An Analysis of E-Waste Collection Across Countries

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Abstract:
In line with technological development, electronic waste has become the world's fastest-growing waste category, increasing three times faster than the world's population. Although e-waste legislation covers about 66% of the world's population, the global recycling rate for e-waste is only 20%. This poses a threat to both the environment and human health, as e-waste emits toxic substances during informal handling. Additionally, e-waste contains raw materials that go to waste, valued at 57 billion USD in 2019. The increase in e-waste generation, combined with the slow adoption of formal management, has become a rapidly increasing global problem and a threat to the circular economy. The urgency of this issue has laid the foundation for this thesis. This thesis aims to explore how variables such as the number of e-waste-related legislation and price changes of gold and metals may affect the generation and formal collection of e-waste in different countries. It also investigates the magnitude of the impact of potential effects.

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ABBREVIATIONS

EEE	Electrical and Electronic Equipment
EOL	End of Life
EPR	Extended Producer Responsibility
ICT	Information and Communication Technology
IoT	Internet of Things
kT	Kilo (thousands) Tonnes
MSW	Municipal Solid Waste
mT	Metric Tonnes
UEEE	Used Electrical and Electronic Equipment
WEEE	Waste of Electrical and Electronic Equipment
WHO	World Health Organization

1. Introduction

To define e-waste, it is necessary to first understand its foundation EEE, which stands for electrical and electronic equipment. According to The Step Initiative 2014, the term is described as “any household or business item with circuitry or electrical components with power or battery supply." This categorizes a wide range of household and business products, including kitchen appliances, white goods, lamps, medical devices, and ICT items like mobile phones and computers. Apart from these common everyday products, EEE have been noted for their growing usage in sectors such as transportation, healthcare, security systems, and energy generators. An additional reason why EEE plays a key role is the increase of the Internet of Things (IoT). IoT contributes to the construction of smart homes and cities by integrating various electronic devices (Forti et al., 2020).

EEE has seamlessly become a part of daily life by improving global standards of living (Forti et al., 2020). However, when owners discard EEE without the intent of reuse, it transforms into WEEE (waste of electrical and electronic equipment), commonly known as e-waste (Step Initiativ 2014). Therefore, it is crucial to clearly express the intended reuse status of EEE items. If it is specified for reuse, it falls under the category of used electrical and electronic equipment (UEEE). Products falling under this category are either exported or given an extended lifespan domestically. The exported items typically end up in low- and middle-income countries that lack a formal e-waste management infrastructure, leading to improper handling. (Forti, Baldé, and Kuehr 2018)

One of the major problems is that e-waste contains hazardous substances which are released by informal e-waste activities, polluting the environment and harming human health. Additionally, finite supplies such as raw-materials are lost in this process. As the impact of our e-waste footprint continues to escalate, it becomes necessary to take steps to implement sustainable e-waste management strategies and legislation (Patil, R.A. et al., 2020).

Today, many countries implement different types of both national and conventional e-waste related regulations. For instance 191 nations have signed the Basel Convention which aims to prevent the flow of e-waste to countries that are not equipped with formal e-waste recycling infrastructures. Further, the WEEE Directive, ensures that all European Union member countries handle e-waste in a uniform manner (Patil, R.A. et al., 2020). Even though e-waste legislation covers about 66% of the world's population, the global recycling rate for e-waste is only 20% (UNE 2019; WEF 2019).

1.1 Research Questions

1. Do selected variables such as the number of legislation, metal prices, and income significantly affect the amount of e-waste generated and formally collected in a country?
2. If they do, what is the magnitude of those impacts?

1.2 Delimitations and Limitations

Given the restricted availability of information and data, the analysis in this thesis is based on a dataset limited to particular years and countries. The dataset is derived from panel data covering the years 2014, 2016, and 2019. One of the three dependent variables in the analysis, the formal recycling rate of e-waste (EWasteC (%), is limited to two years, as the e-waste generated in one year can explain the future formal collection. As a result, the formal collection of e-waste for 2017 and 2015, are divided by the generation data for 2016 and 2014, respectively. Given that the panel data spans only three separate years over a relatively short time frame of five years, it may not depict a fair representation of a country's development in e-waste management effectiveness over time. Furthermore, it may not accurately reflect a country's current formal management performance, as the latest data for e-waste formally collected is from 2018.

In terms of the dataset's geographical scope, it is restricted to 38 selected countries, primarily due to limitations in information availability. These countries are mainly based in Europe, representing 82% of the dataset. Therefore the dataset may be biased towards the EU rather than globally. One limitation is the relatively small number of economically challenged countries included in the dataset. For example, there is only one African country (Mauritius), despite Africa being a hotspot for e-waste exports. This could potentially impact the results of the analysis. The current regressions in this analysis suggests that variables such as income and education do not significantly contribute to the amount of e-waste formally collected. However, if more economically diverse countries, similar to Mauritius with a 15.4% formal recycling rate, were included, the results would maybe be different.

In addition to the geographical and time restrictions of the dataset, there are also limitations to the variables tested. For instance, the Basel Convention's definition of hazardous waste includes all items falling under this category and not only e-waste. This issue is also significant for the variable Export, which denotes the amount of exported hazardous waste, defined by the Basel Convention. Furthermore the export of EEE, which should be classified as WEEE is often illegally exported as used (UEEE), and this category is not classified as hazardous. Even if there were metrics available exclusively for the amount of e-waste exported, they would not accurately represent the real numbers. This shows the challenges in precisely capturing and categorizing e-waste movements.

2. Background

2.1 Global Trends in E-Waste Generation

The increasing amount of e-waste has gained importance in today's global environment, and a significant amount of e-waste adds to the global waste inventory every year. The Global E-waste Monitor reports that the growing amount of e-waste is primarily coming from areas with strong economic development. (Forti et al. 2020)

Continents	**Amount (in million tones)**	**Kilogram per capita**
Africa	2.9	2.5
Americas	13.1	13.3
Asia	24.9	5.6
Europe	12	16.2
Oceania	0.7	16.1

Table 2.1: Total E-Waste categorized by continents in 2019 (Forti et al. 2020)

Data from the Global E-Waste Monitor on the generation of e-waste by continent and by capita in 2019 is shown in Table 2.1. This data highlights the importance of e-waste as a worldwide problem, with a noticeable concentration in areas with the greatest rates of economic development. This is due to the fact that the majority of the world's richest countries, as determined by GDP per capita, are in Europe and North America. (A. Kumar et al., 2017)

2.2 Economic Impact on E-Waste Generation in the World

A Kumar et al. showed in 2017 that there is a correlation between a country's gross domestic product (GDP) and the amount of e-waste it generates. This demonstrates how economic growth influences the environment in the e-waste landscape. Statistics on population and GDP from the World Bank's 2015 database were combined with information on e-waste from Balde et al. (2015) for A. Kumar et al.'s research. The goal of this research was to find correlations between the amount of e-waste generated and the GDP of the 50 largest countries, sorted by both GDP and population in the world. It is important to note that the following figures originate from the work of A. Kumar et al. (2017).

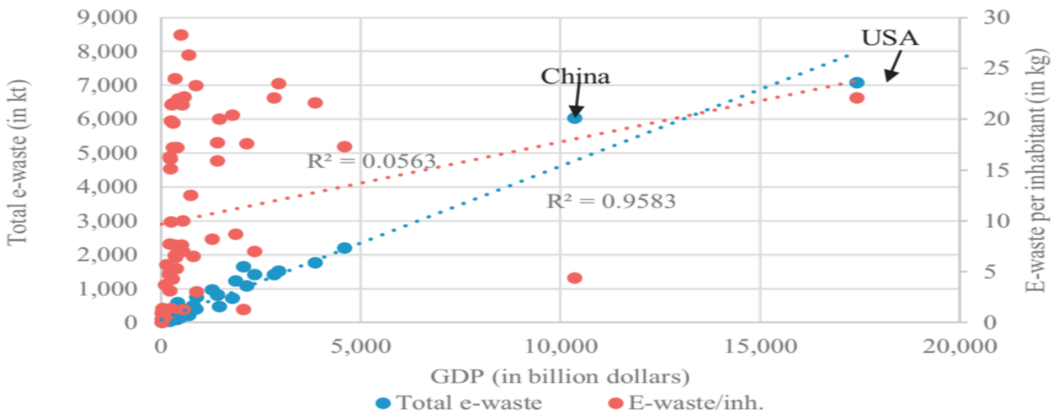

Fig. 2.1: *Total E-waste and E-waste/inh. vs. GDP* (A. Kumar et al., 2017).

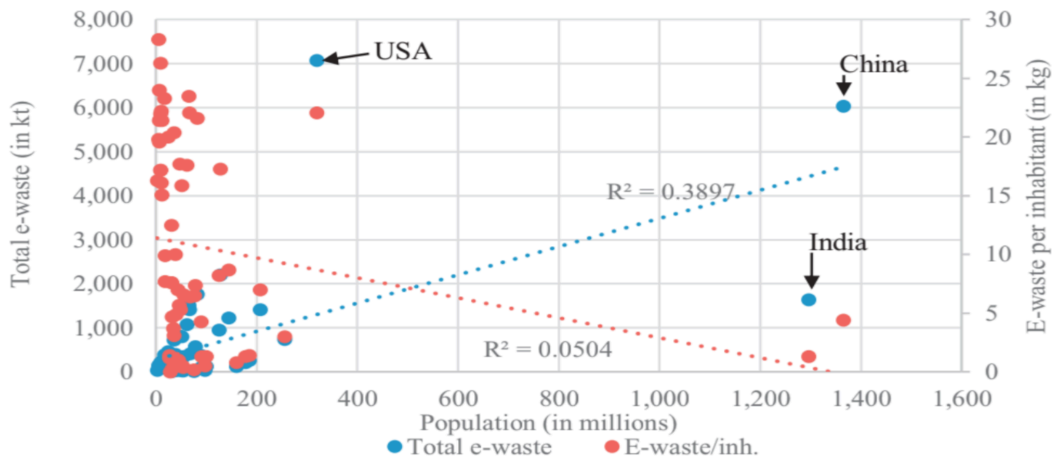

Fig. 2.2: *Total E-waste and E-waste/inh. vs. population* (A. Kumar et al., 2017).

A correlation between the GDP of a country and the amount of e-waste generated is seen in Figure 2.1. China and the US stand out as outliers in Figure 2.1. These two countries had very high GDPs ($17.42 billion and $10.36 billion), and they also generated large volumes of e-waste (7072 and 6033 kt) in 2015. Their higher population and strong economic development are the reasons for this large amount of generated e-waste. In Figure 2.2, the three outliers include the US, China, and India. As previously mentioned, the USA and China both have large GDPs and contribute significantly to the generation of e-waste. Also, India's large population increases the country's overall proportion of e-waste generation (1641 kt), but because of its lower GDP, e-waste generation per inhabitant is comparatively low. (A. Kumar et al., 2017)

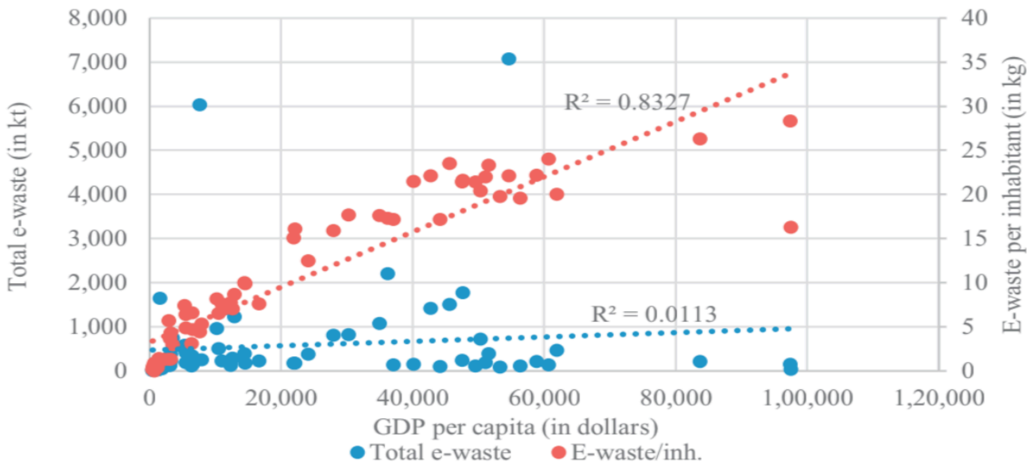

Fig. 2.3: Total e-waste and e-waste/inh. vs. GDP per capita (A. Kumar et al., 2017).

Figure 2.3 shows the correlation between a country's GDP per capita (in US dollars) and the amount of e-waste generated. The correlation shows that a person's personal wealth and purchasing power increase the quantity of e-waste they generate. An observed relationship indicates that the quantity of e-waste produced per inhabitant is strongly correlated with individual purchasing power, which is a measure of personal wealth. (A. Kumar et al., 2017)

2.3 Economic Value and Environmental Concerns in E-Waste Recycling

Material	Amount (kt)	Value (million Euros)
Iron/steel	16,500	9000
Copper	1900	10,600
Aluminum	220	3200
Gold	0.3	10,400
Silver	1.0	580
Palladium	0.1	1800
Plastics	8600	12,300

Table 2.2: Value of materials present in the e-waste stream (Balde et al., 2015).

The growing amount of e-waste poses both challenges and opportunities for recycling. Every four to five years, about a billion electronic devices become useless. This is particularly accurate for small electronic devices like cell phones and tablets. E-waste has valuable metals in it, like gold, silver, copper, and palladium. In 2015, Balde et al. estimated that e-waste was worth 48 billion euros altogether, which is shown in table 2.2. This value is higher than that of metals found in natural ores, showing that e-waste can be a big source of valuable metals if it is recycled properly. But e-waste also contains dangerous materials that can hurt people and the environment if they aren't properly disposed of. Existing recycling methods have struggled with fully recovering metals from e-waste because it is complicated. This shows that new techniques or improvements to existing technologies are needed to make the recycling process better and recover metals from the stream of e-waste. (A. Kumar et al., 2017).

2.4 Waste Recycling in Europe

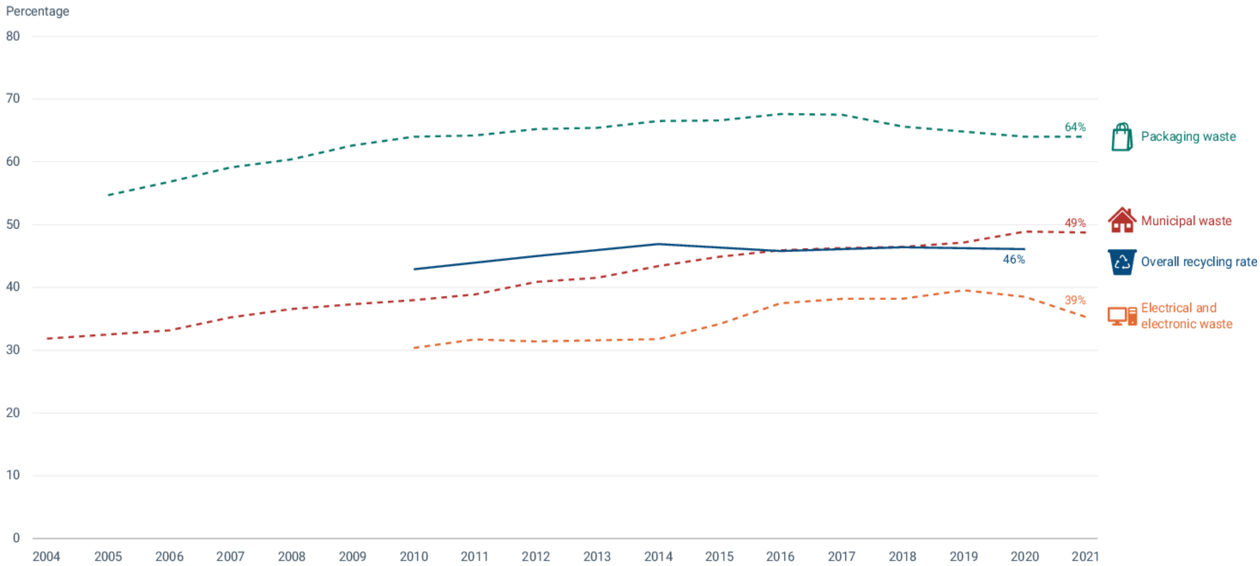

Figure 2.4: Trends in Recycling Rates of Different Waste Categories in Europe 2004-2021 (European Environment Agency, 2023)

Recycling rates for various types of waste in Europe from 2004 to 2021 are shown in figure 2.4. The figure originates from the European Environment Agency (2023) and includes data from 32 countries in Europe. Figure 2.4 shows that the recycling rate for packaging waste has increased over time and reached 64% in 2021. Municipal waste recycling shows an upward trend and is 49% in 2021. The overall recycling rate remained the same at around 46% between 2010 and 2021. But recycling for electrical and electronic waste (e-waste) lags behind, with a small increase to 39% in 2021 from about 30% in 2010. 39% is lower than the EU target of 65% e-waste recycling from 2019 onwards (Eurostat, 2024).

2.5 Literature Review

Our thesis relates to several strands of literature. First, the literature shows there's evidence that poor management and recycling of e-waste is leading to more environmental and public health concerns around the world (Patil, R.A. et al., 2020). Plenty of legislation has been implemented to make sure that e-waste is properly collected and recycled. Most of the time, these legislations are about controlling imports and exports and putting the extended producer responsibility (EPR) idea into action. EPR requires that the companies that make electronic products are responsible for recycling the products that are no longer useful. E-waste legislation works if there is an effective approach and good ways to enforce it in practice (Patil, R.A. et al., 2020). But many countries have trouble because their frameworks aren't well developed, which makes it hard to handle e-waste. Even though e-waste legislation covers about 66% of the world's population, the global recycling rate for e-waste is only 20%

(UNE 2019; WEF 2019). The main cause of the difference is the improper handling of e-waste in some countries. This results in a significant amount of e-waste going missing and not recycled (Patil, R.A. et al., 2020). Also, the fact that different countries have different e-waste legislation makes it harder to keep an eye on global recycling of e-waste (Patil, R.A. et al., 2020). Strong legislation, strict enforcement, and international cooperation are needed to make sure that e-waste collection is sustainable and successful. These steps are needed to make these efforts more successful and to make sure that e-waste is properly collected and recycled around the world (Patil, R.A. et al., 2020).

Second, it also relates to the literature studied in the global ecosystem of peer-reviewed publications that reviews research on consumer behavior and e-waste awareness. The research divides studies into behavioral categories such as consumption, repair and reuse, storage, disposal, and recycling. In the context of the circular economy, the research suggests that e-waste management should focus on the consumer. The findings make it clear that e-waste management systems need to be greatly improved. This includes official e-waste collection, compensation processes, low-cost repair services, and data protection so that consumers can be sure that the information on the electronics they recycle can't be recovered or used. A number of strategies and regulatory systems are suggested in the literature , with a focus on making consumers more aware through education and promotional actions. There could be both physical locations and social media channels used for these marketing activities. The literature recommends government assistance for local recycling companies, including tax incentives and subsidies to increase material circularity and recycling initiatives. The different strategies strive to solve the issues of e-waste disposal while also encouraging a sustainable and ethical consumer mindset. (M.T. Islam et al., 2021)

3. Theoretical Framework

3.1 E-Waste and the Circular Economy

The circular economy is an innovative model with a perspective on production and consumption, prioritizing principles like sharing, leasing, reusing, repairing, and recycling materials and products to maximize their life cycle. Its primary goal is to minimize waste, and as products approach the end of their lives, the model ensures their materials are efficiently recycled. This results in long-term value creation within the economy (European Parliament, 2023).

The circular economy is the opposite of the traditional linear economic model, which is characterized by a take-make-use-dispose pattern. The linear approach follows a straightforward path with a beginning, middle, and end, without considerations for recycling or reuse. Unlike the circular model, the linear model encourages the use of large quantities of cheap and easily accessible materials and energy. Raw materials are extracted from nature at the lowest cost, transformed into products with minimal labor input, and then sold at the highest possible price. This movement of resources has historically driven economic growth but has resulted in numerous issues, including resource draining, pollution, loss of biodiversity, and the increasing amount of waste in landfills. While the linear economy dominated much of the 20th century, it remains a significant problem to this day. One contributing factor is planned obsolescence, which means that products are intentionally designed with a limited lifespan to incentivize consumers to make repeat purchases (European Parliament, 2016). For instance, the average lifetime of a smartphone in the US is 2.5 years (Statista, 2023).

The evolution of technology, combined with decreasing life cycles and limited repair options, has increased consumption and the generation of EEE. This has positioned it as the world's largest growing waste stream, where rapidly outdated and increased electronic waste threaten sustainability and the circular economy (Gollakota et al., 2020). These challenges appear due to the slow adoption of collection and proper recycling practices, resulting in informal e-waste activities such as dumping, acid baths, and open burning (WHO, 2023). As a consequence of mishandling, the amount of greenhouse gases and harmful toxins increases, polluting the atmosphere, soil, and water. (Forti et al., 2020). Some of these chemical compounds are toxic substances such as dioxins, lead, and mercury, which are highly hazardous. Open burning is the most dangerous method, as the emitted toxins spread far beyond the initial point of combustion. Children and pregnant women, despite their increased vulnerability to harmful toxins, are frequently involved in some of the most dangerous tasks, including burning WEEE and disassembling components. In 2020, around 16.5 million children participated in different sectors of waste processing, serving as cost-effective labor as a part of the linear economy. Particularly in the e-waste sector, children were searched for after due to the advantage of their small hands in tasks requiring hand disassembly. (WHO, 2023).

In addition to the hazardous release of toxins during informal recycling, e-waste contains valuable metals like gold, copper, silver, iron, and platinum, all of which are lost in this process. For instance, sourcing metals such as gold and silver from e-waste instead of mining not only ensures higher quality but also leaves a smaller environmental footprint. A reduction in mining capacity has also caused the prices of metals that are used in e-waste to increase. If these metals can be safely and cost-effectively recovered from EoL electronics and put into new products, it has the potential to significantly reduce the consumer price (Drayton, H. L., 2007).

As per Baldé's findings, the potential value of the raw materials within undocumented e-waste in 2019 was estimated to be approximately 57 billion USD (Baldé et al., 2022). In the same year, the documented formal recycling of these raw materials extracted from e-waste contributed to a net saving of 15 million tons of carbon dioxide. By recycling these materials, it would contribute to a waste-minimizing circular economy, which would decrease biodiversity loss. Further, managing raw materials and promoting secondary use would lower the risks associated with finite supplies, including availability, import dependence, and price volatility. By 2030, the predicted shift to a circular economy is expected to annually cut net resource spending in the EU alone by 600 billion euro. However, the path toward a circular economy is not without its challenges. The absence of established markets for secondary raw materials and reliable pricing systems creates demand barriers. This is partly due to fluctuations in raw material prices, which therefore threaten the component market. Additionally, the lack of incentives for collaboration between producers and recyclers reduces efforts to improve the performance of value chains (European Parliament, 2016).

3.2 Challenges with Achieving a Circular Economy

Managing e-waste in an environmentally responsible manner is crucial for achieving a circular economy and preventing harm to both the environment and human health. National e-waste legislation regulates this process, which is known as formal collection. Organizations, producers, or the government typically engage in formal collection activities, gathering e-waste through channels like merchants, local collection centers, and pickup services. The collected e-waste is then transported to specialized treatment facilities, where valuable materials are recovered and hazardous substances are managed in controlled processes (Forti et al., 2018). The key to successful and proper e-waste management lies in economics, unfortunately, this process is expensive. The main factor is that the design of EEE products makes them challenging to disassemble for recycling and is therefore labor-intensive. The value of recycled materials often doesn't fully cover these costs. Therefore, imposing recycling fees becomes necessary to balance these expenses and counter the existing disincentives (Drayton, H. L., 2007).

While recycling e-waste offers numerous positive externalities, the formal recycling rate remains generally low. In the US, only approximately 15% of e-waste is formally managed. One contributing factor is the inconvenience faced by consumers engaging in recycling, such as drop-off locations and recycling fees. Studies indicate that consumers act rationally, seeking to maximize utility and minimize costs, and therefore a reduction in these fees could increase their willingness to recycle. However, due to current expenses, consumers often store e-waste at home or dispose of it in landfills, leading to a market failure similar to the free rider problem. Everyone wants to recycle because the negative externalities are, in the long term, affecting everyone, but no one wants to pay for it. Additionally, this also applies to landfills, which are not really true public goods, as they are neither non-exclusive nor non-rivalrous, but they are often treated as such. This results in uncompensated negative externalities such as groundwater pollution (Drayton, H. L., 2007).

From a game theory perspective, particularly the prisoner's dilemma, a Nash equilibrium arises where stakeholders maximize utility based on each other's strategies. Ideally, this equilibrium would motivate consumers to recycle through strategies implemented by other stakeholders. Legislation is seen as a solution to establish an optimal pollution level at the Nash equilibrium. Another solution involves creating a Pareto optimal outcome, where reallocating resources or goods benefits one person at the expense of another. One approach is a pigouvian tax on landfill disposal, aligning the tax amount with the marginal damage the pollution causes to the economic system. However, accurately setting a tax corresponding to the damage proves challenging (Drayton, H. L., 2007).

3.3 Global Flows of E-Waste

In 2019, the global production of e-waste reached 53.6 million metric tons, averaging 7.3 kg per capita. Out of this total, 44.3 mT, or 82.6%, were not documented for proper collection and recycling (Forti et al. 2020). Among these, approximately 43.7 million mT were likely traded, improperly disposed of or recycled, while the remaining 0.6 million mT found their way into waste bins within EU countries (Forti et al. 2020). In 2019, the worldwide collection and recycling of e-waste reached only 17%, a number that is consistent with the data from 2014, when 44.4 million metric tons were produced (Forti et al. 2020). This shows the slow progress of formal recycling processes, threatening the circular economy. Predictions say that the global generation of e-waste will increase by 2 million metric tons each year, reaching an estimated approximation of 75 million metric tons by 2030 (Forti et al. 2020) and 110 million metric tons by 2050 (Parajuly et al. 2019).

As formally extracting raw materials from WEEE is expensive and labor-intensive, a large portion of the undocumented e-waste and untested UEEE is exported. Mainly from high-income to low- and middle-income regions. The primary reason is the demand for such equipment in lower-income countries where there are developed markets for raw materials and attractive prices offered for reuse. Additionally, the items can be sold to collect spare parts for repair or recycling purposes (Baldé et al., 2022). Due to poor worker and environmental health regulations, informal management of electronics becomes cost-effective. In China alone, the aggregate profit from recycling e-waste in such areas is about $72 million annually (Drayton, H. L., 2007). The insufficient regulation not only leads to the exportation of e-waste but also results in negative external effects. In regions like the EU, extended producer responsibility (EPR) is deployed, requiring EEE producers to pay for recycling costs. These costs are then incorporated into the unit production cost, raising the marginal cost of each product and ultimately increasing consumer prices beyond what customers are willing to pay. This, in turn, may lead some manufacturers to declare bankruptcy, leaving the remaining ones with a more significant competitive advantage. Within the EU, this serves as an incentive for EEE manufacturers to design products with fewer toxic chemicals and in a manner that makes dismantling easier, which leads to reduced recycling costs. This generates a positive externality, benefiting not only the EU but also the countries purchasing these products (Drayton, H. L., 2007).

Common travel routes for e-waste involve both continental shipments, like those from Europe to Africa, and within the same region, such as from East to Southeast Asia or from Western or Northern Europe to Eastern Europe. The last mentioned has emerged as a notable hotspot, with Eastern Europe currently importing over half of its untested UEEE from Western and Northern Europe. In low-income countries, the absence of adequate e-waste management infrastructure and well-developed legislation leaves the environment and human health vulnerable to potential harm. In Western Africa, only 1% of e-waste is formally collected. Additionally, it offers criminals the chance to capitalize on these trade routes for illicit shipments and engage in other related criminal activities (Baldé et al., 2022).

Today, export and import of e-waste are primarily regulated as hazardous waste in both national and international legislation. As a result, e-waste is often blended with UEEE, which is not classified as hazardous, serving as a disguise that makes detection challenging. The pressure within containers during transportation often damages the functional part of the mix that comprises UEEE (Baldé et al., 2022). Further, selling non-functional UEEE is considered an illegal e-waste export. The primary route for the illicit trade of e-waste often involves transportation through used or near-EoL vehicles. This type of WEEE is rarely declared (Forti et al., 2018). Another major problem is the misclassification of e-waste, often falsely declared as new EEE, household goods or other waste types instead of being accurately identified as WEEE. Notably, from 2018 to 2020, e-waste consistently ranked among the top three globally traded waste categories in illicit shipment (Baldé et al., 2022).

4. Methodology

4.1 Data Collection and Empirical Methods

This analysis aims to explore how variables such as the number of e-waste-related legislation and price changes of gold and metals affect the generation and formal collection of e-waste in different countries. The choice of variables is based on previous research. Including Patil, R.A. et al. (2020) research, which showed difficulties in measuring the effectiveness of individual e-waste legislation. Since it is proved difficult to measure the individual effect of legislation, this thesis focuses on studying countries' total amount of legislation that can affect the number of e-waste collected. Furthermore Balde et al. (2015) have highlighted the significant value of raw materials in e-waste when recycling. Therefore this thesis studies the price changes of different metals that may influence the amount of e-waste collected. Additionally, the study by A. Kumar et al. (2017) identified a correlation between total e-waste generated and gross domestic product (GDP) per capita. This analysis builds on these findings by examining whether there is also a link to the amount of e-waste collected.

The method used for the analysis in this thesis is linear regression adjusted for panel data with fixed effects, focusing on e-waste generation, formal collection, and recycling rates as dependent variables. The choice of countries for the regression analysis was based on the availability of data on the three dependent variables. Due to limited data from other continents than Europe, 31 of 38 countries are European countries. Since more than 80% of the included countries are European countries, the result may be biased towards Europe. The analysis uses panel data to study the effect over time.

Panel data is effective in regression analysis since it takes account for variations over time and between different units. Paneldata as well reduces the impact of unobserved variation and improves control over individual differences by studying the same units over several time periods. Fixed effects were included in the analysis to reduce unit-specific heterogeneity and eliminate potential biases from unseen variables affecting the relationship between independent and dependent variables.

The following three linear regressions were used for the analysis.

$$EWasteCit \ = \ \beta 0 \ + \ \beta 1 \times Legislationit \ + \ \beta 2 \times MSW(\%)it \ + \ \beta 3 \times Populationit \ + \ \beta 4 \times Educationit \ + \ \beta 5 \times Incomeit \ + \ \beta 6 \times IndexMetalit \ + \ \beta 7 \times PriceOfGoldit \ + \ \beta 8 \times Exportit \ + \ \alpha i \ + \ \epsilon it$$

$$EWasteGit \ = \ \beta 0 \ + \ \beta 1 \times Populationit \ + \ \beta 2 \times Educationit \ + \ \beta 3 \times Incomeit \ + \ \beta 4 \times IndexMetalit \ + \ \beta 5 \times PriceOfGoldit \ + \ \alpha i \ + \ \epsilon it$$

$$EWasteC\,(\%)it \ = \ \beta 0 \ + \ \beta 1 \times Legislationit \ + \ \beta 2 \times MSW(\%)it \ + \ \beta 3 \times Populationit \ + \ \beta 4 \times Educationit \ + \ \beta 5 \times Incomeit \ + \ \beta 6 \times IndexMetalit \ + \ \beta 7 \times IndexMetalit \ + \ \beta 8 \times Exportit \ + \ \alpha i \ + \ \epsilon it$$

The analysis includes three dependent variables: EwasteC, EwasteG, and EwasteC%. The intercept β0 represents the starting point of these dependent variables when all independent variables are set at zero. The coefficients β1 to β8 measure the effect of each independent variable on the dependent variables. These coefficients show how a one-unit change in an independent variable impacts the dependent variables, with all other variables held constant. The error term ϵit accounts for all external factors that impact the dependent variables, but are not included in the model. The αi term is a fixed effect term in the model that captures the unique and constant characteristics of each country.

Since China and the US in our dataset have very high GDPs and thereby also generate large volumes of e-waste compared to European countries (A. Kumar et al., 2017) a robustness check was performed. To ensure that the results were not affected by these, all non-European countries were excluded. The excluded countries were Canada, China, the USA, Japan, Hong Kong, Australia, and Mauritius. The robustness check included 31 countries instead of the 38 countries included in the regression analysis.

4.2 Presentation of Summary Statistics of the Data

In Table 4.1 the selected group of variables that are used in the regressions are presented.

Variable	**n**	**Mean**	**σ**	**Min**	**Max**
EWasteG	114	745.51	1668	6	10129
EWasteC	114	192.51	318.14	1.5	1546
EWasteC (%)	76	0.41	0.17	0.09	0.81
MSW (%)	107	0.36	0.14	0.08	0.67
Legislation	105	2.67	2.66	0	15
Population	114	64.07	225.98	0.33	1410
Education	110	0.78	0.13	0.38	0.95
Income	114	37.78	23.89	7.569	123.679
IndexMetal	114	73.02	13.62	55	88.08
PriceOfGold	114	1289	73.02	1226	1392
Export	84	242	367.78	4	2090

Table 4.1: Descriptive Statistics of Selected Variables.

EwasteC represents the domestic data on the total amount, measured in kilo tonne (kT), of formal collection of e-waste through licensed take-back programs in 2012, 2015, and 2017. This includes WEEE that is gathered and exported to another nation, where it is treated in accordance with local regulations (Forti, Baldé, and Kuehr 2018). EWasteG denotes the quantity of domestic electronic waste generated by each country in 2014, 2016, and 2019. This measurement is taken before any processes involving collection, reuse, treatment, or export (Forti et al. 2020). The data for both the amount of e-waste generated and formally collected is gathered from the Global E-waste Monitor, a part of UNITAR.

The variable EWasteC (%) represents the proportion of a country's formally collected e-waste in relation to the total generated. It is derived with the help of the equation found in Forti et al.'s (2020) study, and the calculations are performed by the authors in this thesis. The equation is based on EWasteC and EWasteG:

$$EWasteC\ (\%) = \frac{EWasteC}{EWasteG} * 100\ .$$

This formal recycling rate is limited to two years, as the e-waste generated in one year can explain the future formal collection. Consequently, the quantity of the formal collection of e-waste for 2017 and 2015 is divided by the generation figures for 2016 and 2014. Therefore only 76 observations are observed.
Similar to EWasteC (%), the variable MSW (%) represents the percentage of waste that is recycled in relation to the total waste generated within a country. However, unlike EWasteC (%), MSW (%) specifically refers to the rate of municipal solid waste, which includes everyday household waste like metals, plastics, paper, and glass. The data for this variable were compiled from various sources, including Eurostat, the World Bank, the OECD, and government reports for the years 2014, 2016, and 2019.

IndexMetal is a commodity metal price index that tracks fluctuations in the overall prices of major metals on the global market. It includes metals such as copper, aluminum, iron ore, tin, nickel, zinc, lead, and uranium, many of which are components of e-waste. The index is expressed as a numerical value with a base year of 2005 and a base value of 100. It is measured for 2014, 2016, and 2019. Despite IndexMetal inclusiveness of several metals, IndexMetal excludes the price of gold. Notably, gold was identified as one of the metals with the largest value of e-waste in 2015 (Balde et al., 2015). To address this, the variable price of gold is introduced. It represents the global gold prices per troy ounce for the years 2014, 2016, and 2019 and is expressed in the number of nominal U.S. dollars. The price of gold is sourced from Statista, which compiles data from the World Bank's commodity price forecasts. The data for IndexMetal is sourced from the International Money Fund (IMF).

The variable population denotes the total number of inhabitants in a country, expressed in millions. Income represents the gross domestic product (GDP) per capita, expressed in thousands of dollars. Both of these variables are measured for the years 2014, 2016, and 2019 and are sourced from the World Bank.

Education is a measure that indicates the percentage of people aged 25 to 64 who have completed at least upper secondary education. The World Bank and Eurostat provide these statistics for the years 2014, 2016, and 2019. In this dataset, educational attainment is specified by the ISCED categorization, ranging from levels 3 to 8. This includes upper secondary education, post-secondary non-tertiary education, short-cycle tertiary education, bachelor's, master's, and doctoral degrees, or equivalent levels. It's important to note that differences in the duration of education between countries may impact achievement rates. Generally, longer educational durations are associated with higher dropout rates than shorter ones (Eurostat, 2023).

Export quantifies a country's overall exported hazardous waste, measured in kilotons (kT), and is gathered from Eurostat. This includes all hazardous waste categories defined by the Basel Convention and reported to the Basel Secretariat. Export does not exclusively measure the export of e-waste, which falls under the hazardous waste category. The classification includes a range of waste types, such as toxic, poisonous, explosive, corrosive, flammable, ecotoxic, and infectious wastes. Additionally, this variable is only measured for EU countries in 2014, 2016 and 2019 (Eurostat, 2020).

The variable Legislation represents the total number of e-waste-related laws a country has in a specific reporting year. These laws include both national legislation and conventions, such as the Basel Convention. Additional types of legislation include fees, import and export restrictions, and extended producer responsibility (EPR). The variable is measured for the years 2014, 2016, and 2019 and is gathered from the Global Statistics Partnership.

4.3 Presentation of Regressions Statistics of the Data

The following tables 4.2, 4.3, and 4.4, present the results of the regression analyses, where variables are introduced gradually. The coefficients are expressed without parentheses and the standard errors are expressed within parentheses.

EwasteC	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Legislation	31.23*** (5.98)	26.15*** (6.48)	18.75*** (5.88)	17.63** (6.39)	17.93** (6.46)	17.86** (6.50)	16.90** (6.79)	14.91* (5.87)
MSW (%)		9.59 (116.31)	85.08 (102.88)	93.28 (102.73)	94.33 (103.35)	107.57 (107.91)	73.79 (125.81)	-18.49 (107.49)
Population			62.81*** (13.07)	67.12*** (13.21)	69.15*** (13.42)	69.23*** (13.47)	67.61*** (14.96)	34.26 (16.15)
Education				48.45 (248.84)	13.31 (258.40)	45.83 (269.46)	-75.97 (354.96)	15.66 (299.55)
Income					0.95 (1.06)	0.47 (1.26)	0.48 (1.27)	-0.37 (1.09)
IndexMetal						0.17 (.37)	0.02 (.48)	-0.07 (.42)
PriceOfGold							0.03 (0.1)	0.04 (0.09)
Export								0.08** (0.03)
Constant	88.04*** (16.59)	73.59 (40.84)	-1215.94**** (283.93)	-1130.79*** (292.11)	-1149.49***(295.81)	-1182.54*** (306.24)	-1088.26** (355.52)	-534.04 (346.05)
N	105	99	99	96	96	96	96	84
Within R2	0.28	0.22	0.42	0.44	0.44	0.44	0.45	0.49

*** = p<0.001 , ** = p<0.01 , * = p<0.05

Table 4.2: Panel Data Regression Summary Table. Dependent variable: EWasteC.

EwasteG	[1]	[2]	[3]	[4]	[5]
Population	94.30*** (5.21)	82.96*** (60.10)	82.58*** (6.10)	82.28*** (5.81)	78.22*** (5.39)
Education		2020.57*** (650.69)	2174.51*** (657.15)	2519.64*** (643.26)	4039.7*** (704.1469)
Income			4.94 (3.68)	9.83* (3.98)	7.97* (3.66)
IndexMetal				2.87** (1.07)	4.07*** (1.02)
PriceOf Gold					-0.79*** (0.21)
Constant	-5296.56*** (334.21)	-6096.4*** (411.37)	-6005.39*** (414.65)	-6281.32*** (410.82)	-6140.48*** (375.97)
N **Within R2**	105 0.13	114 0.81	110 0.85	110 0.86	110 0.89

*** = p<0.001 , ** = p<0.01 , * = p<0.05

Table 4.3: Panel Data Regression Summary Table. Dependent variable: EWasteG.

EwasteC (%)	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Legislation	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.02 (0.03)	0.02 (0.03)	0.01 (0.03)	0.02 (0.03)
MSW (%)		0.62 (0.41)	0.66 (0.41)	0.65 (0.43)	0.57 (0.41)	0.25 (0.50)	0.86 (0.54)
Population			0.05 (0.05)	0.04 (0.05)	0.03 (0.05)	0.01 (0.05)	0.03 (0.07)
Education				0.32 (1.05)	-0.66 (1.16)	-1.24 (1.26)	-0.45 (1.23)
Income					0.01 (0.01)	0.00 (0.01)	0.00 (0.00)
IndexMetal						0.00 (0.00)	0.00 (0.00)
Export							0.00 (0.00)
Constant	0.34*** (0.06)	0.12 (0.16)	-0.69 (1.05)	-0.85 (1.16)	-0.09 (1.21)	0.87 (1.46)	-0.24 (1.61)
N **Within R2**	70 0.06	66 0.13	66 0.15	64 0.15	64 0.23	64 0.27	56 0.32

*** = p<0.001 , ** = p<0.01 , * = p<0.05

Table 4.4: Panel Data Regression Summary Table. Dependent variable: EWasteC (%).

4.4 Robustness Check

Tables 4.5 and 4.6 show the results of the robustness check for the regression analyses, with variables introduced gradually. The coefficients are shown without parentheses, and the standard errors are presented within parentheses.

EwasteC	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Legislation	27.28*** (6.42)	27.35*** (6.89)	21.02*** (5.57)	19.65** (6.09)	19.89** (6.12)	19.84** (6.21)	19.26** (6.49)	14.91* (5.87)
MSW (%)		-3.81 (121.54)	46.44 (97.03)	39.62 (98.31)	40.77 (99.12)	58.89 (102.88)	39.17 (119.24)	-18.45 (107.49)
Population			84.43*** (13.3)	84.11*** (13.42)	85.02*** (13.61)	85.50*** (13.63)	85.49*** (15.01)	34.26 (16.15)
Education				135.92 (237.2)	111.21 (248.91)	157.42 (258.68)	83.54 (341.09)	15.66 (299.55)
Income					0.05 (1.02)	0.05 (1.19)	0.05 (1.21)	0.37 (1.10)
IndexMetal						0.25 (0.35)	0.15 (0.46)	-0.07 (0.42)
PriceOf Gold							0.00 (0.09)	0.04 (0.09)
Export								.08 * (.03)
Constant	65.53*** (15.97)	66.78 (42.98)	-1356.29*** (240.13)	-1453.76*** (295.34)	-1459.8*** (298.0)8	-1511.53*** (308.43)	-1452.54*** (357.12)	-534.05 (346.05)
N **Within R2**	93 0.23	93 0.23	93 0.52	93 0.53	93 0.53	93 0.53	93 0.53	84 0.49

*** = p<0.001 , ** = p<0.01 , * = p<0.05

Table 4.5: Panel Data Regression Summary Table. Non-EU countries excluded. Dependent variable: EWasteC.

EwasteG	[1]	[2]	[3]	[4]	[5]
Population	8.17 (12.10)	-8.4 (12.28)	-10.53 (12.34)	-11.14 (12.03)	-6.66 (12.78)
Education		32.26 (186.21)	93.23 (191.77)	-42.13 (198.52)	156.18 (273.48)
Income			1.14 (0.92)	0.02 (1.05)	-0.03 (1.05)
IndexMetal				-0.59* (0.29)	-0.43 (0.33)
PriceOf Gold					-0.07 (0.07)
Constant	462.58* (205.26)	440.49 (243.05)	470.99 (243.2)	590.32** (244.26)	453.43 (276.48)
N **Within R2**	93 0.01	93 0.01	93 0.03	93 0.01	93 0.11

*** = p<0.001 , ** = p<0.01 , * = p<0.05

Table 4.6: Panel Data Regression Summary Table. Non-EU countries excluded. Dependent variable: EWasteG.

As a robustness check, the regressions were rerunned while excluding all non-EU countries. This was done to investigate whether the results remained consistent after accounting for outliers such as China and the USA. As shown in Table 4.5, with EWasteC as the dependent variable, the results were very similar to those before the robustness check. The same variables showed significance as before, namely Population, Legislation, and Export. The pattern of significance also remained the same, where legislation changed its level of significance as more variables were introduced, from 0.1% to 5%. Compared to before the robustness check, Population remained consistent with 0.1% level of significance and Export dropped from 5% to 1% level of significance. The remaining variables remained insignificant. This shows that outliers seem to have no effect on the correlation between these variables and the amount of formally collected e-waste. However, it is notable that the effect of legislation on formally collected e-waste has slightly decreased. The largest coefficient for this variable before the robustness check was 31.23, which decreased to 27.28. On the other hand, the effect of Population increased after the robustness check from the largest coefficient being 69.23 to 85.5. This suggests that outliers influence the magnitude of the impact of Population and Legislations on EWasteC.

The results of the robustness check for EWasteG as the dependent variable are not as consistent as for EWasteC. With non-EU countries excluded, as observed in Table 4.6, neither Population, Education, Income, nor Price of gold appear to be significant in any combination of variables. The only variable that retains significance is index metal, but it is only notable in the combination represented by column 4. Furthermore, the level of significance for this variable has shifted from 5% to 1%. Similarly, the coefficient has decreased from 2.87 to -0.59, indicating a shift from a positive to a negative correlation. This suggests that a one-unit increase in the metal index now corresponds to a 0.59 kT decrease in e-waste generated. The presence of outliers appears to have a large influence on the variables that may impact a country's amount of generated e-waste. They also influence the magnitude of the effect of IndexMetal, as shown by the transformation of the correlation from positive to negative.

4.5 Discussion of Results

The variable Legislation shows a strong and significant effect on the dependent variable EWasteC. As seen in Table 4.2, the variable is significant in all possible combinations. However, the level of significance changes as more variables are introduced. In columns 1–3, the variable is significant at a level of 0.1%, in columns 4–7 at 1%, and in column 8 at 5%. This indicates that there may be a presence of multicollinearity, which means that the independent variables are highly correlated. Legislation has the most impact on EWasteC in Column 1, with a coefficient of 31.23. This shows, everything else held constant, that a one-unit increase in a country's number of e-waste-related legislations leads to a 31.23 kT increase in the formal collection of e-waste.

MSW (%) shows varying coefficients and lacks statistical significance in both regressions. In Table 4.2 the coefficients vary widely between 9.59, 107.57, and -18.49. The wideness between the coefficients in combination with the statistical insignificance indicates that the relationship between MSW (%) and the dependent variables is uncertain and not clearly defined.

In the results of the regressions, it is evident that the population is significant for both EWasteC and EWasteG. As seen in Table 4.2, population shows a 0.1% level of significance in every combination except for column 8, where all variables are included. In column 8, the variable shows to be insignificant. In Table 4.3, population is significant on a level of 0.01% in every possible combination. The largest coefficient of population on formally collected e-waste is in column 6 with a number of 69.23. On e-waste generation, it is 94.3 in column 1.

This indicates a positive correlation, implying that an increase in population will increase both EWasteC and EWasteG. This shows (everything else held constant) that a one-unit (1 million people) increase is approximately equal to a 69 kT increase in e-waste formally collected and a 94 kT increase in e-waste generated.

Education shows a consistent positive relationship in the regression with the dependent variable EwasteG. When education is the only variable or combined with other variables, it retains its significance at the 0.1% level. The coefficients range from 2020.57 to 4039.7. This shows that an increase of one unit (percentage unit) in education will increase the generated e-waste by 2050.57 to 4039.7 kT. When education is included in the EwasteC regression, its relationship is less clear and consistent. Here the coefficients vary in size and sign, and all columns are insignificant.

The variable income (GDP/capita) has a significant effect on the dependent variable EwasteG. This significance is evident in the combination of variables in columns 4 and 5 at a level of 5%. The largest coefficient of income is 9.83 in column 4, indicating a positive correlation. A one-unit (thousand of dollars) increase in GDP per capita results in a 9.83 kT increase in the amount of e-waste generated.

IndexMetal shows significance for the dependent variable EWasteG in columns 4 and 5 on a 1% respectively 0.1% level, respectively. The highest coefficient is shown when IndexMetal is combined with all variables, with a coefficient of 4.07. This suggests a positive correlation, meaning that a one-unit increase in the metal index results in a 4.07 kT increase in generated e-waste.

The price of gold (PriceOfGold) demonstrates a significant relationship with the dependent variable EWasteG when combined with all variables at a 0.1% level. The coefficient is -0.79, suggesting a negative correlation. In practical terms, this implies that a one dollar/troy ounce of gold increase would lead to a 0.79kT decrease in the generation of e-waste.

The export of hazardous waste (Export) shows significance in relation to EWasteC at a level of 1%. This is seen in Table 4.2 in column 8 with all variables combined. The coefficient for Export is 0.08. This indicates a positive correlation, implying that a one-unit (1 kT) increase in the export of hazardous waste results in a 0.08 kT increase in e-waste formally collected. None of the variables in the regression for EWasteC (%) showed to be significant at any level. Therefore, no further discussion regarding table 4.4 is done.

5. Conclusion

In the results of the regressions, it is evident that population has a significant impact on both formally collected e-waste and e-waste generation. The greatest coefficients indicate a strong positive correlation, suggesting that for every 1 million inhabitants increase in a population, there is an approximate 69 kT increase in e-waste formally collected and a 94 kT increase in e-waste generated. This implies that the larger the population of a country, the more e-waste is generated and formally collected. This is clearly demonstrated in the dataset of this study, where China and the USA, with the largest populations, also have the highest amounts of generation and formally collected e-waste. In contrast, Malta and Iceland, with the smallest populations, exhibit the lowest generation of formally collected e-waste.

In A. Kumar et al. 's 2017 research, the correlation between population and generated e-waste was not found to be significant, as shown in figure 2.2. Similar to their study, outliers in this research include the USA and China, two countries with high shares of e-waste generation. However, what distinguishes this research from A. Kumar et al.'s 2017 work is the absence of India. India has one of the world's largest populations, yet its e-waste generation per inhabitant is relatively small. Since countries with large populations and low e-waste generation per inhabitant, such as India, are not included in our dataset, the correlation appears to be much more significant due to the outliers. To ensure that the results were not influenced by outliers, a robustness check was performed, excluding all non-EU countries. Without these outliers, the results indicated that, similar to A. Kumar et al.'s 2017 research, there is no significant correlation between a country's population and its e-waste generation, as shown in table 4.6. Population remained a significant variable in formal collection after the robustness check, suggesting that in the EU, an increased population correlates with increased formal e-waste collection.

As stated in A. Kumar et al. 's 2017 research, both the USA, China, and India are countries with large populations. However, these countries' total amount of e-waste generated differs, with India showing a relatively low generation per inhabitant. An increase in GDP per capita causes a higher amount of generated e-waste, as shown in figure 2.3, which explains the significant positive correlation between the two. The positive relationship is also evident in this thesis, where the variable income (GDP per capita) is significant for generated e-waste. According to Kumar et al. 2017, this relationship suggests that the quantity of e-waste produced per inhabitant is strongly correlated with individual purchasing power. In the regression, as seen in Table 4.3, a one-unit, $1,000 increase in GDP per capita results in approximately a 10 kT increase in the amount of e-waste generated.

An interesting result from the regression analysis is that education was found to be significant with all variables for e-waste generation EwasteG. This significance was not maintained during the two robustness tests or for EwasteC. Education has not been directly addressed in our literature review, but the work of M.T Islam et al. 2021 highlights the importance of broad awareness of the environmental and health consequences of improper e-waste management. It suggests the use of environmental education and public campaigns to raise awareness, which can indirectly influence e-waste generation. In this analysis, a more traditional measure of education was included.The fact that education showed significance for e-waste generation can be partly explained by the fact that higher levels of education may correlate with higher GDP per capita, which has been shown to lead to increased e-waste generation (A. Kumar et al., 2017). The correlation coefficient between income and education is 0.1559 in this analysis. This indicates a weak positive correlation between income and education. This means that an increase in the level of education tends to be weakly associated with higher income.

Regarding the absence of significance in the robustness check for EwasteG on Education, it may be due to the removal of the USA. As mentioned, the USA has high levels of generated e-waste and an average of 89% of education compared to all countries' average of 78%. When the USA was excluded from the robustness check, the significance of education disappeared, suggesting that the USA and other countries may have distorted the overall trend for education.

None of the results for the municipal solid waste rate (MSW %) were significant in any of the regressions. The average value for MSW (%) among all countries was 36%, and this excludes China and Mauritius due to a lack of reliable data available. For all countries, the mean value of the e-waste recycling rate was 39%. It is notable that the recycling rate for the municipal solid waste rate is lower than the formal recycling rate for e-waste, especially when we compare recycling data from the European Environment Agency (2023). According to their data, MSW had a recycling rate of 49%, while e-waste had a recycling rate of 39% in 2021 in Europe. This finding is in line with this study regarding the formal recycling rate of e-waste. Our panel data covers several years and countries outside of Europe. Comparing our data to the European waste statistics solely for the year 2021 shows a difference in the reported rates for Municipal Solid Waste. This difference is likely due to the fact that Europe has made significant progress in increasing their MSW recycling rate between 2014 and 2021, the same improvement cannot be said for e-waste. As evidenced by Figure 2.4 from the European Environment Agency (2023) a rise in MSW recycling rate in Europe can be seen, but a stagnant rate for e-waste recycling over time. This makes it clear that Europe has improved its recycling rate for MSW, but not for e-waste from 2014 - 2021.

The regression results, as seen in Table 4.2, show that the export of hazardous waste is significant in relation to the amount of e-waste formally collected. Where the variable is significant, the coefficient is 0.08, indicating a positive correlation. The magnitude of the impact is relatively high, if a country increases its exports by one unit (1 kT), the formal collection increases by 0.08 kT. The leading exporters in the dataset for the years 2014, 2016, and 2019 are France, Italy, Germany, the Netherlands, and Belgium (data from this thesis dataset in 2019). As shown in the regression, population is also a significant variable for the amount of e-waste formally collected. Looking at these countries, they are also in the top ten with the largest populations, indicating a potential correlation. When testing for the correlation between population and the export of hazardous waste, it showed a strong positive correlation of 0.6, further strengthening this hypothesis. Additionally, exporting a part of a country's e-waste is directly equal to less domestic-generated e-waste that can be formally collected. However, it is important to note that countries with a large amount of exported hazardous waste may not exclusively export e-waste but rather include other categories classified as hazardous waste. For instance, Germany stands out as the largest exporter of coal tar, accounting for 69% of the entire European share (Eurostat, 2023).

In terms of legislation, the result for the regression analysis and robust check seems reasonable at first glance, as laws and associated penalties are designed to incentivize a country towards increased collection of electronic and hazardous waste. The significant effect of legislation on EWasteC is clear, with an increase in one unit of e-waste legislation in a country correlating with a 31.23 kT increase in the formal collection of e-waste. This result highlights the role of the number of legislations in improving e-waste collection. The result does not measure the effectiveness of individual e-waste-related laws but highlights that a higher number of legislations results in a higher amount of collected e-waste. The result does not directly contradict Patil, R.A., et al. 2020 research that it is difficult to measure the effectiveness of individual legislations. Our result does not take into account the direct effectiveness of an individual legislation, but that more legislation seems to have an effect on the amount of collected e-waste.

Forti et al.'s 2020 research showed that when designing effective e-waste legislation, key components should be considered. This includes clear definitions of the roles of municipalities and the government, indicating which parties are responsible for organizing e-waste collection and recycling. Financial responsibility related to the value of e-waste, given its rich metal content, needs to be explicitly clarified for transparency. Ensuring national consistency in the definition of e-waste is crucial, especially if the legislation is based on the principle of extended producer responsibility (EPR). A precise definition of a producer is essential for fair enforcement in industries where producer responsibility prevails, as producers must take responsibility for recycling their products at the end of their lives. Without a clear definition, it will be challenging to fairly enforce legal requirements across industries. (Forti et al., 2020).

As seen in the robustness check in Table 4.5, where all non-EU countries are excluded, the metal index shows to be significant to the amount of generated e-waste. Since the coefficient for this variable is -0.59, it indicates a negative correlation, saying that an increase in the metal price would decrease the amount of generated e-waste. In most of the EU countries, EPR regulations are used to increase the amount of formally collected e-waste to decrease negative externalities that appear when e-waste is handled informally. Since consumers of EEE, in many cases, often get the responsibility to pay for e-waste recycling, this creates an incentive to not do so. EPR is therefore used to put this responsibility on the producer, and it is for them to pay for recycling costs. The problem with this is that these costs are being integrated into the unit production cost, raising the marginal cost of each product and ultimately increasing consumer prices beyond what customers are willing to pay. Additionally, finite supplies and a reduction in mining capacity have also caused the prices of metals that are used in e-waste to increase, which, in the same way as EPR, increases the consumer price. The potential decrease in demand would then result in decreased e-waste generation. (Drayton, H. L., 2007).

The metal index, on the other hand, shows to be significant with a positive correlation in Table 4.3, where all countries are included. This indicates that an increase in the metal price also increases the amount of e-waste generated. In the USA, recycling fees are implemented to cover the costs related to the formal processing of e-waste. This creates a disincentive for consumers to recycle, since they act to maximize their own utility and minimize costs. As mentioned in section 3.2, this resembles a free rider problem, where everyone wants to recycle because negative externalities, in the long run, affect everyone, but no one wants to pay for them. Therefore, they would rather store their electronics at home or dispose of them in landfills, where they become e-waste since they are not properly managed.

The positive relationship between metal index and generated e-waste could also be explained by the informal market for e-waste. As mentioned above, formal recycling of e-waste is expensive, but due to poor health and worker safety regulations, informal e-waste recycling, such as dismantling by hand, is cheap. These markets can therefore take advantage of the profit from increased metal prices. In China, the aggregate profit for this market is approximately 72 million USD annually, indicating a large demand for e-waste. The demand could, in turn, explain why increased metal prices would result in increased amounts of generated e-waste (Drayton, H. L., 2007). These explanations are further strengthened by the fact that both China and the USA are the greatest outliers in our dataset.

Similar to the metal index in the robustness check, the price of gold shows a significant negative correlation in Table 4.3, with all countries included. As seen in table 2.2, in 2015, gold was one of the metals that had the largest values extracted from e-waste, but at the same time, it was the one metal that was being extracted in the least amounts. In comparison, only 0.3 kT gold was extracted, while 16500 kT iron or steel was extracted. Of course, EPR or raw material prices could be one explanation of this relationship, but since the extracted values are so small, it is hard to say at what level it would affect electronic prices, demand, and eventually the amount of generated e-waste.

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