Is Environmental Regulation affecting the exports of e-waste? Evidence from European Union Countries

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Resumo

Os resíduos de equipamentos elétricos e eletrónicos, mais conhecidos como lixo eletrónico, tem crescido mundialmente. Países desenvolvidos, como os países europeus, são os que mais geram lixo eletrónico, pelo que estes dependem da exportação deste lixo para outos países como meio de eliminação/gestão do mesmo. Com a transição da Europa para uma Economia Circular e devido aos problemas ambientais atuais, pode-se constatar que o número de políticas e regulação ambiental da União Europeia tem aumentado. Este estudo pretende analisar as práticas de gestão dos resíduos eletrónicos, em particular, pretende perceber o efeito da regulação ambiental na exportação de lixo eletrónico. Para este estudo, foram analisados dados anuais para um painel de 18 países da União Europeia entre 2010 e 2018, recorrendo ao estimador PCSE (Regressão Linear com erros Padrão Corrigidos para Painel). Para quantificar a regulação ambiental, utilizou-se as taxas ambientais da produção de computadores, produtos eletrónicos e óticos. Os resultados deste estudo mostram que as taxas ambientais, como proxy da regulação ambiental, contribuem para aumentar a exportação de lixo eletrónico. Foi possível constatar que, o crescimento económico reduz a exportação, o que pode evidenciar que os países que são economicamente mais desenvolvidos exportam menos lixo eletrónico que os países mais pobres. Evidenciou-se também que a reciclagem reduz o nível de exportação de lixo eletrónico. Expandir a capacidade de reciclagem dentro da Europa significaria também que a dependência que estes países detêm sobre a importação de matéria-prima poderia reduzir. Isto porque o lixo eletrónico contém matérias-primas que poderiam ser reutilizadas. Com a redução da dependência sobre a matéria-prima importada, seria também possível reduzir a exportação de lixo.

Palavras-chave

Lixo eletrónico; Economia Circular; Reciclagem; União Europeia; Regulação de Transporte de Resíduos; Ambiente

Resumo Alargado

Durante as últimas décadas, tem-se verificado um aumento significativo dos resíduos eletrónicos. Este crescimento pode ser explicado pela elevada procura e produção de equipamentos elétricos e eletrónicos (EEE). Com a rápida evolução tecnológica presente nesta área, novos equipamentos eletrónicos surgem no mercado e os equipamentos tendem a ser facilmente ultrapassados tecnologicamente por novas versões. Esta constante evolução origina um aumento na procura e na criação de resíduos. O aumento da geração de resíduos cria um desafio aos países na forma como vão lidar adequadamente com os resíduos de modo a não aumentar os problemas ambientais daí decorrentes. A consciência ambiental dos países tem aumentado e como tal os formuladores de políticas têm procurado evitar que os resíduos sejam direcionados para os aterros sanitários. A reciclagem destes resíduos deveria ser uma forma eficaz de reduzir a quantidade de resíduos que é colocada em aterros sanitários. Devido ao facto que a recolha de EEE em final de vida útil não é eficiente e acessível para os utilizadores, parte destes resíduos acabam por ser colocados no lixo comum, podendo ir para aterros e não centros de reciclagem. Pode-se ainda referir que os centros de reciclagem atuais, ainda não são capazes para lidar com os níveis de produção de lixo eletrónico atual. Devido a falta de capacidade dos países desenvolvidos em lidar com a sua produção de lixo eletrónico, estes começaram a exportar os seus resíduos para países terceiros, na maioria subdesenvolvidos.

A regulação ambiental tem sido amplamente aplicada nos países europeus de modo a incentivar práticas ambientalmente sustentáveis e a reduzir o efeito prejudicial das atividades humanas no ambiente. Esta regulação tem procurado internalizar as externalidades negativas associadas à poluição. A regulação tem também procurado combater a exportação de resíduos tóxicos para países terceiros. O aumento da regulação neste domínio passa por melhorar a gestão dos resíduos, melhorando a sua recolha e o seu tratamento adequado. Esta regulação pretende combater a exportação do problema para países terceiros, países esses que poderão não ter capacidade de tratar os resíduos adequadamente o que resulta em danos ambientais e em problemas de saúde nos países recetores.

Este estudo tem como objetivo analisar se a regulação ambiental contribui para aumentar a reciclagem e reintrodução dos resíduos de EEE nas economias, ou se, pelo contrário, contribui para a perda desse resíduo através da sua exportação. Como tal, o principal objetivo desta investigação é perceber qual o impacto da regulação ambiental

na exportação de resíduos EEE. Para isso, analisaram-se dados anuais de 18 países da União Europeia (UE), no horizonte temporal de 2010 a 2018. Optou-se por analisar países da UE, dado que estes estão comprometidos em alcançar metas ambiciosas para transitar para uma economia circular, e ao facto que todos os países membros prosseguirem objetivos de proteção ambiental similares. Assim, as variáveis utilizadas foram: a exportação de resíduo de EEE (*EXPew*), como variável dependente. Como variáveis independentes, utilizou-se as receitas de taxas ambientais da produção de computadores, produtos eletrónicos *per capita* (*ETEpc*), como proxy da regulação ambiental, o Produto Interno Bruto (PIB) per capita *(GDPpc)*, o rácio entre emissões de CO2 e PIB (*CO_2dep*), o lixo coletado (*Wcoll*), taxa de reciclagem de EEE (*REC*), crédito interno ao sector privado (*DCPS*) e a dependência de material importado (*MID*).

Após os testes preliminares das variáveis serem efetuados, realizou-se o teste *Ramsey Reset*, com o intuito de perceber se não haveria alguma variável omissa que poderia provocar resultados enviesados. Em seguida foi realizado o teste de *Hausman* para testar a presença de efeitos fixos ou efeitos aleatórios. Dado que o painel do estudo, contém um período temporal pequeno, adicionalmente, o teste *robust Hausman* foi realizado. Ambos os testes provaram que o modelo de efeitos aleatórios era adequado. Seguidamente, vários testes de especificação foram realizados que confirmaram a presença de correlação contemporânea, heterocedasticidade e autocorrelação de primeira ordem. Assim, o estimador PCSE (Regressão Linear com erros Padrão Corrigidos para Painel), foi aplicado por ser robusto à presença de todos esses fenómenos. Além disso, este estimador foi também aplicado dada a sua robustez em painéis onde T (dimensão temporal) é menor que N (dimensão espacial).

Os principais resultados mostram que o crescimento económico reduz a exportação de EEE, o que indica que dentro dos países estudados, os países com maior Produto Interno Bruto per capita, tendem a exportar menos resíduos elétricos. Adicionalmente, as taxas ambientais sobre da produção de computadores, produtos eletrónicos e óticos aumentam a exportação de resíduos EEE. Foi também possível observar que a dependência na importação de material aumenta a exportação de resíduo eletrónico. Já a reciclagem é um meio viável para a redução desta mesma exportação.

De acordo com os resultados observados neste estudo será essencial desenvolver a reciclagem, dada a importância da mesma para os planos Europeus para a Economia Circular e em reduzir significativamente a exportação de resíduos elétricos. Outras políticas e regulações são necessárias para aumentar os pontos de recolha de lixo e para facilitar o acesso da população aos mesmos. No que toca aos produtores de EEE, estes deveriam ser incentivados a melhorar a qualidade dos seus produtos, para que estes detenham um maior ciclo de vida. O design do produto deveria também ser alvo de estudos extensivos de modo a facilitar a reciclagem dos produtos no fim de vida. Por último, seria também essencial aumentar a regulação no âmbito de reduzir a dependência da União Europeia em emissões de CO_2.

Concluindo, este estudo sugere que futura regulação da UE seja implementada de modo a diminuir a exportação de lixo para países terceiros. Os sistemas de gestão dos resíduos eletrónicos, devem ser aprimorados, de modo a facilitar a reciclagem e a reutilização. Deste modo, as matérias-primas existentes nesses equipamentos poderiam ser reutilizadas, reduzindo a dependência de matérias-primas estrangeiras e o valor económico existente nesses equipamentos seria mantido na UE, facilitando a transição para uma economia circular.

Abstract

Waste generated from electrical and electronic equipment, usually known as e-waste, is increasing worldwide. Developed countries like the ones on Europe, produce the most e-waste generated worldwide and therefore, rely on exporting it to other countries as a means of waste management/disposal. As Europe is transiting towards a Circular Economy and tackle environmental related problem, there has been an increase in environmental policies and regulations within the European Union. This paper presents an overview of how the European Union's regulation has affected the exporting level. To achieve this, yearly data from 2010 to 2018, for a panel of 18 European Union countries were analysed, using the PCSE (Panel-Corrected Standard Error) estimator. In order to measure environmental regulation, Environmental taxes Revenue from the manufacture of computers, electronic, and optical products were selected. The findings of this paper suggest that taxation is not effective in reducing the export of e-waste. Furthermore, the economic growth reduces the exports, which could mean that the European richer countries export less waste than poorer countries. It was also proved that recycling is a viable option to reduce the exports of e-waste. Expanding the recycling level in Europe would also mean that the dependency that EU countries have on imported raw material would diminish because existing raw material on electronic equipment would be reused and not lost. Lowering the dependency on foreign raw materials would also mean lowering the export of e-waste.

Keywords

E-waste; Circular Economy; Recycling; European Union; Waste Shipment Regulation; Environment

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List of Acronyms

CE	Circular Economy
CD	Cross-Section Dependence
CIPS	Cross-Sectionally Augmented IPS
DCPS	Domestic Credit to Private Sector
EEE	Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
EU	European Union
FGLS	Feasible Generalized Least Squared
GDP	Gross Domestic Product
MID	Material Import Dependency
OLS	Ordinary Least Squared
PCSE	Panel-Corrected Standard Error
RoHS	Restriction of Hazardous Substances
USD	United States Dollar
VIF	Variance Inflation Factors
WDI	World Development Indicators
WEEE	Waste from Electrical and Electronic Equipment
WSR	Waste Shipment Regulation

1. Introduction

The Circular economy (CE) is an economic model that allows countries and economies to achieve sustainable growth by minimizing waste generation. As of today, there no single definition of CE. Therefore, this study adopts the definition of Kirchherr et al. (2017), p.p. 229 defining CE as "*an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes*". CE is the alternative to a linear economy, consisting of material converted into a product and later waste, with a beginning and end. Contrary to this concept, the CE tries to tackle the end of life by either recycling, reusing, or extending the first life of said object, thus reducing waste generated and resources lost.

The R framework and hierarchy, most notably the 3R (reduce, reuse, and recycle) are essentials of CE. Although the 3Rs stand at the base of the CE concept, newer Rs have been introduced throughout the evolution and further understanding of the concept. The R framework has since passed to 6Rs and, more recently, 10Rs (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) (Reike et al., 2018).

The European Union (EU) has started its transition towards a CE in the last years. In 2015, the EU released the first Circular Economy action plan, mapping 54 actions to be implemented, and proposing four waste legislations, thus creating the foundation of the EU plans towards a CE (European Commission, 2015). In December 2019, The European Green Deal was presented, aiming to transition EU´s economies to a more sustainable one. Therefore, the EU aims to take advantage of CE practices, improve the resources' efficiency, and transit towards renewable energy. The Green Deal also aimed to control climate change and the loss of biodiversity in order to achieve a carbon-neutral Europe by 2050 (European Commission, 2020).

Waste from electrical and electronic equipment (WEEE), commonly known as electronic waste or e-waste, can be defined in various ways. Some of these differences result from how it is defined from country to country (Islam et al., 2016). According to Ilankoon et al. (2018), e-waste can be described as any end-of-life piece of electric equipment. StEP (2014), defines e-waste as all types of electrical and electronic equipment (EEE) and all the parts that compose the device, that has been discarded without any intention of reusing these products. According to Perkins et al., (2014), e-waste can be divided into three main categories, namely large household appliances, IT (information technology) and consumer equipment. Products such as batteries, electric cables, electric vehicles, and cathode-ray tubes also fall under e-waste (Chen et al., 2015), although not in the aforementioned main categories.

As the EEE industry is a fast changing and rapidly evolving one, this can cause the consumers to increase their demand and desire for improved equipment, and as such, in the last decades, the demand for EEE has risen drastically. As a result, the e-waste generation has also risen rapidly and is now the fastest growing waste stream (European Parliament, 2020). Most European countries manage their waste either by recycling, landfill disposal or exporting it to other countries. Although landfill disposal has decreased substantially in the last few years, it is still tremendously hazardous to the environment and public health. Human exposure to e-waste has been shown to have greater effects on children, in particular lead poisoning. This exposure has been shown to possible even effect future generations throw breastfeeding, hindering their development, reproduction and even the neurobehavioral systems, if this exposure is made without the appropriate precautions. (Frazzoli et al., 2010).

E-waste exporting has also been a public health issue and environmental hazard to host countries. With the majority of e-waste trading being made illegally, it has become a serious talking point. To stem the tide of exports, the EU is continuously establishing new regulations and tightening the already existing waste shipment regulation. By exporting waste, EU countries could disrupt the environment and go against EU initiatives of transition towards a CE. If the CE plans are met, the increase in recycling levels will provide most of the raw materials needed for EEE production, therefore reducing the importation of said raw materials. E-waste, in general, represents a significant economic opportunity. Considering that the dependency of some raw materials, such as metal ores reach up to 100% for certain countries, if the CE plans are well explored, EU dependency on foreign raw material could be reduced, changing the industry landscape in Europe.

With the rising issues derivative from e-waste management, such as the rise of e-waste in Europe and the illegal exporting to sub-developed world countries, there has been an increased focus from the EU and policymakers on environmental topics and regulations. The regulation can contribute to enlarging the incorporation/recycling of e-waste, or instead, it can incentivise the escape and loss of e-waste. Remarkably, the loss of e-waste, for instance, through exports, represents a significant economic value loss since there are precious metals and critical raw materials in e-waste that ascended in 2019 to 12.9 billion dollars (Adrian et al., 2020). Thus, this study aims to analyse how the regulation established by the EU has affected the exports of e-waste. In sum, the main objective of this paper is to answer the following central question: is environmental regulation affecting the exports of e-waste? By analysing the data, it should be possible to respond to this question and help establish the path to be taken to help tackle the illegal e-waste problem.

In this study, the EU was selected as the case study due to the recent pledge to transit to a CE and the fact that all EU countries follow similar environmental policies and regulations. Some countries were excluded from this study as a consequence of the lack of data available in the time span. Therefore, 18 EU countries were selected for the study, and annual data from 2010 and 2018 were used.

The main contribution of this paper is to address and provide empirical evidence on the e-waste management practices, which are crucial for environmental protection and to allow the transition toward CE. In detail, it innovates by analysing empirically the relationship between regulation and e-waste exports in the context of 18 EU countries. According to our best knowledge, there are a limited number of papers that analyse empirically the effect of environmental regulation on exports of e-waste. The exception is Callao et al. (2021), who found that European countries act in accordance with the proximity and self-sufficiency principles. The findings of this paper are crucial for the policymakers in order to improve the efficiency of the e-waste management practices, particularly, in reducing the exports of e-waste.

The results of the study showed that, taxation as a mean of environmental regulation actually increases the exporting of e-waste, but recycling is proven to be an effective way of reducing exports of e-waste. Furthermore, within the EU studied countries, there are evidence that could indicate that richer countries export lower levels of e-waste. On the receiving end, policies and regulation should be pursued so that the treatment of e-waste does not jeopardize human health. Lastly, countries that rely heavily on CO_2 Emissions show higher levels of e-waste exports, thus further regulation should be pursued on the matter, incentivising the transitions towards green energy.

The remainder of this paper is organized as follows. Section 2 describes the central literature on the field. Section 3 presents the main legislation in progress in the EU. The data and methodology used are presented in section 4. The results are described in section 5 and discussed in section 6. Section 7 presents the main conclusions.

2. Literature Review

The lack of a general global definition of which is e-waste troubles the tracking of the global e-waste illegal trade network (Bakhiyi et al., 2018). Lepawsky (2015) mentioned that measuring e-waste trade is a major difficulty, as long as there is no single definition of e-waste and a lack of trade data that is able to differentiate new and old equipment. Actually, the literature argues that a major issue in the global e-waste trade is presented in the fine line separating legal and illegal trade and how this line can easily be infringed (Efthymiou et al., 2016). As Robinson (2009) highlighted, exporting countries tend to violate treaties concerning the trade of hazardous e-waste. Furthermore, e-waste exports tend to occur to less economically developed countries. Specifically, the illegal trade of e-waste that takes place from economically and socially developed countries to countries with lower economic and social development (Efthymiou et al., 2016).

E-waste, such as all other types of waste, has been exported from EU to other countries to exploit low wages or avoid stricter treatment requirements on the recipient countries. It has also been shown that this illegal shipment has increased, but it is not yet clear if this growth is real or just a result of improved monitoring by the EU (European Environment Agency, 2009). Furthermore, in 2012 the expected amount of e-waste exported by EU countries was about 1.5 million tonnes, but only 200,000 tonnes were documented. It was also found that 3.15 million tonnes of e-waste were recycled not following the current regulation, and that 4.65 million tonnes were mismanaged or illegally traded between European countries (Huisman et al., 2015).

In the last decades, the majority of e-waste collected in the EU was exported to Asia, specifically China and India, due to the lack of regulation and cheaper disposable facilities (Ilankoon et al., 2018). However, due to the increased regulation in the exporting countries and receiving ones, a shift started to occur concerning e-waste exports, and as result, West Africa became one of the new areas to which countries export waste (Ilankoon et al., 2018).

Over the last years there has been an increase in e-waste, and as a consequence of the high demand of EEE. In 2019 the generation of e-waste worldwide was 53.9 million tonnes, and it is expected that by 2030 it will reach 74 million tons (Andeobu et al., 2021). According to the European Parliament (2020), in 2017, 44.7 million metric tonnes of e-waste were generated, but less than 40% of this waste was recycled, and only 20% of the total waste generated was properly recycled. The high demand for EEE has created challenges in managing this additional e-waste. Additionally, these challenges are also a consequence of the fact that manufacturers of this type of product refuse to show interest or are not forced to take responsibility for what happens with these products at the end of their useful life (Andeobu et al., 2021).

Currently, recycling is one of the promising solutions to tackle the presented problem withing e-waste. Recycling could also improve the efficiency of the resources available and limit the extraction of new resources (François & Mainguy, 2010). Although recycling reaches up to 40% of the total waste produced annually in Europe, it is still not enough from the point of view of a CE. Compañero et al. (2021) stated that in order to reach a CE, the recycling industry will have to play a vital role due to its ability to reduce the use of primary raw materials while also preventing environmental damage. Environmental protection can be achieved by using recycled material instead of virgin material, lowering energy consumption, and thus reducing CO_2 emissions. Furthermore, recycling the materials reduces the quantity of waste unproperly managed, benefiting the environment. However, the current level of recycling does not seem to be able to keep up with the increase in e-waste (Perkins et al., 2014). As recycling cannot handle the increase in the generation of e-waste, one of the presented "solutions" for this problem can be traced to the legal and illegal trade of European e-waste to non-European Countries.

According to United Nations (2009), the lifespan of computers ranges from five to eight years, televisions eight years and mobile phones four years. Huang et al. (2020) showed that the average lifespan for the household appliances category is between eleven and nineteen years, but that the average lifespan of products depends highly on the region. According to the author, a possible reason for the increase in the lifespan of some EEE could be the traced to second-hand markets. By promoting reutilization, the products are kept in the market as long as possible, reducing the generated e-waste and the need to extract primary resources to produce new equipment. In most EEE products, when these are damaged, they tend to be immediately replaced and not repaired. This problem can be sourced to the limited technology available, high labour costs, and the time-consuming task of repairing the product (Bakhiyi et al., 2018). Another relevant challenge is the current inadequate product design. The products are designed to be replaced and not repaired, being assembled so that making repairs is hugely time-consuming, thus not worth it at all, and in some cases, these designs can even hinder the recycling process (Pickren, 2015).

In 2019 Europe generated 20 metric tons of e-waste or 16.2 kg per capita, and it is estimated that just the value of raw materials in e-waste reaches around 12.9 million USD

(Adrian et al., 2020). Although the value of e-waste is high, only a fraction of its value is extracted in recycling, which means that various precious metals are lost in the process (Chancerel et al., 2009). Since the production of EEE is highly dependent on the use of scarce materials such as precious metals, the recovery of this equipment presents a remarkable economic opportunity (Cucchiella et al., 2015) and an obstacle to be surpassed so that the EU countries reach the goals set by on The Green Deal.

Regarding environmental legislation, the policymakers can adopt several instruments, such as regulations, informative programmes, subsidies, and taxation (OECD, 2011). According to the European Environment Agency (2016), EU legislations tend to be implemented in environmental policy areas, such as, energy; greenhouse gas emissions and ozone-depleting substance; waste; sustainable consumption and production; biodiversity; among others. These legislations can either set a binding or non-binding goal. Binding goals are established by the EU legislation or legislations to which the EU has agreed to implement, and all other targets are deemed non-binding and thus are not obligatory. In the case of binding targets, the respective legislation comes with a specific time period to either achieve the set target or apply the said legislation (European Environment Agency, 2016).

Over the last decades countries have started to develop both policies and legislation to reduce the environmental impact of products. Several of these are based on Extended Producer Responsibility (EPR) (Nnorom & Osibanjo, 2008), where producers are responsible for the treatment and disposal of the products. Although it is not a policy in itself, policymakers can apply EPR principles to the development of new legislation (Ilankoon et al., 2018), such as the Waste Electrical Electronic Equipment directive, and the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS). Environmental policies are instruments that can be used by policymakers so that new legislation and regulation can be established in order to tackle the environmental problems stated within the policies itself.

Developed countries such as the countries present in the EU tend to implement environmental policies such as taxation in order to be climate-friendly and achieve sustainable growth (Kang & Lee, 2021). Taxation is the main instrument used by policymakers due to its ability to directly address the inability of a market to take environmental impacts into account. Taxation increases the prices of the products or activities to reflect the environmental harm it caused. In other words, the taxation allows policymakers to include in the price of negative externalities of pollution. Therefore, incentivising companies and consumers to consider these environmental problems. The design of these taxes is of extreme importance, given that, if well implemented, allows the company to determine the most cost-effective way to reduce environmental damage (OECD, 2011).

The relationship between environmental policies and trade is already studied in the literature (Cantore & Cheng, 2018; Jug & Mirza, 2005; Kuik et al., 2019; Tsurumi et al., 2015; Van Beers & Van Den Bergh, 1997). The findings are not consensual, possibly as a consequence of the variables selected to measure environmental policies and the countries chosen for the study sample. For example, Jug & Mirza (2005), notes that environmental expenditures are able to decrease exports. On the other hand Tsurumi et al (2015) expressed that proxies of environmental policy stringency such as energy intensity and abatement costs are shown to increase the export flow.

The findings by Rodríguez et al. (2019) show that green tax reforms can improve environmental quality. Likewise, (Esen et al., 2021) argues that environmental taxes can reduce environmental problems and improve the ecological balance if they are well implemented. In the same way, (Tao et al. 2021) and (Safi et al. 2021), state that both environmental taxes and eco-innovation play a major role in carbon abatement and, therefore to achieve the carbon neutrality. Romano & Fumagalli (2018) presented that if governments are reluctant and not committed to adopt green policies, these can negatively impact the environment and governments. Furthermore, Callao et al. (2021) showed that the absence of landfill taxes on the receiving country does not affect Hazardous Waste Shipment for disposal and the EU countries act in accordance with the proximity and self-sufficiency principles.

Concerning e-waste collection, it is essential to up the collection rate since it is the largest growing waste stream and a major environmental hazard in Europe and in the countries where it is exported. As such, increasing the control of collection is vital, but only this will not be enough. It is also important to improve and develop the treatment of waste. As such, recycling will need to be further developed and implemented for the EU to reduce the existing dependency on external raw materials essential for EEE production (European Commission, 2020b).

The economic growth of the economies has been achieved through a significant environmental footprint. Much of this footprint is caused through the use of energy based on CO_2.emissions. Ghosh (2010) and Wang & Wang (2011) have already shown the bidirectional relation between economic growth and CO_2 emissions. Following this bidirectional relationship, (Kasman & Duman, 2015) also found that GDP (Gross Domestic Product) can help understand and somewhat predict the CO_2 emissions of said country. Furthermore, (Kumar et al., 2017) has already stated that the higher GDP of a country, the higher the e-waste generation will be.

Finally, in the case of financial development, Tamazian et al. (2009) showed that it is able to decrease environmental degradation. Shahbaz et al. (2013) and Tamazian et al. (2009) states that financial development can reduce CO_2 emissions. According to Tamazian et al. (2009) this is due to the fact that financial development provides countries with the opportunity to use new technology and the necessary resources for companies to make energy-efficient production.

3. Waste Shipment Regulation

Following the Khian Sea waste disposal incident (1986) and the Koko case (1988) in Nigeria, governmental actions were taken against transboundary movements of hazardous waste. The policymakers have ever since tried to avoid the illegality of transporting hazardous waste to countries in Asia and Africa (Patil & Ramakrishna, 2020). Following the discoveries of the illegal dumping of waste in Asia and Africa, the Basel Convention (The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal) was adopted on March 22, 1989, in Basel, entering into force in May, 1992 (UNEP, 1989). The Basel Convention aimed to protect human health and the environment against the effects of hazardous waste, by defining hazardous wastes according to their origin, composition, and characteristics. Although the illegal shipment of waste persisted after the Basel convention creation, it stands as the base of all legislation created to stop illegal shipment to third world countries, and as of today, there are 189 countries under the Basel Convention treaty.

In 1992 the Organisation for Economic Development and Cooperation (OECD) decided to Control Transboundary Movement of Waste Destined for Recovery Operations. In 1993, legislation was passed on the supervision and control of waste shipment on the European community (Regulation (EEC) No 259/93), which followed into the EU created later in that year (Karamfilova, 2021).

Following the adjustments to the Basel Convention, a need to revise the Regulation (EEC) No 259/93 arose (Karamfilova, 2021). As a result, in 2006 was implemented the Regulation (EC) No 1013/2006, WSR (Waste Shipment Regulation), which implements the provisions of the Basel Convention and Regulation (EEC) No 259/93 adopted in previous years, intending to simplify and specify the procedures present in these regulations. The other objectives of the WSR is the need to keep the regulations and procedures updated. Therefore, since the adoption of the WSR, it has been subject to many revisions, with the last being made in 2021. These revisions are made frequently to ensure that the regulations are applicable in all countries and guarantee that the waste exported out of the EU does not become a hazard to public health or the environment in the destination country. These regulations apply for the shipment of waste in transit through countries belonging to the EU, exported by the EU to third countries, imported to the EU by third countries, and waste shipment within the EU countries, with or without transit throw countries outside de EU.

The rise in the use of batteries and accumulators stimulated the creation of the Directive 2006/66/EC in 2006. This Directive aims to address some of the problems these chemical devices present, precisely the hazardous substances on these batteries and accumulators (mercury, cadmium, and lead), by prohibiting the use of mercury and cadmium above a certain point. The Directive has also encouraged the collection and recycling of batteries and accumulators to reduce the environmental impact (European Commission, 2006). Given the growing demand for batteries in Europe, a review of the regulation on batteries and accumulators was needed. The review proved that the regulation was not able to respond adequately to the challenges created, and therefore the EU later proposed a new Batteries Regulation in order to fill in the gaps in the old Directive, mainly the lack of capacity it had to incorporate technical innovation, and problems rooted in its definitions (Karamfilova, 2020).

In 2008 the EU took additional steps in the matter of waste management, releasing the Waste Framework Directive (Directive 2008/98/EC), on which it is required every EU country to treat its waste without jeopardising human health and the environment, and establishing the principles of self-sufficiency and proximity.

In July 2011, the European Parliament and Council adopted the Directive 2011/65/EU on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS), intending to prevent the risk that e-waste pose to the human health and the environment by restricting the use of substances such as heavy metals, flame retardants or plasticisers. The RoHS also promotes the recycling of e-waste and the change in the product design. Thus, it ensures equal opportunity and laws for all the manufacturers inside the EU, regardless of the country (European Commission, 2011). Directive 2012/19/EU on e-waste aimed to prevent the creation of e-waste, promote reuse, recycling, and other ways to recover e-waste while supporting the use of secondary raw materials. The Directive also encourages cooperation between producers and recyclers for these products to be recycled more easily. Another critical point of the Directive resides in creating a minimum annual e-waste collection rate. This Directive was a recast of a previous directive (Directive 2002/96/EC), thus, when it entered force, it replaced the previous Directive and its amendments (European Commission, 2012). Later in 2017 the RoHS directive was amended to cover other products and impose new obligations on manufacturers (European Commission, 2017).

The last regulation regarding waste shipment came in late 2020 (Directive (EU) 2020/2174), following the plastic waste ban issued by China. This regulation amended Annexes IC, III, IIIA, IV, V, and VIII of the Waste Shipment Regulation (Directive (EC)

No 1013/2006), banning the exporting of hazardous plastic waste and all other types of waste containing plastic that is considered hazardous to the human health from Countries belonging to the EU to non-OECD countries (European Commission, 2020c). Waste can still be shipped to non-OECD countries if it is destined for recycling, or, in the case of hazardous waste, only if both countries authorise the shipment according to older regulations.

4. Methodology

This study uses annual data from 2010 to 2018, and a sample of 18 countries from the European Union, namely Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Slovakia, Slovenia, Spain, and Sweden. These countries were selected based on the criteria of data availability for the time span. Table 1 contains the description, source, and descriptive statistics of the variables used in this study.

Table 1: Variables used in this study and descriptive statistics

Variable	Description/ Measurement	Data Source	Obs	Mean	Std. Dev.	Min	Max
LEXPew	Export of E-waste (total), (Euro, 2015 prices)	UN Comtrade	162	15.0291	2.4113	6.9304	18.7901
LETEpc	Environmental taxes revenues per capita, (Euro (2015 prices)	WDI	162	-0.7433	1.4319	-4.0712	2.3876
LCO_2dep	GDP per Co2 Emissions, (Euro (2015 prices)/kg)	Eurostat/WDI	162	1.3652	0.5266	0.1707	2.6030
LREC	Recycling rate of e-waste (% of total e-waste collected)	Eurostat	162	3.5773	0.2975	2.6741	4.2121
LWcoll	WEEE collected, (Kg)	Eurostat	162	17.9736	1.3905	15.2692	20.5644
LMID	Material Import Dependency (% of direct material inputs)	Eurostat	162	3.6478	0.3975	2.7408	4.5207
LDCPS	Domestic credit to private sector, (%GDP)	Eurostat	162	4.3311	0.4363	3.4777	5.2629
LGDPpc	Gross Domestic product per capita (2015 prices)	Eurostat/WDI	162	10.1994	0.6279	9.1883	11.4892

Note: All variables were converted to their respective natural logarithms.

The dependent variable in this study is related to exports of e-waste. Therefore, data for exports of e-waste both inside and outside of the EU were obtained from UN COMTRADE using HS 2002 code 854810[1], in US dollars. For consistency, the variable was converted to Euro (2015) prices, using GDP deflator(base=2015) and exchange rates, obtained from the Eurostat Database and the OECD Database, respectively. It is important to highlight that this variable does not ensure that all the major e-waste categories have been taken into account (Petridis et al., 2020), because it measures only one category of e-waste (Kahhat & Williams, 2012), which is primary cells batteries and

[1] 854810 - waste and scrap of primary cells, primary batteries, and electric accumulators; spent primary cells, spent primary batteries, and spent electric accumulators

electric accumulators. Notwithstanding, the adequacy of this variable for the study at hand is noticeable for three main reasons. Firstly, this variable allows overcoming the lack of data on the e-waste trade (Petridis et al., 2020). Second, despite the variables lack of capability to capture all of the categories within e-waste, it could allow obtaining the main information of the behaviour of exports of e-waste by the countries. Third, the literature supports the suitability of this variable use (Lepawsky, 2015; Lepawsky & McNabb, 2010; Petridis et al., 2020), and it allows the use of data from a single database, avoiding the inconsistency of using national databases.

Given that the main objective of this paper is to analyse the role of regulation on e-waste exports, Environmental Tax Revenue from the manufacture of computers, electronic, and optical products was included as the explanatory variable as a proxy of environmental regulation. This variable measure total environmental taxes from the manufacture of computers, electronic and optical products in a million euros, and was later converted to euro (2015) prices per capita (*ETEpc*).

The ratio between Gross Domestic Product and CO_2 Emissions (CO_2dep), Recycling rate of e-waste (*REC*), WEEE collected (*Wcoll*), Gross Domestic Product per capita (*GDPpc*), Domestic credit to private sector (*DCPS*) and Material Import Dependency (*MID*) were also used as explanatory variables. CO_2dep was used due to its ability to measure how dependent on pollution the country is, in terms of economic growth (Ma et al., 2019; Wen & Dai, 2020). This variable was constructed by dividing GDP (Euro, 2015 prices) by CO_2 Emissions obtained from WDI (World Development Indicators Database). Recycling rate of e-waste was included to quantify the treatment of e-waste since it is one of the main processes EU regulation has incentivized in tackling the waste issues. WEEE collected was selected to measure the amount of waste collected in EU. This variable was later converted from kilogram per capita to kilogram. GDP per capita (2015 prices) is used as an economic growth proxy, following the studies of (De Pascale et al., 2021; Kang & Lee, 2021; Tamazian et al., 2009). Furthermore, it aims to capture the macroeconomic dimension of the countries. GDP per capita was constructed using GDP (Euro, prices 2015) and total population obtained respectively from Eurostat and WDI. Regarding DCPS it intends to capture the effects of financial development and ascertain if it impacts the environment, as suggested by Esen et al. (2021); Shahbaz et al. (2013).

The dependency of Europe on external material is noticeable, being the region with the highest material import dependency (Giljum et al., 2015). In the case of metal ores, only 13% of the required metal ores are acquired within the EU (Giljum et al., 2016) . Closing the loop is one of many initiatives from the EU in order to transition to a CE. This Directive addresses Europe's dependency on material from outside its borders. Many of these critical raw materials are essential to the manufacture of electronic equipment, and as such, the Commission aims to encourage recovery to reduce EU dependency on importing critical raw materials (European Commission, 2015). For that reason, the material import dependency was included as an explanatory variable.

Although variables like Gross Domestic Product per CO_2 Emissions, Recycling rate of e-waste and Material Import Dependency (MID) do not and cannot measure environmental regulation as a whole, these are able to somewhat represent and measure specific Directives and regulations. For example, CO_2dep can somewhat measure regulations regarding the transition to cleaner energy, and the commitment EU has on reaching carbon neutrality in 2050, with plans like the LIFE Clean Energy transition sub-programme. Recycling is able to quantify regulations such as the Batteries and Accumulators regulation and the WEEE regulation regarding EU commitment on increasing the recycling level to reduce its need for virgin material. Further increase in recycling will also decrease dependency on importing certain materials for the manufacture of EEE.

The preliminary analyses of the variables included: (i) Variance Inflation Factors test (VIFs); (ii) Correlation matrix values; (iii); Cross-sectional Dependence test (CD-test); (iv) Panel unit root test. The VIF test and the correlation matrix values were used to analyse the multicollinearity and the correlation between the presented variables, respectively. As shown in Table 2, both VIF and correlation matrix values do not raise concern, implying that neither correlation nor multicollinearity compromises the robustness of the estimations.

Table 2: Correlation matrix values and variance inflation factors (VIF)

	LEXPew	*LETEpc*	*Llva*	*LREC*	*LWcoll*	*LMID*	*LDCPS*	*LGDPpc*
LEXPew	1.0000							
LETEpc	0.3398	1.0000						
LCO_2dep	0.3490	03734	1.0000					
LREC	0.0274	0.2760	0.3757	1.0000				
LWcoll	0.3453	0.3930	0.2117	0.1181	1.0000			
LMID	0.1225	0.0183	0.2497	0.0185	-0.2058	1.0000		
LDCPS	0.2081	0.3222	0.6587	0.0000	0.3287	0.1465	1.0000	
LGDPpc	0.1843	0.6148	0.7828	0.2942	0.1721	0.4901	0.6386	1.0000
VIF		2.64	3.81	1.42	1.41	1.99	2.57	7.58
Mean VIF		3.06						

The cross-sectional dependence in the variables was evaluated by employing the CD-test proposed by Pesaran (2004). This test's result is essential, because if a variable indicates the presence of cross-sectional dependence, traditional unit root tests are unreliable. Thus, the second-generation unit root tests must be performed.

Table 3: Cross-sectional dependence test and second-generation unit root test

	CD-test	CIPS		Maddala and Wu	
Variable		Without Trend	Trend	Without Trend	Trend
LEXPew	6.82***	-1.806**	-1.819**		
LETEpc	-0.92	-0.617	-0.691	45.403	85.714***
LCO₂dep	31.59***	-2.250**	-1.488*		
LREC	16.76***	-1.941**	0.751		
LWcoll	17.97***	-1.495*	-1.452*		
LMID	34.08***	-2.000**	0.252		
LDCPS	-1.00	-0.693	0.469	65.287***	25.233
LGDPpc	5.04***	-2.254**	0.602		

Notes: ***, ** and * denotes statistical significance at 1%, 5% and 10% levels of significance, respectively.

The null hypothesis of the CD-test indicates that there is cross-sectional independence. The results presented in Table 3, indicate that the null hypothesis was rejected for the majority of the variables, except *LETEpc* and *LDCPS*. In the case of these variables, the first generation test proposed by (Maddala & Wu, 1999) and the second generation test CIPS proposed by (Pesaran, 2007) were conducted. The second generation CIPS test was carried out for the variables that showed cross-sectional dependence, under the null hypothesis of the variables being I(1). The result of this test is displayed in Table 3. Although the tests do not prove the stationarity of the variables in level unequivocally, it is important to consider that when the time spam under analysis is small, the unit root test could not be robust (Karlsson & Löthgren, 2000).

In order to know if there were no omitted variables that could result in biased results in the model, the (Ramsey, 1969) regression specification-error test (RESET) was conducted after a simple Ordinary Least Squared estimation (OLS). The null hypothesis of RESET test is that the model has no omitted variables. Table 4 presents the result of the Ramsey Reset test, showing that the null hypothesis cannot be rejected, and as such, there is no evidence that any essential variable was omitted in the model.

Remembering that the main objective of this paper is to analyse the role of environmental regulation on the exports of e-waste, one model was estimated. The functional form of the model is described in equation (1).

$$lEXPew_{it} = \beta_0 + \beta_1 lETEpc_{it} + \beta_2 lva_{it} + \beta_3 lREC_{it} + \beta_4 lWcoll_{it} + \beta_5 lMID_{it} + \beta_6 lDCPS_{it} + \beta_7 lGDPpc_{it} + \mu_{it} \quad (1)$$

where i denotes de countries and t the time. β_0 denotes the intercept, β_i denotes the coefficients of the parameters, and μ_{it} represents the error term.

The Hausman (1978) test was employed in order to test the presence of fixed effects or random effects in the model, following the equation (1) specification. The null hypothesis predicts that the random effects model is appropriate. Table 4 shows that the null hypothesis was not rejected at the level of significance of 5%, therefore, the random effects model was shown to be appropriate. Aware that the Hausman test could produce biased results in small samples, the robust Hausman test was also performed. The null hypothesis of this test could not be rejected, which reinforces the findings of the traditional Hausman test (Kaiser, 2015)

Given that the Hausman test supports the adequacy of random effects, the suitability of random effects should be tested against a simple OLS regression. Accordingly, the Breusch & Pagan (1980) Lagrangian multiplier test for random effects was carried out. The results displayed in Table 4 show that the null hypothesis cannot be rejected, supporting the appropriateness of the random effects model.

Table 4: Preliminary tests

	Model
Breusch and Pagan LM test for random effects	250.55***
Ramsey Reset test	1.24
Hausman test	13.67*
Robust Hausman test	1.64

Notes: *** and * denotes statistical significance at 1% and 10% levels of significance, respectively.

In order to use an adequate estimator for the data features, a set of specification tests were performed. These features include the evaluation of cross-sectional dependence, first order serial correlation, and heteroskedasticity. In this sense, the Pesaran (2004) test for cross-sectional dependence was carried out under the null hypothesis of cross-sectional independence. To evaluate the existence of first order serial correlation, the (Wooldridge, 2002) test for autocorrelation was performed. Its null hypothesis predicts the absence of first order serial correlation. To assess the existence of heteroskedasticity, two tests were performed after a single OLS, namely the (Breusch & Pagan, 1979) Lagrange multiplier test for heteroskedasticity and the (Breusch & Pagan, 1979) and (Cook & Weisberg, 1983) test for heteroskedasticity. Both tests were performed under the null hypothesis of homoscedasticity.

The results of the specification tests are displayed on Table 5. The null hypotheses of all the realised tests were rejected; therefore, there is evidence of the existence of cross-sectional dependence, first-order serial correlation, and heteroskedasticity.

Table 5: Specification Tests

	Statistics
Pesaran's test	4.632***
Wooldridge test	4.519**
Breusch-Pagan LM	52.312***
Breusch-Pagan/Cook-Weisberg	26.100***

Notes: ***, ** and * denotes statistical significance at 1%, 5% and 10% levels of significance, respectively

The estimators PCSE (Panel-Corrected Standard Error) and FGLS (Feasible Generalized Least Squared) could be adequate for this study due to their ability to deal with the presence of cross-sectional dependence, heteroskedasticity, and first-order serial correlation. However, given that the panel data presented has a small-time dimension (T) compared to the cross-sectional dimension (N) and as the FGLS estimator is mainly used with panels were T > N, the PCSE estimator was used, since it is suitable to panel data with T < N (Hoechle, 2007)

5. Results

The model was estimated by using PCSE estimator. To ensure the stability of the findings, different options were used in the PCSE estimation. The PCSE without any robust option (PCSE), robust to first-order serial correlation (AR1), robust to heteroskedasticity (HET), and robust to both first-order serial correlation and heteroskedasticity (AR1/HET). Additionally, to secure the specification of the estimations, the significance of the squared residuals was evaluated. These were not significant in all four estimations, which can indicate that there are no omitted variables in the model able to bias the results.

Table 6: Estimated Model

	PCSE	PCSE(AR1)	PCSE(HET)	PCSE(AR1/HET)
LETEpc	1.1564***	0.4422*	1.1564***	0.4422**
LCO_2dep	4.2772***	3.1447***	4.2772***	3.1447***
LREC	-1.6109***	-0.4904	-1.6109***	-0.4904
LWcoll	0.3735***	0.5278***	0.3735***	0.5278***
LMID	3.0863***	2.0005***	3.0863***	2.0005***
LDCPS	-0.0879	0.1652	-0.0879	0.1652
LGDPpc	-4.5578***	-2.9305***	-4.5578***	-2.9305***
Constant	44.7076***	25.2325***	44.7076***	25.2325***
R^2	0.4684	0.7589	0.4684	0.7589

Notes: ***, ** and * denotes statistical significance at 1%, 5% and 10% levels of significance, respectively. PCSE represents the estimation without any robust option; PCSE(AR1) represents the estimation robust to first-order serial correlation; PCSE(HET) represents the estimation robust to heteroskedasticity; PCSE(AR1/HET) represents the estimation robust to first-order serial correlation and heteroskedasticity; R^2 means R-squared

Firstly, regarding the variables that presented similar levels of significance for all the estimations, *LCO_2dep* can be seen to have a strong positive effect on the exporting of e-waste, which means that countries whose economies are highly dependent on CO_2 emissions tend to export more e-waste. Secondly, for the variable *LWcoll*, it can be said that the more collection of e-waste there is, the higher the exporting of e-waste.

In terms of material import dependency, it can be stated that it has a high impact on the export of e-waste, meaning that in the countries studied, the higher the dependency of a country on imported material, the higher the exporting of e-waste. This positive effect of *LMID* on exports of e-waste could be explained by the high dependency of EU countries on importing vital material to produce electric and electronic equipment. Lastly, the *LGDPpc,* has a negative and statistically significant effect on e-waste exporting.

Although *LETEpc* appears to be significant in all the estimations, in PCSE(AR1) and PCSE(AR1/HET), the variable is only significant at 10% and 5% significance level, respectively. Nevertheless, it is shown that environmental taxes from the manufacture of computers, electronic, and optical products increase the exporting of e-waste.

Regarding the recycling rate of e-waste, one founds that it is able to reduce the amount of e-waste exporting, which is not surprising and could be a signal of robustness of results. Lastly, the financial development of a country (*LDCPS*) did not show any signs of significance in any of the PCSE estimations, therefore it does not impact the export of e-waste.

6. Discussion

With the increasing production and dependency on EEE, e-waste has risen, which has caused an increase in legal and illegal e-waste exporting to other countries. Whether regulated or illegal, the exporting of waste, both intra EU and abroad, has increased over the years. To deal with this, the EU has implemented measures to control the trade of e-waste. With the continuous increase, regarding e-waste exports, this has caused both human health related problems and environmental problems for the receiving countries

The regulation plays a critical role for the management of e-waste. Whether regulation is contributing to greater reincorporation/recycling or, on the contrary, is it encourage the escape and loss of the e-waste? Therefore, this paper aims to understand the impact of environmental regulation on management of e-waste, in particular, on the exports of e-waste, considering 18 EU countries. When analysing the question, there is clear a lack of data on the matter. This lack of data is clear in this study and in e-waste studies as a whole (Lepawsky, 2015; Luther, 2010; Petridis et al., 2020; Shamim, 2015). This lack of data can be explained by the majority of e-waste trade being carried out illegally.

Focusing on the main objective of this paper, the environmental regulation apparently is contributing to lose the precious materials existent in e-waste. It occurs because the environmental regulation enlarges the e-waste exportation. This finding proves that taxation on the manufacture of computers, electronic, and optical products is not a viable path to reduce e-waste export. Instead, producers of EEE should be further incentivised by the governments to take responsibility for the product whole life. Ideally, this process should start in the design and production process, by reducing the products environmental footprint, by extending their lifetime, and by way of ensuring that the design and assembly of the products are accomplished to facilitate the recycling process (Lancet, 2013; Petridis et al., 2020). As stated by Pickren (2015), the current product design is far from ideal, as these are not designed to be repaired, and in some cases, it can even hinder the recycling process. Furthermore, as proposed by Lancet (2013), producers of EEE should be responsible for the end of life and recycling process. As the end of life of the products is reached, consumers and businesses, should ideally look to the manufacturers to return the products. The collection and recycling process should be either done by the producers, or supervised, in case of resorting to third parties. Additionally, the policymakers should also increase the awareness of the consumers on the need to adequately manage the e-waste and dispose of it properly.

The findings of this study demonstrate that within the EU, richer countries are responsible for lower levels of e-waste exporting than poorer countries. In other words, economic growth reduces e-waste exporting. As Kumar et al. (2017) highlighted, the GDP enlarges the e-waste generation. Accordingly, the finding of this paper can indicate that, although the economic growth causes a possible increase in e-waste generation, the economic development can also allow the countries to invest in more and improved recycling facilities. Additionally, the economic growth could also make the countries committed to environmental protection and allow them to employ strict regulations to reduce the exporting of e-waste. This finding could be explained by the country sample of the study that only includes EU countries (developed countries), in contrast to most e-waste trade studies (Abalansa et al., 2021; Lepawsky, 2015; Petridis et al., 2020). EU policymakers could finance the EU countries with more modest GDP growth so that these countries can invest in waste management and treatment, further preventing e-waste exportation.

The literature states that there is clear evidence that the receiving countries are not prepared and equipped in order to deal with the waste imported, which means waste tends to be managed improperly (Luther, 2010). As such, it would be important to develop the required infrastructure in host countries to deal with e-waste soundly, minimizing the human health risk and the environmental damage (Abalansa et al., 2021; Lancet, 2013; Petridis et al., 2020). Policies would also be required to ensure workers safety and the recycling process is done under the stated regulation (Abalansa et al., 2021; Ilankoon et al., 2018; Lancet, 2013; Petridis et al., 2020). Furthermore, Lancet (2013) supports that this legislation would have to be done locally, nationally, and globally. As a result, the first step would be recognizing the problem at hands and tackling it at all levels and worldwide. Legislations should also be established to guarantee that the developed countries assist the receiving sub-developed ones to protect them from the environmental damage of e-waste importation. In other words, the exporting countries should be responsible for the e-waste management process realized in the receiving countries. The exporter should be penalized if the e-waste is mismanaged in the receiving country. That way, it would be possible to help communities and countries with the waste imported safely.

The e-waste collection is, as expected, a significant positive predictor of the exports of e-waste. To avoid it, the EU member states should increase the number of recycling centers focusing on large e-waste material such as household appliances. It is also crucial to facilitate the access of populations to collection systems. The policymakers should significantly increase the supply of e-waste collection points. Currently, e-waste recycling is not as easy to practice as plastic or paper recycling, as facilities for collecting these types of waste are easier to access. By developing an efficient and easy to access collection system citizens will be incentivized to partake, thus upping the level of collection. Simultaneously, the existence of adequate e-waste collection points and the importance of not putting e-waste on traditional municipal waste collection points must be advertised close to the population. Media campaigns or sensibilizing actions could be an effective way of increasing the consumers awareness and their willingness to recycle e-waste.

Some consumers tend to dispose of the products within their lifecycle not because they are damaged or unsuitable or malfunctioning but because there are improved technological options in the market. Another common way producers make the consumer pursue new products is by pushing updates for products. In some cases, the customer cannot fulfil the update with the current iteration, thus incentivising the consumer to obtain a new updated version of the current product. Incentives should be put forwards in order to prolong the lifespan of EEE. This could be achieved by creating second-hand markets and sensibilizing the consumers not to relinquish the products but to extend their use as much as possible. At the same time, the policymakers could incentivise the collection of the products that are perfectly functioning and could be, for instance, donate to solidarity institutions or to fewer wealthy countries.

In addition, this paper founds that a higher level of dependency of the economies on carbon emissions is associated with higher e-waste exportation. It could mean that when the countries are highly dependent on emissions, in terms of economic growth, measured as the ratio between GDP and CO_2, these countries could be less environmentally responsible. For that reason, these countries could be less concerned about the management of e-waste and, therefore, tend to increase the exporting of e-waste. EU policymakers should pursue further policies and regulations regarding green energy, such as Directive 2009/28/EC incentivizing the development of renewable energy. In 2018 this Directive was subject to a revision due to the recent focus the EU had given on achieving the European Green Deal goals (European Commission, 2021). Further regulation and revisions of the already established regulation will need to be pursued in order to achieve EU environmental goals set for 2030. In that way, the countries could enlarge their environmental concern and be aware of the need to manage the e-waste adequately.

Further measures have to be taken in EU, as exporting e-waste means losing vital raw material. As already stated, recycling needs to have a vital role for EU circular plans to be successful. This could only be achieved by pushing the recycling industry, further incentivizing its adoption, and funding research in order to accelerate new recycling technologies and improve already established processes. As such, further policies such as the Batteries and Accumulators regulation, and the WEEE regulation must be implemented incentivizing the recycling of e-waste. These policies not only push and incentivize recycling but will also tackle the current dependency EU has on importing vital materials. By increasing the recycling of EEE, EU is creating a viable path for sustained raw material within Europe. As demonstrated by (Adrian et al., 2020), the quantity of precious metals within e-waste already presents a viable economic opportunity if well pursued. Lastly, further monitorisation of the already established WSR is essential, as the global e-waste trade network is everchanging. The regulation will need to be further updated in order to keep up with the changes, thus aiming to control and stop further desensitizing countries from exporting e-waste.

7. Conclusion

The regulation is crucial for improving the management of e-waste and avoiding the loss of precious material existent in e-waste. Therefore, the role of environmental regulation on EU exporting e-waste is analysed for 18 EU countries from 2010 to 2018. In order to measure environmental regulation, the total environmental taxes from the manufacture of computers, electronic, and optical products per capita were used. Empirically, various tests were conducted to secure the robustness of the results and the appropriateness of the estimator used. The data featured made the use of the PCSE estimator.

The main findings suggest that environmental regulation drives the exporting of e-waste as well as the e-waste collection. On the contrary, the recycling of e-waste hampers the exporting of e-waste. It implies that the policymakers should invest in recycling facilities and that consumers should be incentivized to dispose of their e-waste correctly. Deployment of collection points with easier access for the population is crucial. This paper also founds that economic growth hampers the exports of e-waste. It could indicate that economic growth is crucial to managing e-waste properly and avoiding the transfer of the e-waste to other countries.

Firstly, care must be taken of e-waste in host countries. As such, more affluent countries should incentivize host countries to develop both structurally and policy-wise. The waste to be treated, and recycled in the receiving countries, if it is at all, should safeguard the environment and the human health of workers. Secondly, exporting countries, should improve both the quality of e-waste and the design, as these are essential to extend the lifetime of EEE and to facilitate the recycling at the end of life. Thirdly, EU policymakers, should increase the collection points for e-waste, enabling citizens to partake. Further regulation should also be pursued to reduce the current dependency of EU economies on CO_2 emissions. As for recycling, it is crucial that government continue to implement policies pushing and incentivising its use, while providing the necessary measures for its development. Lastly, the current WSR should be kept up to date, with the goal to keep the exporting of e-waste under control.

The presented study has two main limitations. Firstly, it could be stated that within the realm of e-waste exists a lack data, which majorly increases the difficulty of analysing subject in question. An improvement of the data availability, quantitatively and in a broader spectrum of types of e-waste, would allow further analysis and studies on the matter. The second limitation was the short time span of the study. This limitation was caused by the lack of data within the variables used in the study, which did not allow a longer times span. Although this limits the study and the results, all the appropriate steps and tests were conducted to preserve the presented results robustness.

As stated, there is a lack of data on e-waste as a whole, and it would be essential for the deployment of further studies. For that, the databases need to be updated and expanded. Thus, future research could better analyse the already established issues and challenges within e-waste management. Additionally, future research should also be focused on host countries in order to evaluate the environmental effects of the e-waste importation.

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