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Bridging the socioeconomic gap in E-waste: Evidence from aggregate data across 27 European Union countries

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A B S T R A C T

The responsible handling of e-waste has become a critical worldwide concern since, as it is essential for both environmental protection and human health because. This is because it prevents the release of harmful chemicals and reduces the ecological impact associated with the electronic waste disposal. Despite efforts the e-waste collection remains low due to a variety of reasons, including inadequate collection systems and socio-economic disparities. The present study aims to investigate the socioeconomic determinants affecting the level of e-waste in a sample of 27 EU countries for the period 2005–2020. The empirical analysis contributes to the existing literature by estimating the short- and long-term relationship between e-waste collection and corruption, income inequalities, imperfect gas market structures and labor market conditions. For this purpose, the study employs panel data techniques and cointegration analysis. The findings robustly suggest that countries with higher levels of socio-economic justice tend to exhibit higher e-waste collection levels, while the concentration of market share among a few dominant natural gas companies decreases collection levels. Low e-waste collection is also associated with concentrated income in the hands of a few individuals in both the short-and long-run. By advocating for equitable resource allocation and establishing a supportive environment, we can encourage increased levels of e-waste collection. Encouraging gas market entries and discouraging anti-competitive practices through regulatory frameworks is also crucial. Strategies to reduce wealth disparities and promote income equality involve implementing progressive taxation systems, redistributive policies, and inclusive economic development initiatives.

1. Introduction

Circular Economy (CE) transition necessitates substantial restructuring (Zisopoulos et al., 2022) along with a comprehensive waste management system that encompasses not only the management, recycling, or recovery of generated waste, but also the reduction of waste generation (Pomázi and Szabó, 2020; Robaina et al., 2020). During the 1970s, Europe initiated the formulation of waste regulations with the introduction of the initial Waste Framework Directive 75/442/EEC (European Commission, 1975). This initiative progressed, leading to the creation of several directives targeted at specific waste categories. In 1990, WEEE was identified as a Priority Waste Stream, followed by the publication of the first WEEE-specific Directive by the European Parliament in 2002 (European Commission, 2003). In 2012, the WEEE Directive underwent revision, leading to the introduction of various new obligations and objectives (European Commission, 2012). The collection of e-waste constitutes a fundamental CE element as the generation of such stream poses a significant global challenge due to the lack of an official e-waste collection system in place (Ilankoon et al., 2018). This gap hinders the sustainable handling of electronic products at the end of their life, as noted by Chatterjee (2012).

E-waste management is a pressing issue for global societies, both for environmental protection within the framework of addressing climate change and for economic reasons, by treating waste as tradable goods with economic value. Uncollected e-waste signifies a foregone chance to curtail the release of greenhouse gases (Islam et al., 2019; Yang et al., 2020) particularly in relation to carbon dioxide (Ibanescu et al., 2018; Clarke et al., 2019). It is worth noting that, even though Asia holds the title of the largest global generator of e-waste, Europe claims the second spot (Baldé et al., 2017) with quantities of e-waste continuing to escalate. One possible reason is that many EU countries lack the necessary environment to ensure the producer responsibility implementation (Widmer et al., 2005) entailing in achieving a minimum annual e-waste collection (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019 available at July 03, 2023).

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List of abbreviations

E-waste collection EWC
Waste Electrical and Electronic Equipment WEEE
Control of Corruption CC
Inequality of income distribution INEQUALITY
Employment rate EMPL
The market share of companies supplying the largest volume of natural gas MSNG

Academics acknowledge the significant challenges presented by the rapid increase in e-waste, impacting socio-economic and environmental well-being (Singh et al., 2020; Parajuly et al., 2020; Xu et al., 2020). Managing e-waste is of utmost importance (Cole et al., 2019) as it encompasses valuable recyclable materials such as plastics, glass, and precious metals (Oguchi et al., 2011), as well as hazardous substances like brominated flame retardants, lead, and mercury (Arduin et al., 2019). The reasons driving the rise in e-waste are not fully understood. Previous investigations have identified a correlation between a nation's economic progress, as indicated by its GDP and e-waste generation (Kusch and Hills, 2017; Awasthi et al., 2018; Namlis and Komilis, 2019; Boubellouta and Kusch-Brandt, 2021).

Various impediments, such as insufficient control of corruption, hinder the countries' endeavors to effectively address the increasing volumes of e-waste, which can have environmental and human health implications if not managed in compliance with environmental regulations. E-waste is often transported between countries due to legislative gaps in e-waste management, high levels of corruption, and profit-driven motives. Corruption undermines transparency in the e-waste management sector, creating opportunities for illicit dumping and other environmentally harmful activities. Illegal dumping of e-waste pertains to the informal act of discarding e-waste in a manner that is prohibited by law or regulations and includes a range of electronic devices and equipment, such as computers and mobile phones that have reached the end of their useful life. It engenders tensions between the public and private interests, leading to decisions that prioritize "informal sector's" profit and power over environmental and public health concerns. The concept of "informal sector" originates from studies within the framework of the so-called "Third World" since the late 1950s (Hart, 1970). However, there is still no clear definition of the "informal" concept that applies consistently across the entire spectrum of theoretical, empirical, and policy analyses. The term "informal" is approached as something that affects various mechanisms of official governance characterized by structural flaws (Guha-Khasnobis et al., 2006) which encourage the development of informal activities (Briassoulis, 1999). Gerxhani (2004) distinguishes the informal economy based on socio-economic and political criteria. Informal activities are increasing and occur in countries and regions with different levels of economic development (Castells and Portes, 1989). Schneider and Enste (2003) categorize informal economic activities into legal (informal sector) and illegal activities, further distinguishing between an informal sector that produces illegally but has legal output for goods or services, and a criminal sector that supplies illegal products. Informal waste management is prevalent in primarily Asian countries, such as India (Agarwal et al., 2005; Streicher-Porte et al., 2005; Hayami et al., 2006), Ghana (Brigden et al., 2008), Turkey (Tinmaz and Demir, 2006), Vietnam (Mitchell, 2008), and Tanzania (Kaseva and Gupta, 1996). Illegal dumping of e-waste can take many forms, including dumping in unauthorized locations such as landfills or exporting e-waste to developing countries without proper authorization or compliance with international regulations(Osibanjo and Nnorom, 2007; Rajesh Ejiogu, 2013). In this light, Bisschop (2012) investigated the global movement of e-waste from Antwerp to Africa and Asia. The findings demonstrated that those involved in waste collection, waste transportation, and other participants in the e-waste movement are prone not just to legal but also to illegal methods. In countries where environmental regulations are lax, there is fertile ground for illegal dumping of e-waste, which in turn leads to the release of hazardous chemicals and metals into the environment, causing health problems for local communities (Rožnik, 2020). This practice takes also advantage of lower recycling costs and higher revenues obtained from reuse in other countries, as noted by Chi et al. (2011). For example, the strategic rationale behind governments importing e-waste into Africa is to create job opportunities and raise fundamental standards. However, regrettably, this desired outcome remains unattainable for most African countries, except for Uganda and Rwanda (Hoornweg and Bhada-Tata, 2012), as they lack the necessary infrastructure for e-waste management. Although, Africa does not engage directly in e-waste manufacturing, it carries a significant share of the worldwide e-waste generation. In South Africa, Nigeria and Kenya, insufficiencies in regulatory frameworks and ineffective recycling practices led to untraceable e-waste flows, in addition to a prospering illicit trade of e-waste (Lydall et al., 2017). It is also worth mentioning, that the leading e-waste generator in the American continent is the United States and Canada, with the United States being the primary e-waste exporter to various locations, including Latin America and China (Duan et al., 2013) due to its non-ratification of the Basel Convention, which restricts the international movements of hazardous e-waste (Schumacher and Agbemabiese, 2019). This is explained by the fact that low wages, low prices, and a lack of environmental and overhead costs create viable profit margins from the collection and sale of secondary raw materials (Porter, 2002) being a common practice in China (Liu et al., 2006; Terazono et al., 2006; Yang et al., 2008).

Income inequality creates demand for cheap electronic devices, as individuals with lower incomes may not be able to afford higher-quality, longer-lasting electronic products. Low-income households purchase cheaper, less durable electronic products that are more likely to be discarded after a short period of use. In Mexico, migrants participate in informal endeavors related to e-waste as supplementary sources of income (Tsydenova and Heyken, 2019), whereas in Brazil, the e-waste industry serves as a livelihood for a significant share of population (Migliano et al., 2014). Concentrating on the e-waste disposal practices of Indian individuals and households where income inequality is a prevalent issue, Singh et al. (2023) analyzed primary data from 491 respondents in urban, semi-urban, and rural areas. The study revealed that a minority of consumers opt for formal disposal methods, while the informal disposal system prevails and dominates in all regions.

At the same time, non-competitive conditions in the gas market create, among other things, a disincentive for the development of energy-efficient electronics, as companies controlling the market may lack motivation to invest in environmentally friendly technologies that would reduce overall demand for natural gas. In energy markets with non-competitive structures (Lagendijk, 2008; Kartal, 2022), higher prices for e-waste collection may arise due to the greater market power of dominant companies. This can reduce the incentive for e-waste collection, particularly for SMEs that struggle to compete with larger firms. Companies may prioritize the use of e-waste for energy generation rather than collection, which can reduce their availability for collection while undermining the effectiveness of the EU's efforts to develop an effective e-waste collection system. Additionally, e-waste collection facilities and e-waste management centers require electricity to power their operations. Depending on the region and the gas availability, e-waste collection facilities may use natural gas-fired power plants to meet their electricity needs. Increased demand for e-waste collection can indirectly contribute to higher demand for natural gas to generate electricity. As highlighted by Dar et al. (2022), the consumption of natural gas correlates negatively with CO_2 emissions. Ghazanfari (2023) notes the interconnection of energy markets' structure, linear decarbonization policies, complexities related to demographics, hindrances stemming from culture and regulations, and the lack of adequate environmental consciousness. Kartal (2022) posits that the structural elements of the energy markets have the potential to exacerbate environmental stresses, leading to the deterioration of the natural ecosystem. As emphasized by Piebalgs (2006) based on the European Commission's stance, the importance of a competitive structure within the energy market is paramount for facilitating a transition toward environmentally friendly practices and ensuring the security of energy supply.

One of the main reasons why e-waste is not properly collected and recycled is due to lack of human resources. When employment rates are high, more resources are allocated in e-waste collection programs and higher access to skilled labor. This means higher levels of innovation and technological advancements and the buildup of a more resilient economy to address environmental challenges. Governments and private organizations may have more financial resources to allocate to the hiring of trained personnel, which can enhance the level of efficiency in e-waste collection. In this light, the advantages of work prospects, have been recognized as "ostensible benefits" by Sovacool (2019), Zhang et al. (2012) and Rodrigues et al. (2020). As identified by Umair et al. (2016), profitability acts as the impelling element in the market for reprocessing e-waste, with all parties involved, from importers to recyclers, reaping substantial profits. Conversely, Shaikh et al. (2020) emphasize that notwithstanding the wage discrepancies, what stands out is the prominent role of laborers in e-waste management, making them the most susceptible. In pursuit of income for their families, they engage in perilous working conditions, employing informal practices for recycling. Illiteracy and impoverished living conditions seem to leave these laborers with scarce alternatives, making them content with securing regular employment. Another recognized aspect of e-waste management is the use of informal methods for processing materials emphasizing the necessity of government intervention to ensure improved working conditions in e-waste management.

Although the above-analyzed socio-economic disparities, such as control of corruption, inequality of income distribution, gas market oligopolistic conditions, and labor market conditions are crucial in managing e-waste efficiently, they have received relatively limited attention in empirical research. The present study aims to address the existing literature gap by providing insights for the first time into the socio-economic determinants of e-waste collection, with a particular focus on promoting equity, social cohesion, controlling corruption, and establishing Bertrand competitive conditions. In this regard, the short-term deviations from the long-term equilibrium are investigated during the period 2005–2020. This is achieved by employing various estimation techniques such as Fixed Effects, Fully Modified Ordinary Least Squares (FMOLS), M-estimation with Robust Least Squares and Error Correction Model with Generalized Least Squares. The analysis considers the pace of adaptation, as indicated by the lagged Error Correction Term (ECT) and identifies the required timeframe for policy outcomes to manifest. To shape a European future based on proper e-waste collection behavior, more than just reducing e-waste generation is necessary, as this is in constant interaction with the need to address socio-economic disparities and create equal opportunities for all to achieve balanced sustainable and inclusive economic growth.

The paper documents the theoretical debate on e-waste in Section 2, while Section 3 highlights the data and methodology used in the empirical analysis. The 4 section analyzes the empirical results while Section 5 outlines the discussion. Conclusions and suggestions for future research are presented in the last section.

2. E-waste determinants in the light of socioeconomic disparities: A brief literature review

The relationship between e-waste generation and economic development is examined by Awasthi et al. (2018) through a comparative analysis of the performance of the 28 EU member states for the period 2009–2014. The results show that economic development positively affects the e-waste collected. Kusch and Hills (2017) group countries into five different categories based on geographical criteria and then examine the production of electrical and e-waste in 2014 for 50 countries from Western Europe, Central Europe, Southeastern Europe (including Turkey and Israel), Eastern Europe (including Russia), the Caucasus, and Central Asia. While e-waste generation is higher in countries with higher development levels, the intensity of e-waste, based on nominal GDP, is found to be lower in high-income countries. Countries with lower economic development exhibit higher e-waste intensities, while in countries with higher development, the intensity of e-waste flows is lower. This reflects a "saturation pattern" in rich countries, where higher income levels result in a greater disposition to e-waste in the market and consequently, the generation of higher quantities of e-waste, but not to the extent observed in poorer countries. Gaidajis et al. (2010) focus on the current and future generation of e-waste, the environmental challenges associated with their disposal, and their management practices by examining case studies of waste management systems in Greece, Japan, and Switzerland. The researchers first define the concept of e-waste, the equipment categories that generate them to a greater extent, and the estimated life cycle, emphasizing that e-waste generation increases as levels of economic development increase, due to the development of new technologies. A higher economic development means a higher demand for electronic goods, which in turn produces a higher volume of e-waste. Boubellouta and Kusch-Brandt (2021), focusing on the EKC hypothesis for a set of 174 countries in the year 2016 point out that e-waste generation does not increase as economic development approaches high levels, specifically beyond the point where environmental quality suffers the greatest degradation. Diao et al. (2009) examine the effect of economic development on environmental quality. In this regard, they focus on the EKC using the pollution index as an indicator of environmental degradation. The researchers use annual data for the period 1995–2005 for the city of Jiaxing in China finding a weak N-shaped relationship between economic development and industrial waste generated. Namlis and Komilis (2019) investigate the nexus between socio-economic factors and waste generation focusing on 10 European countries for the years 2008–2015. They point out that as development levels increase, all waste streams generated by batteries tend to increase. Boubellouta and Kusch-Brandt (2020) examine the EKC hypothesis by examining the generation of e-waste as an indicator for environmental degradation. Under this line of thought, they utilize annual data for the period of 2000–2016 for 30 European countries and observe an inverted U-shaped relationship between economic development and e-waste generation in EU countries.

Environmental degradation means higher carbon footprint levels. However, Dar et al. (2022) point out that CO_2 emissions are eliminated due to natural gas consumption thus contributing to lower carbon footprint levels. In the absence of Bertrand-like competitive pressure in energy markets, oligopolistic or even monopolistic behavior emerges. Kartal (2022) identifies a positive correlation between the anti-competitive structure of energy markets and the ecological footprint. Lagendijk (2008) emphasizes the importance of an open internal electricity market for addressing environmental issues, while the European Commission (2006) advocates for the need for competition in energy markets to address energy poverty. Eikeland (1998) notes that liberalized markets shape an environmentally concerned behavior with enhanced responsibility. A fragmented monopoly, as stated by Borowski (2020), is associated with the overexploitation of fossil fuels.

Lepawsky and McNabb (2010) examine the impact of international trade on e-waste generation for the period 2001–2006 across 200 countries. In this context, they attempt to identify the global flow and international trade of e-waste. Researchers examine the validity of the pollution haven hypothesis through a statistical adjustment of each country's annual net trade balance against relative wealth and poverty, and then examining each trade transaction between trading countries in relation to their development levels. As economic development decreases, the likelihood of a country being a net importer of e-waste increases. However, in the years 2001, 2002, and 2006, no statistically significant relationship is found, which also holds true for the relationship between net trade balance and debt for each year. Trade transactions are examined based on the relationship between the development levels of an importing country and its trading partners. Countries are classified into two categories: "lower" if the importer has a lower development level than the exporter, and "higher" if the importer has a higher development level than the exporter. For each year except 2006, most of e-waste import transactions occur when the importing country has a lower economic development than the exporter. This can be explained, among other factors, by the pollution haven hypothesis regarding the trend of international trade in e-waste. Although e-waste is traded inter-regionally, moving from developed to developing countries, significant trade in e-waste is observed among developing countries as well. Bisschop (2013), in turn, focuses on the case of illegal transports of e-waste at the European level. Specifically, it is examined whether the actors involved in the trade of e-waste and the roles they play in the process can be considered legal or illegal, while depicting the legal and illegal interfaces in the flows of e-waste. The data for the analysis are derived from primary and secondary sources, interviews with key informants, and on-site visits and is based on government sources (inspection reports and statistics, police reports, customs and trade statistics), research reports, corporate documents, and documents from civil society organizations (environmental organizations, NGOs, media). Additionally, 50 semi-structured interviews are conducted with 29 government agencies, 19 private sector entities, and 14 public sector entities. The results indicate that at the beginning of the e-waste flow, consumers tend to sell their e-waste to entities that offer to handle them at excessively low prices. This is due to either a lack of awareness and proper care or a conscious choice for cheaper illegal disposal. However, both cases represent a legal-illegal interaction in which governments, companies, and individual consumers can be involved. The disposal of e-waste can be a result of either in-house processing or outsourcing, which allows the involved entity operating legally to externalize the cost. The researcher emphasizes that the recycling of e-waste, especially in developing countries, operates on the "borderline" between environmental sustainability and violation of environmental and labor standards. For example, in Antwerp, only 20% of the total e-waste consists of domestic e-waste, while the remaining 80% represents inflows from abroad. This indicates how the globalized market leads to illegal cross-border mobility of e-waste. Efthymiou et al. (2016) investigate the impact of macroeconomic and social factors on the illegal trade of e-waste, focusing on the factors that make the waste sector vulnerable to waste crime. The results show that, with few exceptions, all sender countries have higher economic development levels or higher scores in the Open Market Index, Human Development Index and the Social Progress Index compared to recipient countries. Therefore, the illegal trade of e-waste is directed from economically and socially developed countries to economically and socially developing countries. The researchers further posit that while sender countries may experience superior economic development, the same cannot be said for social development, given that the illegal trade of e-waste is not solely a matter of economic assessment, but also a reflection of inadequate legislation and ineffective law enforcement (Streicher-Porte et al., 2010). As such, this form of environmental transgression is poised to persist until the demarcation between legal and illegal e-waste trade is unequivocally delineated. Almer and Goeschl (2015) investigate the determinants of illegal waste disposal by employing dynamic panel data. They included data on illegal waste dumping, waste markets, county income and the number of public officials' prosecutors, and judges for the period 1995–2005 from 44 counties in the federal state of Baden-Württemberg. The results show that waste violations decrease as enforcement controls increase and corresponding penalties are imposed, while waste violations partially respond to fluctuations in the imprisonment rate. Additionally, it is found that waste-related criminality increases ceteris paribus as per capita gross GDP and total revenues from the processing sector rise, whereas as the number of individuals employed in the processing sector and the contribution of corporate taxes to the county's total income increase, the rates of illegal waste disposal decrease. Su and Chen (2018) examine the existence of an EKC for the generation and illegal disposal of medical waste for the period 2001–2015 for Taiwan. In the linear model, a positive correlation is observed between development levels and the number of beds per capita in the production of medical waste that is improperly treated. As development levels and hospital capacity increase, the generation of medical waste that is not adequately treated also increases. On the other hand, the implementation of the Diagnosis Related Groups policy has a significant impact on reducing the illegal disposal of medical waste.

Darby and Obara (2005) investigate consumers' attitudes towards the disposal of e-waste (such as mobile phones), which are among the fastest-growing streams of waste in the EU, as well as the key issues accompanying the implementation of the directive on Waste Electrical and Electronic Equipment. Focusing on the case of small electrical appliances, the results indicate that households lack awareness and have low recycling rates. At the same time, they are not interested in delving into the reasons why recycling is necessary but are more concerned about how they can recycle. As income increases for both men and women, households are more likely to visit a waste collection point to dispose of their electronic items compared to households with incomes below £10,000, most likely due to lack of convenient transportation access. At the same time, the researchers note that poorer households tend to keep their electronic items for a longer period and engage in more reuse activities compared to wealthier households. Favot and Grassetti (2017) examine the linkages between socio-economic variables and the presence of e-waste collection points and the collection rate focusing on 20 Italian regions from 2008 to 2015. The presence of collection points is expressed as the number of collection points per 100.000 inhabitants, while the collection rate is expressed as the number of kilograms of e-waste collected annually per capita. The results show that a 1% increase in the presence of collection points leads to a 0.25% increase in the e-waste collection process.

The creation of more employment opportunities can lead to higher household incomes, which in turn can increase the likelihood of households visiting waste collection points to dispose of their electronic items. Chen (2010), focusing on the EKC hypothesis, utilizes annual data for the period 1998–2008 including as urban areas the municipalities of Taipei, Taichung and Kaohsiung and as rural areas the counties of Yilan, Hualien and Taitung. The results show that the higher the unemployment rate, the lower the waste per capita (Chen, 2010). Namlis and Komilis (2019) investigate the impact of unemployment on waste generation focusing on the period 2008–2015 for 10 European countries. The results show that 5 waste streams are negatively correlated with the unemployment rate and therefore as the unemployment rate increases, waste generation decreases. In addition, the association between employment and municipal waste generation is examined by Gardiner and Hajek (2020). The results in the long-run show, that a 1% increase in the employment rate is associated with a 0,001% increase in the municipal waste generation on average, ceteris paribus. Respectively, for the new EU member states the model estimated with the FMOLS shows that a 1% increase in the employment rate reduces the waste generated by 0,002 % on average, ceteris paribus.

Fig. 1 represents the evolution of e-waste collection providing evidence of the electrical and electronic equipment consumption differences that arise from country to country. In Austria and Finland, the volume of e-waste generated is accompanied by adequate e-waste collection systems, placing these two countries above the EU average. Following good practices from countries that have demonstrated improved e-waste collection methods, other EU countries will be able to ensure that e-waste is properly disposed of and collected, rather than ending up in landfills or being illegally exported to other countries. Despite the challenges posed by increasing volumes of e-waste, such collection systems can also help mitigate negative impacts and ensure sustainable end-of-life management for electrical and electronic

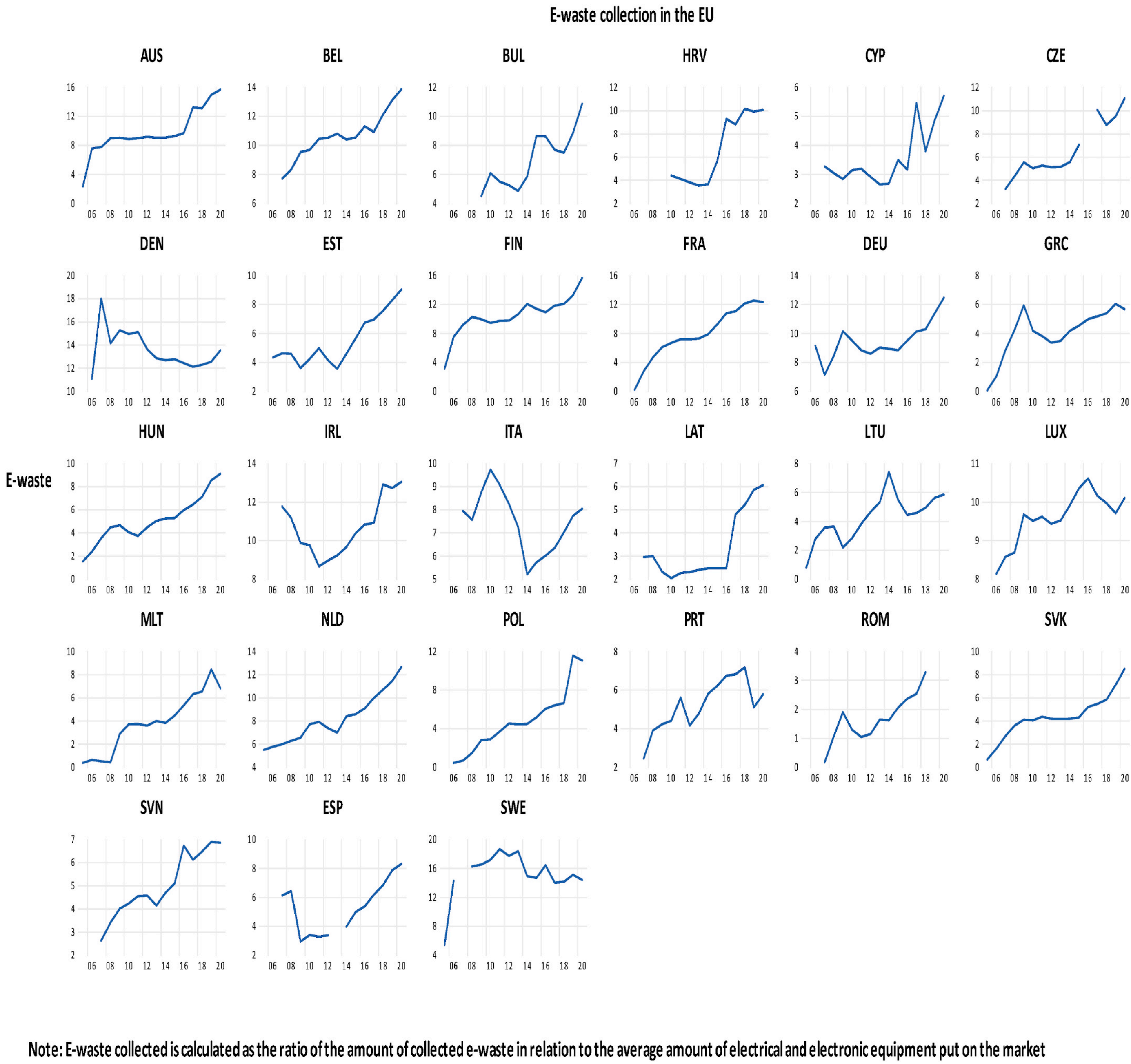

Fig. 1. E-waste in EU countries.

equipment. This is of paramount importance as e-waste is a growing problem around the world, and without proper management, it creates unsafe conditions for humans, the environment and the economy.

3. Methodology and data

Our empirical analysis includes a sample of 27 EU countries over the period 2005 to 2020, subject to data availability. When investigating the determinants of e-waste collection, the empirical model considers various variables, which encompass factors related to socioeconomic disparities (such as income distribution inequality) as indicated by previous studies (Migliano et al., 2014; Kusch and Hills, 2017; Tsydenova and Heyken, 2019; Boubellouta and Kusch-Brandt, 2020). Additionally, it accounts for the extent of control held by gas monopolies or oligopolies (measured by the market share of companies supplying the largest volume of natural gas) based on prior research (Eikeland, 1998; Borowski, 2020; Kartal, 2022; Dar et al., 2022; Ghazanfari, 2023). Furthermore, the model considers labor market conditions, such as the employment rate, as discussed in previous studies (Umair et al., 2016; Sovacool, 2019; Zhang et al., 2012; Shaikh et al., 2020; Rodrigues et al., 2020), and incorporates proxies for assessing the control of corruption based on prior research (Bisschop, 2012, 2013; Almer and Goeschl, 2015; Efthymiou et al., 2016; Lydall et al., 2017). Considering the literature mentioned for variable selection and the European Union's imperative to establish a formal e-waste collection system rooted in socio-economic justice, our model is constructed as follows:

$$\log(EWC)_{it} = \beta_0 + \beta_1 \log(CC)_{it} + \beta_2 \log(INEQUALITY)_{it} + \beta_3 \log(EMPL)_{it} + \beta_4 \log(MSNG)_{it} + u_{it} \quad (1)$$

where the e-waste collected of country i at time t is represented by *EWC* and the coefficients to be estimated by β_i. *EWC* as derived from the OECD in Environment database, is used as dependent variable and is defined as the total volumes of WEEE collected. The explanatory variables include the Control of Corruption *(CC)*, inequality of income distribution *(INEQUALITY)*, employment rate *(EMPL)* and the market share of companies supplying the largest volume of natural gas *(MSNG)*. The error term is represented by u_{it}. Table 1 provides an overview of the variables of interest.

As the variables are included in logarithmic form, the coefficients are interpreted as constant elasticities. To estimate the long-term relationship between the variables of socio-economic justice on e-waste levels, we employ OLS, Fixed Effects (FE), Random Effects (RE), Fully Modified Least Squares (FMOLS), and Robust Least Squares (RLS) techniques. OLS is widely preferred for providing optimal linear unbiased estimates, yet it rests upon the assumption of independent and identically distributed error terms. The use of a FE model facilitates estimation even when there is correlation across cross-sections, heteroskedasticity across panels and first-order autocorrelation within panels as introduced by Parks (1967). It accounts for time-invariant variables but doesn't accommodate unobserved heterogeneity. On the other hand, RE accommodates unobserved heterogeneity but assumes no correlation between regressors and individual effects. To assess the cointegrated vectors while addressing issues related to serial correlation and endogeneity the FMOLS estimator is used as proposed by Phillips and Hansen (1990). It is robust to endogeneity but requires strict exogeneity. To provide robustness to outliers and heavy-tailed distributions the M-estimation with the RLS estimator is employed, as stated by Huber (1973). M-estimation can handle heteroscedasticity, while producing more accurate estimates of the underlying regression coefficients. However, it requires a robust function choice. To address multicollinearity issues which cause problems in the regression analysis, such as inflated standard errors, unstable coefficients, and reduced predictive power, the Variance Inflation Factor (VIF) is calculated by regressing each independent variable against all the other independent variables in the model and then taking the reciprocal of the R-squared value (Nachane, 2006). A commonly used threshold for VIF values is 10. If the VIF value for a particular independent variable is less than 10, it is generally considered to be acceptable and not a significant cause for concern in terms of multicollinearity. However, if the VIF value exceeds 10, it may indicate that the variable is highly correlated with other variables in the model and may need to be dropped or combined with other variables to reduce the multicollinearity. Additional tests such as Cross-Section SUR are conducted to assess the model's robustness. The findings demonstrate that the coefficient estimates and their respective t-statistics exhibit consistency across all alternative runs, underscoring the reliability of the model. To ascertain the model's resilience, we re-estimate the relationship between corruption, inequality, gas market's structure, employment and e-waste on subsets of countries with FE model, with either southern or northern countries excluded, and the outcomes confirm the overall robustness of our conclusions.

Accordingly, the short-run dynamics of *CC*, *INEQUALITY*, *EMPL* and *MSNG*, on the behavior of *EWC* are investigated by employing different specifications. When cointegration is detected, Engle and Granger's (1987) approach allows for the establishment of an error correction representation which measures the extent to which changes in the dependent variable are influenced by the degree of disequilibrium in the cointegrating relationship, as well as short-term changes in explanatory variables. The magnitude and statistical significance of the Error Correction Term (ECT) provide insight into the extent to which each dependent variable tends to revert to its long-run equilibrium. For a short-term equilibrium relationship, the ECT coefficient must be both negative and statistically significant. The study employs the Error Correction Model (ECM) with Generalized Least Squares (GLS) estimates for first differences (Δ) and lagged first differences of the variables to analyze the short-term relationship between the variables of interest. Employing an ECM with GLS can be a useful approach for estimating models with heteroscedasticity, autocorrelation, endogeneity, or when efficiency is a concern. It relies on appropriate lag selection and assumes no cointegration misspecification. Careful consideration of data characteristics and research objectives is necessary for the selection of this method. To determine the optimal time lags for the independent variables in the ECM Hendry, 1980, the Akaike Information Criterion (AIC) is employed which is a model selection criterion that evaluates the goodness-of-fit of statistical models while penalizing models with too many parameters. By selecting the models with the lowest AIC score, we can ensure that the model is well-fitted and the results are reliable and accurate. The ECM with GLS is specified as follows:

$$\Delta \log(EWC)_{it} = \beta_0 + \beta_1 \Delta \log(CC)_{it} + \beta_2 \Delta \log(EMPL)_{it} + \beta_3 \Delta \log(MSNG)_{it} + \beta_4 \Delta \log(INEQUALITY)_{it} + \beta_5 \Delta \log(EMPL)_{it-1} + \beta_6 (ECT)_{it-1} + u_{it} \quad (2)$$

In the next step, the first difference (Δ) of the dependent variable *(EWC)* is included as an independent variable with one-time lag -as determined by the AIC- and is specified as follows:

$$\Delta \log(EWC)_{it} = \beta_0 + \beta_1 \Delta \log(CC)_{it} + \beta_2 \Delta \log(EMPL)_{it} + \beta_3 \Delta \log(INEQUALITY)_{it} + \beta_4 \Delta \log(MSNG)_{it} + \beta_5 \Delta \log(EWC)_{it-1} + \beta_6 (ECT)_{it-1} + u_{it} \quad (3)$$

Variables are extracted from the OECD, Eurostat and World Bank databases and include the following indicators: Control of Corruption *(CC)* as sourced from the World Bank in the World Governance Indicators database is part of the Institutional Quality Index and assesses the extent to which public officials use their power for personal gain while including measures of the influence of private interests on the state. It is scored on a scale of 0–100, with higher scores indicating lower corruption levels. A positive correlation with *EWC* (OECD) is expected. Employment rate *(EMPL)* represents the available labor and is extracted from the Employment Performance Monitor database of Eurostat. A relationship with the *EWC* is expected. Inequality of income distribution *(INEQUALITY)*, derived from the social protection performance monitor database of Eurostat, measures the income inequality. A negative relationship with *EWC* is expected. The market share of companies supplying the largest volume of natural gas *(MSNG)* reflect the impact of energy markets on *EWC* and is extracted from the Eurostat database. A relationship with *EWC* is expected. The statistical characteristics of the variables of interest are presented in Table 2.

Table 1
Variables description and sources.

Variable	Measurement Units	Source	Available at:
EWC	"The total volumes of WEEE collected"	OECD in Environment database	https://stats.oecd.org/Index.aspx?DataSetCode=EWASTE
CC	"Control of Corruption"	World Bank in the World Governance Indicators database	https://databank.worldbank.org/source/worldwide-governance-indicators
INEQUALITY	"Inequality of income distribution"	Eurostat in the Social protection performance monitor database	https://ec.europa.eu/eurostat/databrowser/product/view/tespm151
EMPL	"Employment Rate"	Eurostat in the Employment performance monitor database	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Employment_-_annual_statistics
MSNG	"The market share of companies supplying the largest volume of natural gas"	Eurostat in Energy statistics database	https://ec.europa.eu/eurostat/databrowser/product/view/nrg_ind_market

Table 2
Summary statistics.

Variable	Obs	Mean	Std.Dev.	Min	Max
E-waste collected	126	7.59	3.25	2.40	18.39
Corruption Control	126	76.27	13.38	53.37	98.58
Income Distribution Inequality	126	4.94	1.16	3.03	7.46
Employment Rate	126	65.91	6.31	48.48	76.85
Gas Market Dominance	126	64.91	23.70	23.38	100.00

4. Results

Accordingly, it is crucial to verify that the assumptions of cross-sectional dependence (correlation between individual units) and slope homogeneity (equal relationship between dependent and independent variables across all units) are not violated. Pesaran's CD test is used to determine the presence of cross-sectional dependence in panel data. It calculates a correlation matrix of the residuals from a FE model and detects significant correlation among them, indicating cross-sectional dependence. The Pesaran-Yamagata test, on the other hand, is employed to test for slope homogeneity in panel data. It uses a FE model with individual-specific time trends to estimate if the slope coefficients are the same across all units in the panel. The results of these tests are presented in tables, and a rejection of the null hypothesis indicates the presence of cross-sectional dependence and/or slope heterogeneity *(Table 3)*.

The order of integration of the series is determined by performing standard unit root tests (ADF tests). The results suggest that all variables except the CC and INEQUALITY are integrated of order one *(Table 4)*.

Accordingly, a panel co-integration analysis is performed by employing the Pedroni and Kao statistics to examine the existence of long-term equilibrium relationships between the variables of interest across the 27 EU countries. The findings, which are presented in Table 5, demonstrate the presence of a co-integration relationship among the variables of interest offering statistical support for Equation (1) in the panel dataset.

Table 6 presents the long-run coefficients by employing OLS, FE, RE, FMOLS, and RLS models after verifying that the variables have the same order of integration and the results of the Breusch-Pagan test which rejected the null hypothesis. As can be observed, by taking EWC as a dependent variable, CC and EMPL are estimated positively and statistically significant in all econometric specifications underscoring the importance of creating equal employment opportunities and effective control of corruption for higher EWC. According to the FE model, a 1% increase in CC and EMPL is associated with a 1.27% and 2.60% increase in EWC in EU countries respectively. Countries that effectively combat corruption generally have stronger governance and regulations, which encourage proper EWC through well-implemented laws. These regulations are enforced through inspections and penalties, discouraging illegal dumping. On the contrary, in countries with low CC, e-waste is often disposed of informally and illegally, posing among other things significant environmental and health risks. The outcomes aligns with the studies of Bisschop (2012, 2013), Almer and Goeschl (2015), Efthymiou et al. (2016) and Lydall et al. (2017). Higher EMPL means increased economic activity and more investments in e-waste management infrastructure by the government and private sector. This includes the establishment of e-waste collection centers, recycling facilities, and improved transportation for waste collection, making it more convenient for people to dispose of their e-waste properly. On the contrary, when there is a decrease in the number of people employed, it often suggests a slowdown in economic activities, and limited capacity to invest in effective waste management practices conforming with the findings of Umair et al. (2016), Sovacool (2019), Zhang et al. (2012) and Rodrigues et al. (2020).

Decreased EWC is also robustly associated to INEQUALITY and MSNG. The interplay between CC and EWC becomes stronger under the RLS estimator. According to the FE, RE and RLS models, INEQUALITY and MSNG are estimated negatively and statistically significant. Income inequality and the dominance of oligopolies in the natural gas market may limit access to collection facilities, perpetuating a lack of awareness and education, and reducing financial resources for e-waste management. The control of natural gas supply by oligopolies or monopolies, means increased energy costs and limited market competition (Eikeland, 1998; Borowski, 2020; Kartal, 2022; Dar et al., 2022; Ghazanfari, 2023). This can have a ripple effect on the overall economy, resulting in reduced economic activity, limited funds available and diminished investment in environmental initiatives, including e-waste collection programs. Needless to say, that governments often derive revenue from natural gas taxes and royalties. In countries where gas is controlled by a few entities, this reduces government revenue, impacting funding for public services, including e-waste management. The concentration of market share among a few dominant natural gas companies can exacerbate inequalities. In countries with high INEQUALITY, individuals and communities may have limited access to proper e-waste collection facilities as they may be concentrated in wealthier areas or may require a fee that is unaffordable for lower-income individuals. People in those countries may resort to improper disposal methods such as dumping e-waste in landfills or incinerating it, rather than seeking out appropriate collection options. This is stressed in the studies of Migliano et al. (2014), Kusch and Hills (2017), Tsydenova and Heyken (2019) and Boubellouta and Kusch-Brandt (2020). INEQUALITY also means disparities in access to education and knowledge about the importance of proper e-waste collection and the potential environmental and health risks associated with incorrect disposal methods. Without adequate education and awareness, people may not prioritize e-waste collection.

The short and long-term relationship between CC, INEQUALITY, EMPL, MSNG and EWC is analyzed by employing ECM with GLS *(Table 7)*. In all equations, the Error Correction Term (ECT), measuring the deviation in e-waste collection rates from short-run to long-run equilibrium, is both negative and statistically significant. The results of the parsimonious ECM_1 with GLS show that the speed of adjustment is about 54%. The magnitude of 1.21 of CC implies that a 1% increase in CC is associated to a 1.21% increase in EWC in Europe on average, ceteris paribus. The magnitude of −0.13 of MSNG and −0.28 of INEQUALITY implies that a 1% increase in the concentration of market share among a few dominant natural gas companies and income inequality in Europe decreases the EWC by 0.13% and 0.28% respectively on average, ceteris paribus.

The coefficient of the parsimonious ECM_2 with GLS is correctly signed and significant at a 1% level. The value of −0.61 indicates that the speed of adjustment is approximately 61%. The results demonstrate a positive effect exerted by better CC, higher EMPL the year t and EWC the year before. As CC increases by 1%, the collection rates in Europe raises by 1.14% on average, ceteris paribus. Countries with better CC, are more likely to collect e-waste by developing e-waste facilities to mitigate the environmental footprint. A 1% increase in EMPL tends to increase EWC by 1.11% on average, ceteris paribus. Incorporating in the field of empirical analysis the first difference of the dependent variable *(EWC)* as an independent variable with one-time lag, the results suggest that a 1% increase in the e-waste collection the previous year tends to increase collection rates the year after by 0.28% on average, ceteris paribus. As EU gas markets are dominated by monopolies or oligopolies and the market share of companies supplying the largest volume of

Table 3
Tests for cross-sectional dependence and slope homogeneity.

		Value
Cross-sectional dependence	Pesaran CD-test	7.66***
Slope homogeneity	Pesaran and Yamagata (2008)	Delta-adjusted (Δadj) 2.06**

***1% level of significance. **5% level of significance.

Table 4
Panel Unit root tests.

Variable	E-waste collected	Corruption Control	Income Distribution Inequality	Employment Rate	Gas Market Dominance
Null: Unit root (assumes common unit root process)					
Levin, Lin & Chu t*	−3.93***	−2.39***	−3.69***	−4.80***	−4.53***
Null: Unit root (assumes individual unit root process)					
Im, Pesaran and Shin W-stat	−2.89***	−0.74	−0.08	−1.85**	−0.28
ADF - Fisher Chi-square	118.57***	61.85	63.64	59.45*	45.72*
PP - Fisher Chi-square	179.26***	65.60	63.28	28.95	48.61**

*10% level of significance. **5% level of significance. ***1% level of significance.

Table 5
Panel co-integration tests for heterogeneous panel.

Pedroni Cointegration Test				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	−1.54	0.94	−1.61	0.95
Panel rho-Statistic	3.20	1.00	3.11	1.00
Panel PP-Statistic	−2.22	0.01	−3.03	0.00
Panel ADF-Statistic	−1.72	0.04	−2.33	0.01
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	4.85	1.00		
Group PP-Statistic	−6.11	0.00		
Group ADF-Statistic	−3.81	0.00		
Kao Residual Cointegration Test				
RESID(-1)	−0.63	0.00		
D(RESID(-1))	0.26	0.02		

natural gas increases by 1%, e-waste collection rates tend to decrease by 0.10% on average, ceteris paribus.

5. Discussion

In modern societies, e-waste collection plays an immensely important role in addressing rapid economic growth while lowering the ecological burden (Cole et al., 2019). E-waste, is rapidly becoming one of the swiftest growing waste streams, characterized by its complex material composition (Vadoudi et al., 2015). While it comprises valuable elements such as nickel, gold, copper and rare earth elements (Wang and Xu, 2014; Tansel, 2017), it also contains hazardous substances that can lead to environmental and health hazards if not handled appropriately (Rucevska et al., 2015). Nevertheless, a substantial amount of e-waste is improperly collected and processed, resulting in overall collection levels far below the amount of electrical and electronic equipment leaving the market (Vidal-Legaz et al., 2016). EU currently lacks an official e-waste collection system to manage the fastest growing streams of electronic products at the end of their life in a resource-efficient manner (Patil and Ramakrishna, 2020). Establishing e-waste collection systems that are accessible to everyone promotes responsible disposal and prevents e-waste from ending up in landfills or being illegally exported (Efthymiou et al., 2016).

However, developing an official e-waste collection system is not without its challenges (Tanskanen, 2013). Income inequalities (Tsydenova and Heyken, 2019; Boubellouta and Kusch-Brandt, 2020), poor corruption control (Bisschop, 2012; Almer and Goeschl, 2015; Efthymiou et al., 2016; Lydall et al., 2017), low employment rates (Chen, 2010; Namlis and Komilis, 2019), and imperfect competition in gas markets (Eikeland, 1998; Borowski, 2020; Kartal, 2022; Dar et al., 2022; Ghazanfari, 2023) can all undermine the EU's efforts. EWC involves energy-intensive processes to extract valuable materials and rare earth

Table 6
Regression results. Dependent variable: E-waste collection.

Variable	Fixed Effects	Fixed Effects_VIF	Random Effects	Random Effects_VIF	FMOLS	FMOLS_VIF	Robust Least Squares	Robust Least Squares_VIF
Corruption Control	1.27***	1.12	1.12***	1.14	1.35**	1.15	1.38***	1.31
Income Distribution Inequality	−0.45*	1.42	−0.45**	1.29	−0.37	1.65	−0.45***	1.18
Employment Rate	2.60***	1.49	1.99***	1.39	2.87***	1.65	0.04	1.46
Gas Market Dominance	−0.28***	1.25	−0.34***	1.12	−0.26**	1.23	−0.28***	1.05
R^2	0.89		0.55		0.85		0.49	
F-statistic	44.48***		37.53***					
Breusch-Pagan Test	121.77***							
Hausman Test	16.03***							

*10% level of significance. **5% level of significance. ***1% level of significance.

Table 7
Error correction model with generalized least squares.

Variable	Parsimonious ECM_1	ECM_01_VIF	Parsimonious ECM_02	ECM_02_VIF
D(LOG (Corruption Control)	1.21[b]	1.12	1.14[b]	1.08
D(LOG (Employment Rate)	1.42[b]	1.67	1.11[b]	1.10
D(LOG (Gas Market Dominance)	−0.13[b]	1.14	−0.10[a]	1.04
D(LOG (Income Distribution Inequality)	−0.28[a]	1.08	−0.05[a]	1.14
D(LOG(Employment Rate)(-1))	1.00[a]	1.87		
D(LOG(E-waste collected) (−1))			0.28[b]	1.18
ECT(-1)	−0.54[b]	1.07	−0.61[b]	1.11
R^2	0.45		0.48	

*10% level of significance.
[a] 5% level of significance.
[b] 1% level of significance.

elements (Oguchi et al., 2011; Arduin et al., 2019) from electronic devices. These processes often require a significant amount of energy, which is typically derived from natural gas. The demand for energy in e-waste collection facilities results in the consumption of natural gas. In gas markets with anti-competitive behavior, there are signs of lower EWC. Less transparency and accountability in gas markets results in inefficiencies in e-waste management, which can undermine the EU's efforts to promote sustainable waste management practices and reduce environmental harm. Imperfect competition in gas markets hinder progress towards the development of appropriate e-waste collection facilities because higher MSNG means higher prices for e-waste disposal and collection. This can reduce the incentive for EWC, particularly for SMEs that may struggle to compete with larger firms. Gas market's structure creates less transparency and trust in the effectiveness and strength of a country's policy to maintain stability, which is accompanied by several inefficiencies in the development of e-waste collection points. The negative relationship between gas market's oligopolistic system and EWC is in line with previous studies conducted by Kartal (2022) finding a positive correlation between the anti-competitive structure of energy markets and the ecological footprint, Lagendijk (2008) stressing the importance of an open internal electricity market for addressing environmental issues, Eikeland (1998) noting that liberalized markets shape an environmentally concerned behavior with enhanced responsibility, Borowski (2020) and European Commission (2006). As the MSNG rises, the EWC is lower, and the footprint on the planet increases.

Improper disposal of e-waste is associated with environmental degradation (Singh et al., 2020; Parajuly et al., 2020; Xu et al., 2020) through the release of harmful greenhouse gases (Ibanescu et al., 2018; Clarke et al., 2019). The results suggest that in both the short- and long-run the EWC increases with an increase in CC. This is a reasonable finding because when CC increases, there is a lower level of corruption in the country, which means a more efficient resources' allocation and higher economic efficiency. Poor corruption control increases compliance costs, provides an unfair advantage to some players (Mauro, 1995), and results in the inefficient allocation of resources (Škrinjarić, 2020). Corruption directs inefficient e-waste collection processes and a lack of transparency in public procurement, which increases the number of suppliers who do not comply with e-waste collection requirements. This causes an asymmetrical competition where ambiguous e-waste collection regulations can result in illegal dumping (Bisschop, 2012), further increasing the ecological footprint. In a corrupt environment, individuals and businesses are less likely to dispose of e-waste properly, as there is higher "capture" of the country by private interests or elites. This means a decrease in EWC in the short- and long-term, as countries fail to offer access to all society members for proper e-waste collection facilities which they are not concentrated only in wealthier areas and require a fee that is unaffordable for lower-income individuals. People in those countries may resort to improper disposal methods such as dumping e-waste in landfills or incinerating it, rather than seeking out appropriate collection options. With lower CC, there is lower levels of trust and transparency in the effectiveness and strength of a country's policy to maintain and enhance stability.

INEQUALITY contributes to a less supportive environment for e-waste collection in both the short- and long-run as households or individuals with lower incomes have limited access to e-waste collection points due to their location or financial constraints are less likely to properly dispose of their e-waste. At the same time, they are not aware of the necessity of e-waste collection or the potential negative consequences of improper disposal resulting in a lack of motivation which exacerbates the e-waste pollution. INEQUALITY also limits participation in e-waste collection programs and there is a lower likelihood of future generations with lower incomes to inherit the benefits of the long-term well-being of the environment and society. It undermines social cohesion and the sense of community as the well-being of all members of society is not prioritized. This creates a less inclusive and equitable CE (Thapa et al., 2023), as EWC is part of the broader CE concept (Ilankoon et al., 2018) and the establishment of efficient and widespread e-waste collection points or drop-off locations where individuals and businesses can easily dispose of their electronic devices is of paramount importance (Darby and Obara, 2005; Favot and Grassetti, 2017). The negative relationship between indicators of socioeconomic disparities and e-waste is supported by Bisschop (2013) finding that in Antwerp, only 20% of the total e-waste consists of domestic e-waste, while the remaining 80% represents inflows from abroad, Efthymiou et al. (2016) pointing out that the illegal trade of e-waste is directed from economically and socially developed countries to economically and socially developing countries, Almer and Goeschl (2015) noting that waste violations decrease as enforcement controls increase and corresponding penalties are imposed and Su and Chen (2018) examining the existence of an EKC for the generation and illegal disposal of medical waste for the period 2001–2015 in Taiwan.

In all econometric specifications EMPL exerts a positive and significant effect on EWC having the potential to mitigate socioeconomic disparities and safeguard vulnerable groups, thereby promoting a greater inclination to dispose of e-waste in a sustainable manner. Higher EMPL cultivates a culture of equality for both others and the environment, which can foster the social and environmental well-being. Promoting equal working opportunities and access to skilled labor is of immense importance to realize the need for collective responsibility for EWC while more jobs mean higher levels of innovation and technological advancements and the buildup of a more resilient economy to address environmental challenges. Technological advancements are often accompanied by more efficient EWC as e-waste is a valuable resource which is non-finite. Higher EMPL increases confidence in the business environment, making it more likely for individuals to increase EWC. Prior research have investigated the correlation between EMPL and waste management including Chen's (2010) empirical study finding that the higher the unemployment rate, the lower the waste per capita for the municipalities of Taipei, Taichung and Kaohsiung and the counties of Yilan, Hualien and Taitung the years 1998–2008, Namlis and Komilis (2019) reaching the same conclusion for the period 2008–2015 for 10 European countries, Gardiner and Hajek (2020) pointing out that an increase in EMPL raises the generation of municipal waste. The results of these studies consistently suggest that improper waste management and unsustainable practices in employment come at the expense of environmental protection. EWC may be challenging for employees and employers and require significant investments in reskilling and retraining programs.

E-waste collection is a complex process that requires the integration of socio-economic factors. When socio-economic disparities (low EMPL and high INEQUALITY) are present, individuals have financial constraints and reduced purchasing power so they are less likely to allocate funds for proper e-waste disposal, resulting in lower collection rates. At the same time, they are also more inclined to sell their electronic equipment informally or through unauthorized channels to have an immediate income, rather than paying for formal e-waste collection services. Higher socio-economic disparities translate into lower accessibility of formal e-waste collection points. In a country with limited access to public transportation, residents are less likely to travel to authorized e-waste collection points located in distant areas. This makes it even more challenging for unemployed to access appropriate channels for disposing of their e-waste. Socio-economic disparities are also associated with a lack of resources for awareness campaigns and educational programs focused on e-waste collection. When funding for public education initiatives is limited, there may be reduced efforts to inform the public about the necessity of proper e-waste disposal, the potential environmental risks of improper disposal, and the available formal collection points. To the best of our knowledge, there has been no study conducted at the macro-level to examine the determinants of EWC in the light of socioeconomic disparities with particular attention to the interplay between e-waste collected, control of corruption, income inequality, employment, and imperfect competition in gas markets. This represents a significant limitation in the field, as it only focuses on the progress of waste without acknowledging socio-economic implications. To form a European vision centered on appropriate e-waste collection practices, more than simply reducing e-waste generation is essential, as this constantly interacts with the necessity of tackling socio-economic disparities and establishing equitable possibilities for all. The necessary time frame for policy effects to become evident is also identified for the first time noting a speed of adjustment of around 54% and 61% as indicated by the results of the parsimonious ECM_1 and the ECM_2, respectively. For example, a 54% speed of adjustment for CC implies that 54% of the 1.21% increase in EWC is achieved due to changes in corruption control measures. Similarly, a 61% speed of adjustment for INEQUALITY suggests that 61% of the 0.05% decrease in EWC occurs because of alterations in income distribution patterns.

6. Conclusions

The present study investigates the determinants of EWC in the light of socioeconomic disparities in EU countries with particular attention to the nexus between e-waste collection, control of corruption, income inequality, employment, and imperfect competition in gas markets. While acknowledging the significance of the factors that shape inequalities, their impact on the efficiency of managing e-waste has not been thoroughly explored in academic research. The study aims to fill the existing gap in the literature by offering, for the first time, an understanding of how countries' endeavors to tackle corruption, socioeconomic disparities, gas market dominance and fluctuating conditions in the labor market influence EWC and the time required for policy measures to yield visible results. Within the scope of the study, the temporary divergences from the steady state are examined using estimation methods including Fixed Effects, FMOLS, M-estimation with Robust Least Squares and Error Correction Model with Generalized Least Squares. The findings highlight the importance of promoting transparency, equity, employment opportunities and perfect competition to support CE. EWC tends to increase with improvements in CC and EMPL. Promoting transparency is crucial for building public trust in businesses, which is essential for higher EWC. EWC requires collaboration among businesses, policymakers, and other stakeholders, who can work together to develop sound policies. The development of competitive conditions for EWC requires a protection system that can increase social welfare and establish effective policies. Significant structural and radical changes in current perceptions, and attitudes are required. EWC tends to increase in countries with robust corruption control system, where citizens have higher levels of trust in democratic institutions.

The positive correlation between CC and EWC makes sense because effective CC means better governance, which in turn can improve the implementation and enforcement of e-waste management policies. It includes the establishment of regulations for EWC, transportation, and disposal, as well as the creation of incentives for individuals and businesses to properly dispose of their e-waste. Corruption is associated with e-waste mismanagement in both the short-and long-run. When CC is absent, lack of transparency and accountability is arisen, which result in a lower EWC. For instance, in countries like Finland (score 87/100 according to Corruption Perception Index, 2nd in global corruption ranking) and Norway (score 84/100 according to Corruption Perception Index, 4th in global corruption ranking), where corruption levels are notably low (Transparency international, 2022), there has been the implementation of transparent and efficient e-waste management systems. This has led to increased participation from both the public and private sectors in e-waste collection programs, resulting in higher recycling rates and a reduction in improper disposal practices. Furthermore, in countries such as Austria (score 71/100 according to Corruption Perception Index, 22nd in global corruption ranking) and Switzerland (score 82/100 according to Corruption Perception Index, 7th in global corruption ranking), strong anti-corruption measures have facilitated the development of well-regulated e-waste collection networks which has encouraged the establishment of specialized collection centers and the implementation of stringent monitoring mechanisms, ensuring the proper handling and disposal of e-waste. The positive correlation underscores the need to prioritize CC as a mean of improving EWC. Enhancing collaboration between law enforcement agencies and environmental regulatory bodies can streamline enforcement efforts against corruption, leading to the prosecution of illicit activities and the imposition of stringent penalties. This serves as a deterrent to corruption and promotes a fair and ethical business environment conducive to sustainable e-waste collection practices. Investing in public awareness campaigns and educational initiatives is a step in the right direction to raise awareness about the detrimental impacts of corruption on the environment and public health.

The short- and long-run negative correlation between INEQUALITY and EWC is a rational finding since lower-income households are less likely to dispose of their e-waste properly, either because they lack the resources or knowledge to do so. In countries with higher INEQUALITY, such as Greece and Italy, marginalized communities often face financial constraints that hinder their ability to participate in e-waste collection programs. This results in reduced access to proper disposal facilities and a higher likelihood of improper e-waste disposal, leading to environmental contamination and health hazards within these communities. Where INEQUALITY persists, the lack of equitable access to e-waste collection services among lower-income households contributes to increased informal e-waste disposal practices (Streicher-Porte and Geering, 2010). Implementing targeted subsidy programs can enable lower-income households to afford proper e-waste disposal services, thereby fostering more inclusive participation in collection initiatives. Establishing community outreach programs and educational campaigns to help raise awareness among marginalized communities about the importance of responsible e-waste management is of paramount importance. These efforts promote community engagement and empower individuals to actively participate in e-waste collection activities. In the short-run, addressing these challenges require targeted interventions aimed at improving EWC in lower income areas, such as the establishment of community collection points. In the long-run, however, measures aimed at reducing poverty and increasing access to resources, such as education and healthcare, will increase the likelihood of proper e-waste disposal.

EMPL is positively associated with EWC underscoring the importance of employment reforms by creating new jobs and industries that support circular practices and business models. When EMPL is high, there is increased participation in e-waste collection initiatives among the workforces. This results in a greater availability of manpower for efficient e-waste management practices, leading to improved collection efficiency and enhanced recycling rates. High EMPL contributes to a more robust economy, enabling greater investments in advanced e-waste collection technologies and infrastructure. This leads to the establishment of comprehensive collection networks and the implementation of innovative recycling methods, promoting sustainable waste management practices and environmental conservation. There is also a heightened sense of social responsibility among employed individuals, fostering active engagement in community-led e-waste collection campaigns. To protect labor conditions while managing e-waste, employment reforms that promote the development of new green jobs or support circular innovation and entrepreneurship are vital. It emphasizes the need of greater economic stability and prosperity to increase collection rates. Employed individuals tend to have better knowledge necessary to properly dispose of their e-waste and more opportunities to participate in e-waste management programs, either because of a company's regulatory requirements or corporate social responsibility initiatives. Such reforms improve working conditions, stimulate economic growth, and foster a more supportive environment for CE.

An interesting finding is the short-and long-run negative correlation between MSNG and EWC which underscores the need of a holistic and multi-faceted approach. As the market share in the natural gas industry and imperfect competition increases, a lack of investment in e-waste management infrastructure arises. Implementing comprehensive regulatory frameworks promotes market competition and encourages the entry of new players in the gas industry, resulting in a more diverse and competitive market. This, in turn, drives down gas prices and reduces production costs for e-waste recycling facilities. To tackle this concern, it is necessary to implement regulations that encourage competition and diminish market dominance, such as enforcing anti-trust laws and rules that inhibit mergers and acquisitions resulting in market concentration. Additionally, effective measures should be devised to facilitate the entry of new participants into the market, including providing subsidies to small and medium-sized gas producers. Fostering international collaboration and trade partnerships can help mitigate the influence of gas market monopolies or oligopolies. By promoting cross-border energy exchange and diversifying gas supply sources, EU countries can reduce their dependence on dominant market players, thereby ensuring a more stable and competitive gas market environment conducive to sustainable e-waste collection practices. At the same time, investing in renewable energy research and development initiatives the transition towards alternative energy sources will be facilitated, reducing reliance on traditional gas market players. The abuse of market power and the promotion of fair competition can be achieved by setting requirements for gas companies to report on their pricing and supply practices. To ensure that consumers have access to affordable gas, a government-owned gas company that can compete with private companies and increase competition in the gas market is important. At the same time, investments are needed in renewable energy infrastructure and e-waste collection facilities.

It is worth stressing that prudence is required when interpreting the empirical results of the present analysis, as only a single CE indicator, the EWC, is examined along with data availability. However, the results of the present analysis can contribute to the discussion of developing an official EU e-waste collection system to ensure the effective management of electronic products at the end of their life. This requires shaping an equitable and inclusive EU environment where the benefits must be shared by all members of society, which can be achieved through better corruption control, equity, more employment opportunities, and correction of imperfect competition in gas markets. Considering the findings of the current study, future research could investigate societal and cultural perspectives on e-waste generation, collection, and disposal practices in EU countries through qualitative methodologies, including content analysis. Furthermore, crafting and conducting surveys aimed at engaging stakeholders, policymakers, and industry experts could offer valuable insights into how they perceive, act, and approach e-waste management. Comparative studies involving non-EU countries are indispensable for drawing comprehensive conclusions about global e-waste management dynamics. Evaluating the effectiveness of existing and proposed policies aimed at reducing e-waste levels, while considering the interplay among control of corruption, income inequality, gas market structures, and employment rates, is crucial. Finally, employing spatial analysis techniques to visualize, map, and analyze the geographical distribution and patterns of e-waste generation, collection, and disposal sites in the EU countries would enhance the spatial understanding of the environmental and socio-economic impacts associated with e-waste management practices.

Declaration

The views expressed are those of the authors and not those of their respective institutions.

Consent for publication and competing interest

The study represents original material that has not been published elsewhere. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of competing interest

None.

Data availability

Data will be made available on request.

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References

Agarwal, A., Singhmar, A., Kulshrestha, M., Mittal, A.K., 2005. Municipal solid waste recycling and associated markets in Delhi, India. RCR 44 (1), 73–90. https://doi.org/10.1016/j.resconrec.2004.09.007.

Almer, C., Goeschl, T., 2015. The Sopranos redux: the empirical economics of waste crime. Reg. Stud. 49 (11), 1908–1921. https://doi.org/10.1080/00343404.2013.854323.

Arduin, R.H., Grimaud, G., Leal, J.M., Pompidou, S., Charbuillet, C., Laratte, B., Alix, T., Perry, N., 2019. Influence of scope definition in recycling rate calculation for European e-waste extended producer responsibility. Waste Manag. 84, 256–268. https://doi.org/10.1016/j.wasman.2018.12.002.

Awasthi, A.K., Cucchiella, F., D'Adamo, I., Li, J., Rosa, P., Terzi, S., et al., 2018. Modelling the correlations of e-waste quantity with economic increase. Sci. Total Environ. 613, 46–53. https://doi.org/10.1016/j.scitotenv.2017.08.288.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P., 2017. The Global E-Waste Monitor 2017. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

Bisschop, L., 2012. Is it all going to waste? Illegal transports of e-waste in a European trade hub. Crime Law Soc. Change 58, 221–249. https://doi.org/10.1007/s10611-012-9383-0.

Bisschop, L., 2013. Go with the e-waste flows: the governance reality of illegal transports of e-waste in a European trade hub. In: Human Dimensions in Organised Crime, Money Laundering and Corruption. Wolf Legal Publishers, pp. 393–424.

Borowski, P.F., 2020. Zonal and nodal models of energy market in European union. Energies 13 (16), 4182. https://doi.org/10.3390/en13164182.

Boubellouta, B., Kusch-Brandt, S., 2020. Testing the environmental Kuznets Curve hypothesis for E-waste in the EU28+ 2 countries. J. Clean. Prod. 277, 123371 https://doi.org/10.1016/j.jclepro.2020.123371.

Boubellouta, B., Kusch-Brandt, S., 2021. Cross-country evidence on environmental Kuznets curve in waste electrical and electronic equipment for 174 countries. Sustain. Times 25, 136–151. https://doi.org/10.1016/j.spc.2020.08.006.

Briassoulis, H., 1999. Sustainable development and the informal sector: an uneasy relationship? J. Environ. Dev. 8 (3), 213–237. https://doi.org/10.1177/107049659900800302.

Brigden, K., Labunska, I., Santillo, D., Johnston, P., 2008. Chemical contamination at e-waste recycling and disposal sites in Accra and Korforidua, Ghana. In: Greenpeace Research Laboratories Technical Note. Greenpeace International, Amsterdam, The Netherlands. http://www.greenpeace.org/international/press/reports/chemical-contamination-at-e-wa.

Castells, M., Portes, A., 1989. World underneath: the origins, dynamics and effects of the informal economy. In: Portes, A., Castells, M., Benton, L.A. (Eds.), The Informal Economy: Studies in Advanced and Less Developed Countries. JHU Press, Baltimore, MD, pp. 11–40.

Chatterjee, S., 2012. Sustainable e-waste management and recycling process. Am.J. Environ. Engineer 2 (1), 23–33.

Chen, C.C., 2010. Spatial inequality in municipal solid waste disposal across regions in developing countries. IJEST 7, 447–456. https://doi.org/10.1007/BF03326154.

Chi, X., Streicher-Porte, M., Wang, M.Y., Reuter, M.A., 2011. Informal e-waste recycling: a sector review with special focus on China. Waste Manage. 31 (4), 731–742. https://doi.org/10.1016/j.wasman.2010.11.006.

Clarke, C., Williams, I.D., Turner, D.A., 2019. Evaluating the carbon footprint of WEEE management in the UK. Resour. Conserv. Recycl. 141, 465–473. https://doi.org/10.1016/j.resconrec.2018.10.003.

Cole, C., Gnanapragasam, A., Cooper, T., Singh, J., 2019. An assessment of achievements of the WEEE Directive in promoting movement up the waste hierarchy:

experiences in the UK. Waste Manag. 87, 417–427. https://doi.org/10.1016/j.wasman.2019.01.046.

Dar, A.A., Hameed, J., Huo, C., Sarfraz, M., Albasher, G., Wang, C., Nawaz, A., 2022. Recent optimization and panelizing measures for green energy projects; insights into CO2 emission influencing to circular economy. Fuel 314, 123094. https://doi.org/10.1016/j.fuel.2021.123094.

Darby, L., Obara, L., 2005. Household recycling behaviour and attitudes towards the disposal of small electrical and electronic equipment. RCR 44 (1), 17–35. https://doi.org/10.1016/j.resconrec.2004.09.002.

Diao, X.D., Zeng, S.X., Tam, C.M., Tam, V.W., 2009. EKC analysis for studying economic growth and environmental quality: a case study in China. J. Clean. Prod. 17 (5), 541–548. https://doi.org/10.1016/j.jclepro.2008.09.007.

Duan, H., Miller, T.R., Gregory, J., Kirchain, R., Linnell, J., 2013. In: Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics. Analysis of Generation, Collection, and Export in the United States, vol. 121. https://step-initiative.org/files/_documents/other_publications/MIT-NCER%20US%20Used%20Electronics%20Flows%20Report%20-%20December%202013.pdf.

Efthymiou, L., Mavragani, A., Tsagarakis, K.P., 2016. Quantifying the effect of macroeconomic and social factors on illegal e-waste trade. IJERPH 13 (8), 789. https://doi.org/10.3390/ijerph13080789.

Eikeland, P.O., 1998. Electricity market liberalisation and environmental performance: Norway and the UK. Energy Pol. 26 (12), 917–927. https://doi.org/10.1016/S0301-4215(98)00035-4.

European Commission, 2006. Green paper: a European strategy for sustainable, competitive and secure energy. Available at: https://www.econstor.eu/bitstream/10419/166261/1/cesifo-forum-v07-y2006-i2-p08-20.pdf.

Engle, R.F., Granger, C.W., 1987. Co-integration and error correction: representation, estimation, and testing. Econometrica. https://doi.org/10.2307/1913236.

European Commission, 1975. Council Directive of 15 December 1975 on Waste (75/442/EEC), 1975. Off. J. Eur. Union, pp. 39–41.

European Commission, 2003. Directive 2002/96/EC of the European parliament and of the council on waste electrical and electronic equipment (WEEE). Off. J. Eur. Union L 37, 24–38. https://doi.org/10.3000/19770677.L_2012.197.eng.

European Commission, 2012. Directive 2012/19/EU of the european parliament and of the council on waste electrical and electronic equipment (WEEE). Off. J. Eur. Union 13, 1–24. https://doi.org/10.3000/19770677.L_2012.197.eng.

Favot, M., Grassetti, L., 2017. E-waste collection in Italy: results from an exploratory analysis. Waste Manage. (Tucson, Ariz.) 67, 222–231. https://doi.org/10.1016/j.wasman.2017.05.026.

Gaidajis, G., Angelakoglou, K., Aktsoglou, D., 2010. E-waste: environmental problems and current management. JESTEC 3 (1), 193–199.

Gardiner, R., Hajek, P., 2020. Municipal waste generation, R&D intensity, and economic growth nexus–A case of EU regions. Waste Manag. 114, 124–135.

Gerxhani, K., 2004. The informal sector in developed and less developed countries: a literature survey. Publ. Choice 120 (3–4), 267–300. https://doi.org/10.1023/B:PUCH.0000044287.88147.5e.

Ghazanfari, A., 2023. An analysis of circular economy literature at the macro level, with a particular focus on energy markets. Energies 16, 1779.

Guha-Khasnobis, B., Kanbur, R., Ostrom, E., 2006. Linking the Formal and Informal Economy: Concepts and Policies. OUP, New York, pp. 1–4.

Hart, K., 1970. Small scale entrepreneurs in Ghana and development planning. J. Dev. Stud. 6 (4), 104–120. https://doi.org/10.1080/00220387008421338.

Hayami, Y., Dikshit, A.K., Mishra, S.N., 2006. Waste pickers and collectors in Delhi: poverty and environment in an urban informal sector. J. Dev. Stud. 42 (1), 41–69. https://doi.org/10.1080/00220380500356662.

Hendry, D.F., 1980. Econometrics: alchemy or science? Econometrica 47, 387–406. https://doi.org/10.2307/2553385.

Hoornweg, D., Bhada-Tata, P., 2012. What a Waste: a Global Review of Solid Waste Management.

Huber, P.J., 1973. Robust regression: asymptotics, conjectures and monte carlo. Annal. Statist. 1 (5), 799–821. http://www.jstor.org/stable/2958283.

Ibanescu, D., Cailean, D., Teodosiu, C., Fiore, S., 2018. Assessment of the waste electrical and electronic equipment management systems profile and sustainability in developed and developing European Union countries. Waste Manage. (Tucson, Ariz.) 73, 39–53. https://doi.org/10.1016/j.wasman.2017.12.022.

Ilankoon, I.M.S.K., Ghorbani, Y., Chong, M.N., Herath, G., Moyo, T., Petersen, J., 2018. E-waste in the international context - a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manage 82, 258–275. https://doi.org/10.1016/j.wasman.2018.10.018.

Islam, R., Nazif, T.H., Yuniarto, A., Uddin, A.S.M.S., Salmiati, S., Shahid, S., 2019. An empirical study of construction and demolition waste generation and implication of recycling. Waste Manage 95, 10–21. https://doi.org/10.1016/j.wasman.2019.05.049.

Kartal, M.T., 2022. The role of consumption of energy, fossil sources, nuclear energy, and renewable energy on environmental degradation in top-five carbon producing countries. Renew. Energy 184, 871–880. https://doi.org/10.1016/j.renene.2021.12.022.

Kaseva, M.E., Gupta, S.K., 1996. Recycling – an environmentally friendly and income generating activity towards sustainable solid waste management. Case study –Dar es Salaam City, Tanzania. RCR 17 (4), 299–309. https://doi.org/10.1016/S0921-3449(96)01153-6.

Kusch, S., Hills, C.D., 2017. The link between e-waste and GDP – new insights from data from the Pan-European region. Resources 6, 15. https://doi.org/10.3390/resources6020015.

Lagendijk, V., 2008. Electrifying Europe. The Power of Europe in the Construction of Electricity.

Lepawsky, J., McNabb, C., 2010. Mapping international flows of e-waste. The Canadian Geographer/Le Géographe canadien 54 (2), 177–195. https://doi.org/10.1111/j.1541-0064.2009.00279.x.

Liu, X.B., Tanaka, M., Matsui, Y., 2006. Generation amount prediction and material flow analysis of electronic waste: a case study in Beijing, China. Waste Manag. Res. 24 (5), 434–445. https://doi.org/10.1177/0734242X06067449.

Lydall, M., Nyanjowa, W., James, Y., 2017. Mapping South Africa's waste electrical and electronic equipment (WEEE) dismantling, pre-processing and processing technology landscape. In: Waste Research Development and Innovation Roadmap Research Report. Mintek external report prepared for the Department of Science and Technology and the Council for Scientific and Industrial Research.

Mauro, P., 1995. Corruption and growth. Q. J. Econ. 110 (3), 681e712. https://doi.org/10.2307/2946696.

Migliano, J.E.B., Demajorovic, J., Xavier, L.H., 2014. Shared responsibility and reverse logistics systems for e-waste in Brazil. JOSCM 7 (2), 91–109. https://ageconsearch.umn.edu/record/289419/files/41520.pdf.

Mitchell, C.L., 2008. Altered landscapes, altered livelihoods: the shifting experience of informal waste collecting during Hanoi's urban transition. Geoforum 39 (6), 2019–2029. https://doi.org/10.1016/j.geoforum.2008.07.006.

Nachane, D.M., 2006. Econometrics: Theoretical Foundations and Empirical Perspectives, first ed.

Namlis, K.G., Komilis, D., 2019. Influence of four socioeconomic indices and the impact of economic crisis on solid waste generation in Europe. Waste Manage 89, 190–200. https://doi.org/10.1016/j.wasman.2019.04.012.

Oguchi, M., Murakami, S., Sakanakura, H., Kida, A., Kameya, T., 2011. A preliminary categorization of end-of-life electrical and electronic equipment as secondary metal resources. Waste Manag. 31, 2150–2160. https://doi.org/10.1016/j.wasman.2011.05.009.

Osibanjo, O., Nnorom, I.C., 2007. The challenge of e-waste (e-waste) management in developing countries. Waste Manag. Res. 25 (6), 489–501. https://doi.org/10.1177/0734242X07082028.

Parajuly, K., Fitzpatrick, C., Muldoon, O., Kuehr, R., 2020. Behavioral change for the circular economy: a review with focus on electronic waste management in the EU. Resour. Conserv. Recycl. X 6, 100035. https://doi.org/10.1016/j.rcrx.2020.100035.

Parks, R.W., 1967. Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated. J. Am. Statist. Assoc. 62 (318), 500–509. https://doi.org/10.1080/01621459.1967.10482923.

Patil, R.A., Ramakrishna, S., 2020. A comprehensive analysis of e-waste legislation worldwide. Environ. Sci. Pollut. Res. 27, 14412–14431. https://doi.org/10.1007/s11356-020-07992-1.

Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econom. 142 (1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010.

Phillips, P.C.B., Hansen, B.E., 1990. The review of economic studies, ltd. Statistical inference in instrumental variables regression with I (1) processes statistical inference i n instrumental variables regression with (1) processes. Source: Rev. Econ. Stud. https://doi.org/10.2307/2297545.

Piebalgs, A., 2006. Green paper: a European strategy for sustainable, competitive and secure energy. Available at: https://www.econstor.eu/bitstream/10419/166261/1/cesifo-forum-v07-y2006-i2-p08-20.pdf.

Pomázi, I., Szabó, E., 2020. Circular economy policy-related national initiatives in Visegrad countries. Eur. Spat. Res. Policy 27, 131–154. https://doi.org/10.18778/1231-1952.27.2.09.

Porter, C.R., 2002. The Economics of Waste. RFF, Washington, DC.

Rajesh Ejiogu, A., 2013. E-waste economics: a Nigerian perspective. Manag. Environ. Qual. Int. J. 24 (2), 199–213. https://doi.org/10.1108/14777831311303083.

Robaina, M., Villar, J., Pereira, E.T., 2020. The determinants for a circular economy in Europe. Environ. Sci. Pollut. Res. 27, 12566–12578. https://doi.org/10.1007/s11356-020-07847-9.

Rodrigues, L.M., Angelo, A.C.M., Marujo, L.G., 2020. Conceptual framework to social life cycle assessment of e-waste management: a case study in the city of Rio de Janeiro. In: Singh, P., Singh, R.P., Srivastava, V. (Eds.), Contemporary Environmental Issues and Challenges in Era of Climate Change. Springer Singapore, Singapore, pp. 219–234. https://doi.org/10.1007/978-981-32-9595-7_12.

Rožnik, A., 2020. Electrical and E-waste trading cases in Slovenia and the necessity for prevention, 6. In: Challenges of Comparative Crimino Logical Research, GERN Research Paper Series, pp. 185–218.

Rucevska, I., Nellemann, C., Isarin, N., Yang, W., Liu, N., Yu, K., Sandnæs, S., Olley, K., McCann, H., Devia, L., Bisschop, L., Soesilo, D., Schoolmeester, T., Henriksen, R., Nilsen, R., 2015. Waste crime – waste risks: gaps in meeting the global waste challenge. A UNEP Rap. Resp. Assessment.

Schneider, F., Enste, D.H., 2003. The Shadow Economy: an International Survey. CUP, Cambridge, UK.

Schumacher, K.A., Agbemabiese, L., 2019. Towards comprehensive e-waste legislation in the United States: design considerations based on quantitative and qualitative assessments. Resour. Conserv. Recycl. 149, 605–621. https://doi.org/10.1016/j.resconrec.2019.06.033.

Shaikh, S., Thomas, K., Zuhair, S., Magalini, F., 2020. A cost-benefit analysis of the downstream impacts of e-waste recycling in Pakistan. Waste Manage 118, 302–312. https://doi.org/10.1016/j.wasman.2020.08.039.

Singh, N., Duan, H., Tang, Y., 2020. Toxicity evaluation of e-waste plastics and potential repercussions for human health. Environ. Int. 137, 105559 https://doi.org/10.1016/j.envint.2020.105559.

Singh, S., Routroy, S., Dasgupta, M.S., 2023. Electrical and electronic equipment consumption pattern and e-waste disposal behaviour of individuals and households in India. J. Mater. Cycles Waste Manag. 1–17. https://doi.org/10.1007/s10163-023-01697-6.

Škrinjarić, T., 2020. Empirical assessment of the circular economy of selected European countries. J. Clean. Prod. 255, 120246.
Sovacool, B.K., 2019. Toxic transitions in the lifecycle externalities of a digital society: the complex afterlives of electronic waste in Ghana. Resour. Pol. 64, 101459 https://doi.org/10.1016/j.resourpol.2019.101459.
Streicher-Porte, M., Geering, A.C., 2010. Opportunities and threats of current e-waste collection system in China: a case study from Taizhou with a focus on refrigerators, washing machines, and televisions. Environ. Eng. Sci. 1 (27), 29–36. https://doi.org/10.1089/ees.2009.0134.
Streicher-Porte, M., Kummer, K., Chi, X.W., Denzler, S., Wang, X.J., 2010. Chinese e-waste legislation, current status and future development. ELNI Review 1, 7–17.
Streicher-Porte, M., Widmer, R., Jain, A., Bader, H.P., Scheidegger, R., Kytzia, S., 2005. Key drivers of the e-waste recycling system: assessing and modelling e-waste processing in the informal sector in Delhi. Environ. Impact Assess. Rev. 25, 472–491. https://doi.org/10.1016/j.eiar.2005.04.004.
Su, E.C.Y., Chen, Y.T., 2018. Policy or income to affect the generation of medical wastes: an application of environmental Kuznets curve by using Taiwan as an example. J. Clean. Prod. 188, 489–496. https://doi.org/10.1016/j.jclepro.2018.04.011.
Tansel, B., 2017. From electronic consumer products to e-wastes: global outlook, waste quantities, recycling challenges. Environ. Int. 98, 35–45. https://doi.org/10.1016/j.envint.2016.10.002.
Tanskanen, P., 2013. Management and recycling of e-waste. Acta Mater. 61 (3), 1001–1011. https://doi.org/10.1016/j.actamat.2012.11.005.
Terazono, A., Murakami, S., Abe, N., Inanc, B., Moriguchi, Y., Sakai, S., Kojima, M., Yoshida, A., Li, J.H., Yang, J.X., Wong, M.H., Jain, A., Kim, I.-S., Peralta, G.L., Lin, C.-C., Mungcharoen, T., Williams, E., 2006. Current status and research on E-waste issues in Asia. J. Mater. Cycles Waste Manag. 8 (1), 1–12. https://doi.org/10.1007/s10163-005-0147-0.
Thapa, K., Vermeulen, W.J., Deutz, P., Olayide, O., 2023. Ultimate producer responsibility for e-waste management–A proposal for just transition in the circular economy based on the case of used European electronic equipment exported to Nigeria. Bus. Strategy Dev. 6 (1), 33–52. https://doi.org/10.1002/bsd2.222.
Tinmaz, E., Demir, I., 2006. Research on solid waste management system: to improve existing situation in Corlu Town of Turkey. Waste Manage 26 (3), 307–314. https://doi.org/10.1016/j.wasman.2005.06.005.
Transparency international, 2022. Corruption Perceptions Index 2022. https://www.transparency.org/en/cpi/2022. accesed on 1/11/23.
Tsydenova, N., Heyken, M., 2019. Formal and informal E-waste collection in Mexico city. In: Pehlken, A., Kalverkamp, M., Wittstock, R. (Eds.), Cascade Use in Technologies 2018. Springer Vieweg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-57886-5_5.
Umair, S., Anderberg, S., Potting, J., 2016. Informal electronic waste recycling in Pakistan. J. Solid Waste Technol. Manag. 42 (3), 222–235. https://doi.org/10.5276/JSWTM.2016.222.
Vadoudi, K., Kim, J., Laratte, B., Lee, S.-J., Troussier, N., 2015. E-waste management and resources recovery in France. Waste Manag. Res. 33, 11. https://doi.org/10.1177/0734242X15597775.
Vidal-Legaz, B., Blengini, G.A., Mathieux, F., Latunussa, C., Mancini, L., Nita, V., Hamor, T., Ardente, F., Nuss, P., Torres de Matos, C., Wittmer, D., Talens Peiró, L., Garbossa, E., Pavel, C., Alves Dias, P., Blagoeva, D., Bobba, S., Huisman, J., Eynard, U., di Persio, F., Gervasio dos, H., Ciupagea, C., Pennington, D., 2016. Raw Materials Scoreboard - European Innovation Partnership on Raw Materials. Commission, European Centre, Joint Research. https://doi.org/10.2873/586373.
Wang, R., Xu, Z., 2014. Recycling of non-metallic fractions from waste electrical and electronic equipment (WEEE): a review. Waste Manage 34, 1455–1469. https://doi.org/10.1016/j.wasman.2014.03.004.
Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Böni, H., 2005. Global perspectives on e-waste. Environ. Impact Assess. Rev. 25 (5), 436–458. https://doi.org/10.1016/j.eiar.2005.04.001.
Xu, Y., Yeh, C., Yang, S., Gupta, B., 2020. Risk-based performance evaluation of improvement strategies for sustainable e-waste management. Resour. Conserv. Recycl. 155, 104664 https://doi.org/10.1016/j.resconrec.2019.104664.
Yang, W.H., 2008. Regulating electrical and electronic wastes in China. RECIEL 17 (3), 337–346. https://doi.org/10.1111/j.1467-9388.2008.00608.x.
Yang, H., Zhang, S., Ye, W., Qin, Y., Xu, M., Han, L., 2020. Emission reduction benefits and efficiency of e-waste recycling in China. Waste Manag. 102, 541–549. https://doi.org/10.1016/j.wasman.2019.11.016.
Zhang, K., Zeng, E.Y., Schnoor, J.L., 2012. E-waste recycling: where does it go from here? Environ. Sci. Technol. 46 (20), 10861–10867. https://doi.org/10.1021/es303166s.
Zisopoulos, F.K., Teigiserova, D.A., Schraven, D., de Jong, M., Tong, X., Ulanowicz, R.E., 2022. Are there limits to robustness? Exploring tools from regenerative economics for a balanced transition towards a circular EU27. CLPL 3, 100014. https://doi.org/10.1016/j.clpl.2022.100014.