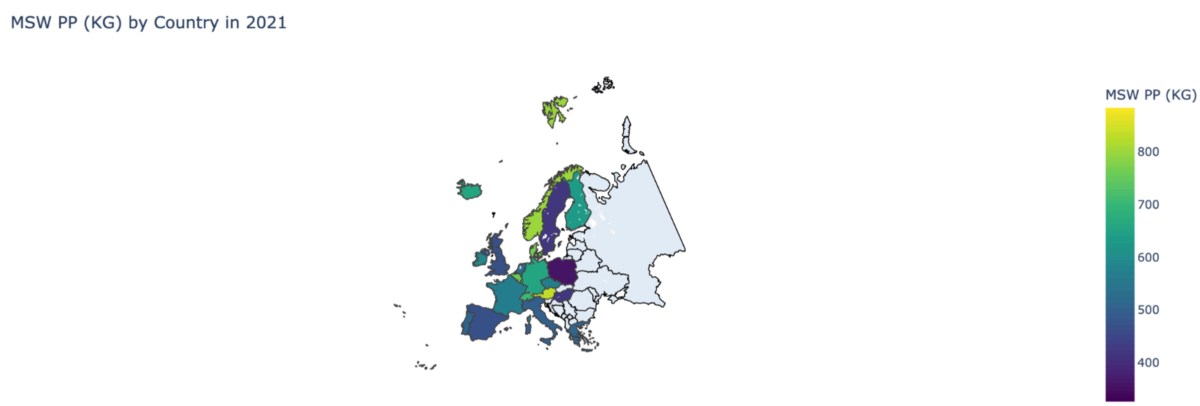

Figure 12*: MSW Per Capita (KG) in Europe - 2021*

Ritchie (2023) and the EPA (2016) both state that reducing consumption is more effective in reducing global GHG emissions than recycling and waste valorization processes. For this reason, the statistical findings of this case study indicate that despite high levels of environmental tax and technology, MSW generation is not slowing down in Denmark. As the literature described, and confirmed by the statistical findings, the Danes require MSW for their energy systems.The added value of waste-to-energy processes is apparent, but may result in negative effects on the environment and human health. Furthermore, the dependence on MSW generation makes it challenging to reduce consumption, as reduced MSW would impact the effectiveness of these energy systems.

To conclude this case study, It is advisable that Denmark and other European countries reconsider their bias for waste-to-energy systems, as over time the direct and indirect negative effects of these energy systems could eclipse its benefits.

6.2 Japan

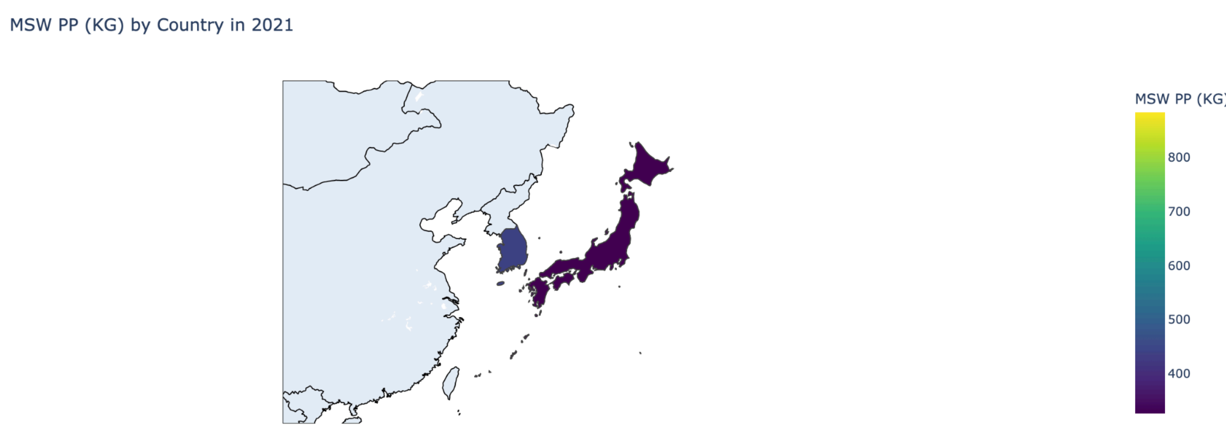

Figure 13*: MSW Per Capita (KG) in Japan in 2021*

Not all countries show the same trends. In fact, Japan (Figure 13) showed much lower trends in MSW generation over the study period, needing a specific inquiry into each region. Following literature suggests unique characteristics in Japan that differentiate them from other OECD members in terms of MSW generation. Based on a study from Tanaka (2013), Japan's MSW management law was initiated in the early 1900s to address sanitary problems in cities, of which was enhanced through "Public Cleansing Law" in 1954, "Waste Management and Public Cleansing Law" in 1970s. The policy measures, according to another author (Ding et al., 2016), are aimed at "[shifting] the target from proper treatment and disposal to establishing a Sound Material-Cycle society", promoting environmental education, especially recycling and compliance and responsibility of the discharger. Furthermore, the Japanese government also enacted unit-based pricing (UBP) of solid waste to decrease household waste generation and encourage recycling among its citizens (Usui & Takeuchi, 2014). While the effects of such policies are responded differently at each income level, according to Usui and Takeuchi, the long run trend of enacting such taxation policies is that it increases voluntary recycling. These findings suggest that Japan's policy and fiscal landscape contribute to higher levels of participation in recycling and waste awareness, and in turn lowering urban waste levels compared to the OECD average.

Comparable to the situation in Denmark, Japan also employs incineration as a means to convert waste into energy. In 1996 alone, Japan had 1800 incinerators operating that were responsible for 70% of the MSW stream (Sakai et al., 1996), with an average of 34,190 thousand tonnes incinerated every year from 1997 to 2021. In that same time period, Denmark incinerated 2,157 thousand tonnes every year. Such articles illustrate the importance of considering incineration as a part of research, and how efficient they may have in waste production. However, these cases are not universal, as some countries (Turkeye) do not use incineration while other nations (Greece, Iceland) only do at a minimal level.

To prove if political factors may have a disproportionate effect on the MSW generation in Japan, a further OLS regression analysis is conducted. Based on the prior literature, factors such as rate of waste recovery operation (*waste_recovery_ops_pp*), stringency (*string*), environmental tax per person (envtaxpp) and education (meanschool) is selected as a dependent variable for the initial model. As environmental tax proved to be insignificant (p value over .05), the variable is removed from the final model. Since waste recovery is highly correlated with the MSW, the model is run both with and without the waste recovery variable. The results for both regression are illustrated on the table 13 and 14 below

Independent Variable	**Coefficient**	**Standardized Coefficient**	**Standard error**	**P value**
Mean schooling in years	-146.3764	-.8860041	18.04645	0.000
Stringency	24.70658	.3752017	7.429461	0.003
Waste Recovery Operation per Person	600597.1	.4997682	83776.18	0.000

Table 13: *Results of regression for Japan with Waste Recovery Operation as a variable*

Independent Variable	**Coefficient**	**Standardized Coefficient**	**Standard error**	**P value**
Mean schooling in years	-141.9952	-.8594848	26.37247	0.000
Stringency	23.85892	.3623289	10.84719	0.039
Waste Incineration (kg)	0.00657777	.4829386	0.0017021	0.001

Table 14: *Results of regression for Japan with Incineration as a variable*

Both models are statistically significant, as p values are less than .05. Therefore, null hypothesis is rejected. The first model had the adjusted r squared value of 0.9685 and the latter 0.9364, capturning most of the variance in MSW. Both models indicate that mean schooling is a significant factor in Japan's MSW production. With additional years in schooling, MSW generation has decreased by around 140 kilograms. This finding aligns with Ding et al (2016).

Compared to the main OLS and Panel model, the mean years of schooling have a higher impact, emphasizing the role of education in combating waste in some countries. On the other hand, the higher stringency creates more waste (23.85 kg and 24.70 kg), implying that environmental stringency of the government is ineffective, which contradicts Tanaka's research. Waste Recovery Operation and Incineration shared similar outcomes, a unit of increase in waste incineration or recovery operation could generate 600597 / 657777 kilograms of MSW. The cause of such a positive relationship could be attributed to high correlation between waste recovery operations and MSW generation, as high MSW production would bring more recovery operations.

This study case of Japan reveals that each indicator may have a disproportionate effect on MSW production of countries, highlighting the need for a region-specific approach in some cases. Although education proved to be a universal factor, stringency exhibits contradictory effects.

6.3 United States

Figure 14: *MSW in United States in 2021*

The United States (Figure 14) shows the highest MSW generation among all the countries in our analysis. Given this observation, we believe it is important to examine in detail why the US leads in MSW generation compared to other countries. This deeper investigation could discover meaningful insights or unique characteristics that contribute to the country's exceptionally high levels of waste production.

The United States shows significantly lower recycling rates compared to other countries, which contributes to its status as the world's largest generator of MSW. According to research by Mukherjee et al, the US has a recycling rate of approximately 25.8% Additionally, 53% of U.S. MSW is landfilled, while only 8.9% is composted, 12.8% incinerated for energy recovery, and the remainder recycled. And, in terms of plastic use, end-of-life plastic recycling is only 6.2%(Di et al). These research and statistics implies that one of the most important factors that drives up MSW generation in the USA is significantly related to the USA's sustainable practices at the national, governmental, and individual levels as the reliance on landfilling and the inadequacy of recycling systems are shown. Furthermore, the recycling industry in the U.S. faces significant challenges, as noted by Rogoff et al , including falling revenues, strict contamination standards imposed by countries like China, and volatile markets for recyclable materials. This indicates that we need to take action to look into how much impact political factors have on MSW generation in the US so we can reveal where underlying issues lie and improve sustainability in the long term. This analysis is particularly significant as the United States is the world's largest generator of MSW. Identifying the most influential factors, particularly those tied to environmental policies and political frameworks, could provide valuable insights into strategies for reducing MSW in the U.S. This study could contribute to global efforts to mitigate MSW generation and address related environmental challenges for countries that have the similar issues to the US's.

To explore this, we conducted an OLS regression analysis with MSW as the dependent variable. The initial independent variables included environment tax, environment related patents, environmental stringency index, gross national income, human development index, life expectancy, mean years schooling, gross domestic income growth %, household spending(mil), household spending per person, temperature, urban population, population size, population density, fertility rate, waste recovery operations per person, environment tax per person, and environment related patents per person. We decided to include all the independent variables to identify what factors influence the generation of municipal solid waste in the US most.

As for the process of analysis, since we are dealing with the time series data whose range is from 1997 to 2021, it is crucial to identify whether there are any non - stationary variables. It is important to address the issue of temporal autocorrelation to prevent spurious regression which can lead to incorrect results or insights. Hence, conducting dickey-fuller unit root test, it turns out that some variables are non-stationary including: MSW, Environmental Tax (Total), Environmental Technology (Total), Stringency of Environmental Policies, Gross National Income, Human Development Index, Household Spending (Total, in Millions), Household

Spending (Per Capita), Fertility Rate, Environmental Tax (Per Capita), Environmental Technology (Per Capita), Waste Recovery Operations (Total), Waste Recovery Operations (Per Capita), Life Expectancy, Mean Years of Schooling. In order to address the potential spurious regression issue, we made a use of the first difference for those variables. The next step is to ensure that there is no multicollinearity among the independent variables. Highly correlated independent variables can lead to misleading results and interpretations with large standard errors. For example, it may appear that one independent variable significantly impacts the dependent variable, when in reality, the effect is driven by another independent variable that is highly correlated with the first. Addressing multicollinearity is essential to obtain accurate and reliable insights into the relationships between the variables.

The correlation matrix (Appendix C) revealed a high degree of correlation among the independent variables. To confirm this more precisely, we conducted a Variance Inflation Factor (VIF) test. The results indicated that all independent variables, except for the first difference of fertility rate (d_fer), first difference of mean years of schooling (d_meanschool), and first difference of the environmental stringency index (d_string), had VIF scores below 10. However, the remaining variables showed VIF scores ranging from 20 to an extremely high value of 66891.23, indicating a serious multicollinearity issue.

Variable	1/VIF
dens	0.000015
pop	0.000015
d_hhspendpp	0.000109
d_hhspendmit	0.000113
d_envtax	0.000197
d_envtaxpp	0.000203
d_waste_re~p	0.000583
f_waste_re~s	0.000594
d_envtech	0.000609
d_envtechpp	0.00063
d_hdi	0.017113
d_lifeexp	0.022326
d_gni	0.038154
gdi	0.050718
d_ter	0.113898
d_meanschool	0.13879
d_string	0.301193

***Table 15**: VIF Test US*

Therefore, we used backward stepwise selection method to drop insignificant features, reduce dimensionality, and mitigate multicollinearity.The model selected through this approach includes gross domestic income (gdi), first difference of environmental patents per person (d_envtechpp), population density (dens), first difference of waste recovery operations per person (d_waste_recovery_ops_pp), first difference of environmental patents (d_envtech), and first difference of life expectancy (d_lifeexp).

Variable	VIF	1/VIF
d_envtechpp	617.5	0.001619
d_envtech	607.72	0.001645
dens	2.36	0.42402
gdi	2.24	0.447038
d_lifeexp	1.41	0.710136
d_waste_re~p	1.16	0.859356

***Table 16**: MSW Per Capita (KG) in Japan in 2021*

Highly correlated variables are eliminated, resulting in acceptable VIF scores that indicate no significant multicollinearity issues overall. However, d_envtechpp and d_envtech are still showing high VIF. This is expected, as d_envtechpp was derived from d_envtech to examine its impact on MSW at a smaller, per-person scale. Given their direct relationship, the high correlation between these variables is understandable and reflects their intended analytical purpose.

Observations	24
F Statistic (6, 17)	28.58
P value	0.000
R^2 Value	0.9098
Adjusted R^2 Value	0.8780
Root MSE	8.6918

***Table 17**: OLS Model US 1*

Independent Variable	Coefficient	Standard error	P value

Gross National Income	4.387011	1.419299	0.007
d_envtechpp	101000000.0	22700000.0	0.0
dens	101000000.0	22700000.0	0.0
d_waste_recovery_ops_pp	6.538871	1.433406	0.004
d_envtech	553855.9	143428.0	0.0
d_lifeexp	-0.3257263	0.0708117	0.0
_cons	15.30462	5.376006	0.011

***Table 18**: OLS Model US 2*

Our model has the p-value of 0.0000 for F-statistic, indicating that our model is showing great fit overall. Its R-squared value is 91 %, indicating that variation in the dependent variable is 91% explained by independent variables. The adjusted R-squared value of 87.8% accounts for the number of predictors and the relatively small sample size, indicating a strong overall model fit. Hence, we can consider that our model is reliable.

According to the model, the main factors that drive MSW generation in the US are complicatedly combined with political, socioeconomic, and demographic factors. The most impactive factors are political factors based on the result. Waste Recovery Operations Per Person has the coefficient of 553855.9 indicates that an increase in per-person waste recovery operations leads to a massive increase in MSW, which is statistically significant with a p-value of 0.001. This could imply that waste recovery systems handle more waste, reflecting increased waste generation in the system. The positive association between waste recovery and MSW suggests that while waste recovery systems are crucial for managing waste, they might reflect higher overall waste generation. Efforts could focus on reducing waste at the source, alongside improving recovery systems.

Environmental Patents has a negative coefficient of -0.326 suggests that an increase in environmental patents reduces changes in MSW, and the effect is highly significant with a p - value of 0.000. This might reflect that innovation in environmental technologies can help manage waste generation. However, Environmental Patents Per Person shows a contrasting relationship with Environmental Patents unexpectedly. The coefficient suggests a positive impact of changes in per-person environmental patents on MSW. However the value is extremely small that is close to zero, potentially indicating that it does not actually have an impact on MSW. The contrasting effects of total environmental patents and per-person patents suggest nuanced impacts. While overall technological advancements may reduce waste, focusing on per-person innovation might indicate localized or sector-specific increases in waste due to scaling technologies. By investigating which types of innovations are most effective, we can take max advantage of environmental patents to reduce MSW.

The second most impactive factors are demographics factors. Population Density has a coefficient of 6.54 shows that higher population density is significantly associated with increased changes in MSW generation at the common alpha level of 0.05. Higher population density correlates with increased MSW generation, possibly due to urbanization and concentrated consumption. This suggests a need for efficient waste management systems in densely populated areas. Life Expectancy has A coefficient of 15.30 means that a one-unit increase in life expectancy is associated with a 15.30-unit increase in d_mswd_msw. This effect is significant with a p-value of 0.011 and may reflect that longer life expectancy is tied to greater resource consumption and waste generation. The positive relationship with MSW suggests that as people live longer, their lifetime consumption contributes to more waste. Long-term strategies should focus on sustainable resource use to minimize waste over a lifetime.

Also, socioeconomic factors such as Gross Domestic Income accounts for MSW generation in the USA. It has a coefficient of 4.39, meaning a one-unit increase in GDI leads to a 4.39-unit increase in MSW. The p-value of 0.007 indicates this effect is statistically significant at the common alpha level of 0.05. The positive relationship between GDI and MSW indicates that economic activity drives waste generation. As income increases, consumption likely rises, leading to higher waste output. Policymakers could focus on promoting sustainable consumption patterns to decrease waste generation from economic growth.

This case study reveals that the most significant factors influencing MSW generation in the U.S. are environmentally related political factors, while demographic and socioeconomic factors also play a role. By focusing on political aspects of MSW generation such as promoting sustainability practices, advancing environmental technology, and ensuring its effective implementation, the U.S. has the potential to significantly reduce its MSW levels. This case highlights the importance of exploring the relationship between MSW and political factors in depth, offering valuable insights for improving waste management and sustainability practices in the U.S. and encouraging to investigate the relationship at local and individual level for more meaningful and precise insight.

7. Discussion and Conclusion

7.1 Implication of Results

Research Question: *To what extent is municipal solid waste (MSW) generation per household influenced by socioeconomic, geographical and political factors in OECD countries from 1997 to 2021?*

Based on the results from the main model, the key variables identified from both panel and OLS model are:

- **Socio Economic:** life expectancy, mean years of schooling, and household spending
- **Demographic/Geographic:** urban population
- **Political:** patents on environmental technologies, environmental tax per capita, waste recovery operations per capita, and stringency

SQ1: *Which socioeconomic variables influence MSW generation per household?*

Our analysis showed that life expectancy, mean years of schooling, and household spending are correlated with the amount of MSW. The positive relationship between household spending and the MSW is in accordance with the literature (Cohen, 2019; Ichinose , 2014; Magazzino 2021) that higher spending correlates with higher consumption behavior which in turn aggravates total waste. However, Gross National Income (GNI) was found to be irrelevant, since this indicator is less suitable for comparisons over time (OECD 2024). Additionally, mean years of schooling showed to be significant, supporting the notion that higher education is negatively associated with MSW generations (Noufal et al., 2020; Halkos et al., 2020). This theory was also manifested through the case study of Japan, where multiple studies (Tanaka, 2013; Ding et al., 2016) and the analysis manifested the significance of education in MSW management. However, interpretation of the effect of education is complicated as the discrepancy in coefficient exists between two models. Higher life expectancy was linked to lower MSW in both the panel and OLS model, since the study has suggested that this indicator can be effective at explaining MSW generation (P Beigl et al.). Due to the rarity of the studies on proving life expectancy as an indicator of MSW, further validation might be necessary. Nevertheless, Ghinea et al (2016) assert that the effect of life expectancy attribute is nonsignificant compared with total population.

SQ2: *Which geographic/demographic? variables/factors influence MSW generation per household?*

This study also analyzed the impact of demographic & geographic factors in MSW generation per household. The panel regression analysis revealed the fertility to be a factor in decrease in MSW, supporting Masebinu (2023), Lebersoger and Beigl (2011) which argued larger households generate less per capita waste. Based on the model, the density proved to be insignificant to the MSW generation, and the higher urban population resulted in less MSW. This is in contrast to Dangi et al.(2011) and Brown (2015) that reported positive correlation between population density and urban population and MSW produced. The conflicting results may also require further inquiry.

SQ3: *Which political variables/factors influence MSW generation per household?*

This study found that the patents on environmental technologies, and waste recovery operations per capita influence MSW generation per household. For every unit increase in the number of patents, MSW generation is expected to decrease by a small margin, based on the model. The results are similar to ones hypothesized by Kounetas (2015) and Mazzanti & Nicolli (2011). The waste recovery operation per capita had a coefficient of 481394 for panel and 634866.9 for OLS. While the Environmental Stringency Index was excluded from the main model, the ANOVA showed that there are differences between levels of stringency index, suggesting that differences in environmental regulations may have an slight impact on MSW generation.

SQ4: *Which countries that are part of the OECD generate the most MSW per household?*
Based on the figure 15 of MSW per capita for each nation over the time period, the OECD country that generates the most MSW per household is Denmark, Germany, Ireland, Luxembourg, Switzerland and the United States. When compared to household spending of each nation (figure 8), most of the countries with high MSW are positively associated with household spending. This outcome is in agreement with preexisting knowledge (Magazzino et al., 2021; Cohen, 2019; Malouf & Mavropoulos, 2022).

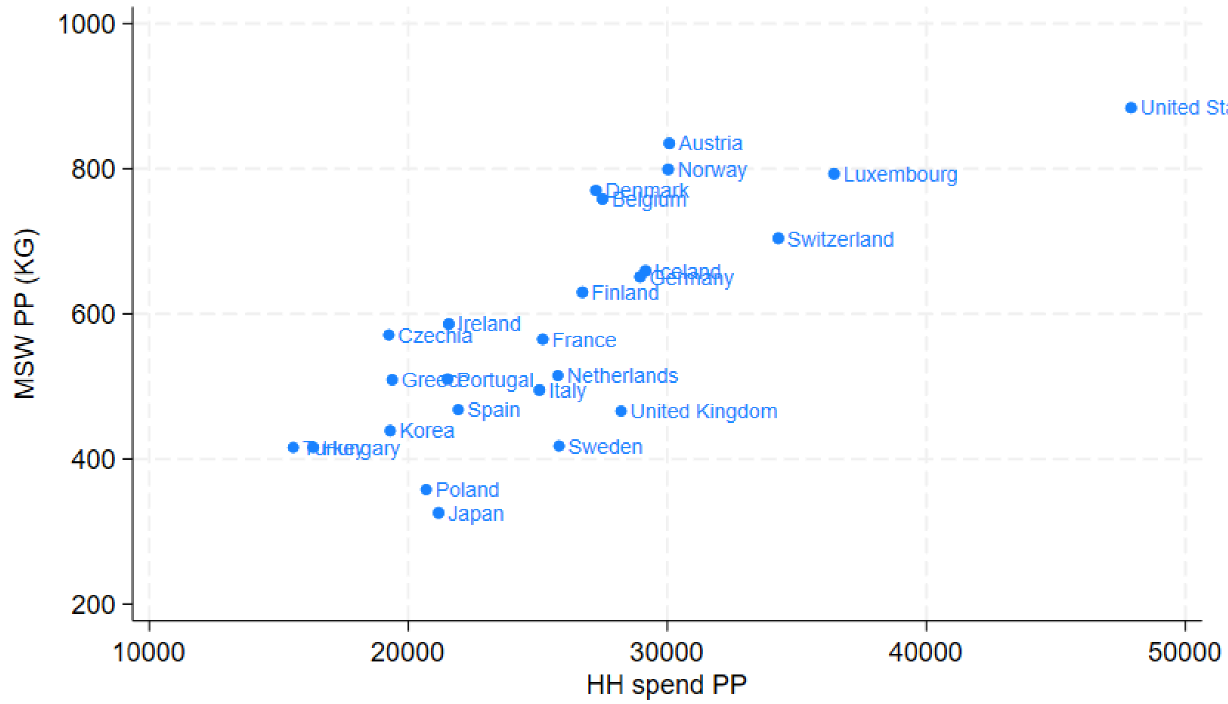

***Figure 15**: MSW vs Household Spending per Capita in 2021*

7.2 Practical and Theoretical Contribution

The findings of this study have theoretical and practical implications. Firstly, theoretical implications consider the impact the findings of this study have on the body of research on this matter. The statistical findings in the panel regression model, OLS regression model and in the case studies, indicate that there is a positive relationship between wealth and MSW generation. This concurs with different studies that also discovered this relationship studies that had discovered this relationship (Malouf & Mavropoulos, 2022; Magazzino et al., 2021; Ichinose et al., 2014). While this relationship has already been discussed significantly, it was important to test this relationship in this study. Furthermore, the panel regression model indicates that there is a negative relationship between environmental tax and MSW generation, as well as between environmental technology and MSW generation. This indicates that fiscal and technological policies may be effective in decreasing MSW generation in OECD countries (Lama, 2024). However, when zooming in on specific cases, these policies are not always directed at decreasing MSW generation. As discovered in Denmark, these policies appear to have a positive relationship with the MSW generation. Therefore, the theoretical implications of this finding indicate that these policies do not always reduce MSW generation and future research must consider that countries have differences in waste management and policies.

With regards to practical implications, the statistical findings of this study may help to influence present and future environmental and waste policies. Firstly, different countries within the scope of this research are involved in waste-to-energy processes. However, the findings indicate that these processes have a counterproductive effect on reducing consumer consumption. MSW is a resource in waste-to-energy processes and for this reason, an increase in MSW results in an increase of final energy for households. However, research by Agamuthu and Babel (2023) indicates that consumption, production and waste management have seen significant global increases since the last century. Knowing this, if governments rely on MSW for energy generation and do not reduce consumption, these factors will continue to increase. The primary issue with this is that this exacerbates the global inequality issue of waste generation and overconsumption. Malouf and Mavropoulos (2022), states that industrialized countries generate 34% of global MSW, which has a direct negative impact on developing nations.
For this reason, if developed countries do not reduce their MSW generation, the negative impact on marginalized countries will become worse. Understanding this, the practical implications of this study indicate that OECD countries need to consider how their processes and policies contribute to global inequality issues. Even if increasing MSW generation is beneficial for domestic energy systems, industrialized countries should refrain from adopting policies that have negative effects on a global scale.

7.3 Limitations

While the study attempts to explain the relationship between MSW and various geographical, socioeconomic, and political factors, it is important to acknowledge the limitations that may influence the interpretation of the results of this study.

Firstly, the data availability and quality varies between OECD countries. According to OECD report (2022, page 10), the quality of data varies widely by countries, time, topic and policy. Moreover, each state may have different ways of measuring MSW, complicating the comparisons between countries. For example, the United States does not have environmental data such as recycling, MSW after 2018, due to complexity in aggregating data from states (Staub & Heffernan, 2024). Such cases exist for many states, necessitating imputation to fill in empty values. In other instances, the observation may include a time series break, where there is a change in the standard for observing or collecting the variable over time, making estimates no longer comparable from one period to another (Tebrake, 2019). Such cases further complicate the interpretation of the result and addressing these discrepancies and standardizing the data collection will be essential for more robust analysis.

The report also underrepresents developing countries since OECD was selected for study due to data availability not because it can represent the global trends. For instance, the lowest GDP per capita between OECD countries in 2023, represented in US dollars per person (PPP converted), was Greece, with $40,000, whereas the global average is $23,010 (OECD, 2024). While developing countries generate less MSW than those of developed nations (Malouf & Mavropoulos, 2022), the economic expansion and rising income might facilitate MSW generation over time. Thus, focusing only on OECD may omit patterns in waste generation and related factors in emergent nations where rapid urbanization and industrialization might be occurring.

7.4 Future Research

This section of the paper intends to discuss recommendations for future research directions. While this analysis was able to resolve some questions about the relationship between MSW and various factors, it also highlighted areas that necessitate further investigation.

Future studies could investigate how sociocultural factors influence solid waste. One study (Agyeiwaah, 2020; Salsabila et al. 2021) asserts that community attitude toward waste could bring a holistic understanding of waste dynamics, which may also account for some of the variances in the model. However, lack of resources and data hamper attempts to apply cultural perspectives in MSW production (Resolute, 2024). To approach this matter, the study suggests identifying prior case studies or surveys on people’s attitudes towards recycling, waste habit and practices, and household composition.

Other Research could also examine the problem at different scales. The OECD report (2022) states that waste management policy decisions are often done at municipal level. Therefore, focusing on MSW generation in specific cities and municipalities could shed light to patterns and trends that were not visible at the national level. Other than city level analysis, other research could also provide analysis of waste generation in urban vs rural areas, state or county level, or at cross-continental scale.

Finally, some inquiry could quantify the nation's willingness to participate in sustainable development and waste reduction initiatives. While there are various global organizations that support ongoing drive against MSW, one initiative that might be worth factoring in is the waste policy framework by OECD. This organization produces Environmental Performance Reviews for each nation that provide assessments of states' progress towards environmental policy objectives. This framework could be used to categorize if nations met their own waste reduction goals. Furthermore, research could analyze if nations have met the UN's sustainable development goals, such as meeting sustainable consumption and production national action plan and level of implementation of sustainable procurement policies. Such analysis could provide meaningful insights into how political influences on a waste generation of a nation.

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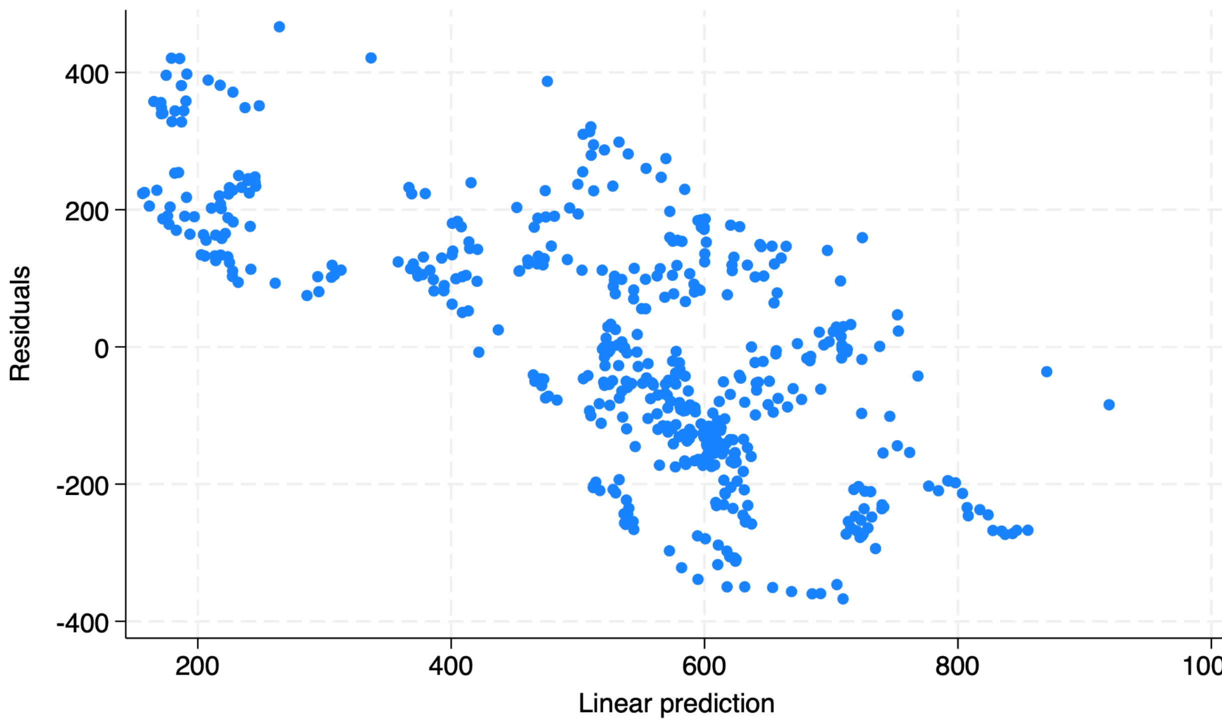
Appendix

Appendix A: Unit root tests

Variable Name	**P value**	**Root test (.xtunitroot ips)**
Environmental tax per capita	0.5727	Non-stationary
Environmental tech	0.0780	Non-stationary
Environmental stringency	0.6040	Non-stationary
Gross National Income	1.0000	Non-stationary
Life expectancy	0.1338	Non-stationary
Mean years of schooling	0.0008	Stationary
Gross Domestic Income Growth (in %)	0.0000	Stationary
Household spending per capita	1.0000	Non-stationary
Municipal solid waste per capita (in kg.)	0.9958	Non-stationary
Temperature	0.000	Stationary
Urban Population (in %)	1.000	Non-stationary
Total population	1.000	Non-stationary
Population density	1.000	Non-stationary
Fertility rate (in %)	0.9998	Non-stationary
Recycled MSW per capita	1.000	Non-stationary

Appendix B: Heteroscedasticity test (Model vs Residual)



Appendix C: Correlation Matrix among variables for US

```
. corr(envtax country envtech string gni hdi gdi hhspendmil msw hhspendpp temp urpop pop dens fer envtaxpp envtechpp waste_recovery_ops
>  waste_recovery_ops_pp lifeexp meanschool)
(obs=25)
```

	envtax	country	envtech	string	gni	hdi	gdi	hhspen~l	msw	hhspen~p	temp	urpop	pop
envtax	1.0000												
country	.	.											
envtech	0.8122	.	1.0000										
string	0.9405	.	0.8300	1.0000									
gni	0.9875	.	0.7856	0.9488	1.0000								
hdi	0.9645	.	0.9251	0.9447	0.9419	1.0000							
gdi	-0.1558	.	-0.3953	-0.3050	-0.1865	-0.2918	1.0000						
hhspendmil	0.9858	.	0.7927	0.9551	0.9989	0.9448	-0.2072	1.0000					
msw	0.3877	.	-0.1789	0.2276	0.4256	0.1501	0.2937	0.4102	1.0000				
hhspendpp	0.9870	.	0.7965	0.9475	0.9984	0.9457	-0.2081	0.9993	0.4134	1.0000			
temp	0.4838	.	0.3220	0.4785	0.4926	0.4140	0.0457	0.4840	0.2492	0.4804	1.0000		
urpop	0.9786	.	0.8298	0.9558	0.9907	0.9559	-0.2733	0.9929	0.3528	0.9922	0.4801	1.0000	
pop	0.9757	.	0.8677	0.9637	0.9842	0.9723	-0.2952	0.9877	0.2812	0.9868	0.4688	0.9963	1.0000
dens	0.9751	.	0.8688	0.9647	0.9836	0.9727	-0.2962	0.9873	0.2776	0.9864	0.4673	0.9960	1.0000
fer	-0.8048	.	-0.5595	-0.8648	-0.8363	-0.7499	0.0648	-0.8386	-0.3850	-0.8182	-0.4490	-0.8254	-0.8157
envtaxpp	0.9934	.	0.7845	0.9044	0.9682	0.9475	-0.0951	0.9637	0.4180	0.9673	0.4809	0.9513	0.9463
envtechpp	0.7658	.	0.9961	0.7812	0.7351	0.8929	-0.4105	0.7427	-0.2382	0.7484	0.2884	0.7840	0.8255
waste_reco~s	0.9697	.	0.7491	0.9157	0.9727	0.9182	-0.1838	0.9714	0.4618	0.9712	0.4718	0.9634	0.9543
waste_reco~p	0.8855	.	0.5889	0.7889	0.8809	0.7967	-0.0728	0.8751	0.5838	0.8769	0.4303	0.8542	0.8345
lifeexp	0.7450	.	0.9400	0.7205	0.6741	0.8753	-0.3225	0.6813	-0.2378	0.6888	0.1981	0.7147	0.7580
meanschool	0.8217	.	0.5379	0.8844	0.8514	0.7574	-0.1060	0.8504	0.4414	0.8316	0.4560	0.8251	0.8138

dens fer envtaxpp envtec~p waste_~s waste_~p lifeexp meansc~l

	dens	fer	envtaxpp	envtec~p	waste_~s	waste_~p	lifeexp	meansc~l
dens	1.0000							
fer	-0.8169	1.0000						
envtaxpp	0.9454	-0.7593	1.0000					
envtechpp	0.8267	-0.4881	0.7401	1.0000				
waste_reco~s	0.9534	-0.8153	0.9567	0.6979	1.0000			
waste_reco~p	0.8327	-0.7260	0.8907	0.5360	0.9605	1.0000		
lifeexp	0.7593	-0.4266	0.7429	0.9458	0.6518	0.5140	1.0000	
meanschool	0.8147	-0.9654	0.7855	0.4643	0.8369	0.7681	0.4087	1.0000