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**Article**

## The Impact of Globalization on the Rate of E-waste Recycling: Evidence From European Countries

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**THE IMPACT OF GLOBALIZATION ON THE RATE OF E-WASTE RECYCLING:  
EVIDENCE FROM EUROPEAN COUNTRIES****Rasim Yilmaz<sup>1\*</sup>** and **Cuneyt Koyuncu<sup>2</sup>**<sup>1)</sup> *Tekirdağ Namik Kemal University, Tekirdag, Turkey*<sup>2)</sup> *Bilecik Seyh Edepali University, Bilecik, Turkey***Please cite this article as:**

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**Abstract**

E-waste recycling and the better collection of e-waste are two of the most important strategies for the implementation of the circular economy and the reduce-reuse-recycle paradigm envisaged by the EU and UNDP. Since the rate of e-waste recycling is one of the most important indicators of the circular economy, it is necessary to identify the factors that affect it, and to determine the degree to which these factors influence it in order to foster e-waste recycling. Using the panel quantile regression technique on panel data including 30 European countries (EU28+2) and the time period from 2008 to 2018, this study analyses the effects of overall globalization and its three sub-dimensions (economic, political, and social globalization) on the rate of e-waste recycling. The results indicate that overall globalization and its three sub-dimensions have a positive impact on the rate of e-waste recycling in 30 European countries (EU28+2) during the estimation period, thus contributing to the circular economy. Therefore, supporting all aspects of globalization (economic, political, and social) will enhance the circular economy.

**Keywords:** circular economy, e-waste recycling, globalization, Panel Quantile Regression**JEL Classification:** Q01, Q53, F64, C31

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## **Introduction**

Discarded and secondary electrical and electronic products are considered as electronic waste or e-waste and include a growing number and a large range of devices and equipment in our daily life. The Global E-waste Monitor 2020 prepared by Forti et al. (2020) claims that waste electrical and electronic equipment (WEEE or e-waste) is the world's one of the fastest growing waste streams in regard to both its volume and impact on the environment.

E-waste recycling and the better collection of e-waste are two of the most important strategies for the implementation of the circular economy and the reduce-reuse-recycle paradigm envisaged by the EU and UNDP. Since the rate of e-waste recycling is one of the most important indicators of the circular economy, it is necessary to identify the factors that affect the rate of e-waste recycling and to determine the degree to which these factors influence the rate of e-waste recycling in order to foster e-waste recycling.

This article aims to investigate the impact of globalization on the rate of e-waste recycling, besides other related factors in the case of European countries. In previous studies, globalization was not considered as one of the determinants of e-waste recycling. One of the objectives of this study is to fill this gap by proposing a new determinant that may affect the rate of e-waste recycling. To our best knowledge, no known empirical research has investigated the effect of globalization and its sub-dimensions on the rate of e-waste recycling. This research contributes to the current literature by identifying globalization and its sub-dimensions as a new determinant of the rate of e-waste recycling. This study also contributes to the literature on the impact of globalization on the environment. It provides new evidence for the positive impact of globalization on environmental improvement proxied by the rate of e-waste recycling.

The remainder of this study is structured as follows. The next section reviews the literature on the determinants of e-waste recycling as well as the impact of globalization on the environment. Section 2 provides research methodology and data while section 3 gives information about estimation technique used in the study. Section 4 presents the estimation results and a discussion on the empirical findings of the study. The final section concludes with overall policy implications and scope for future research.

## **1. Literature review**

The literature review part of this study is divided into three sections. The first section reviews the literature on the determinants of e-waste recycling. The second section reviews theoretical impacts of globalization and its sub-dimensions on environmental protection while the third section reviews the results of empirical studies on the impact of globalization and its sub-dimensions on the environment.

### **1.1. Determinants of e-waste recycling**

The emerging empirical literature on e-waste recycling is a part of the empirical literature on recycling. The empirical literature on the determinants of e-waste recycling can be grouped into two main groups. The first group of studies analyses the knowledge, awareness, willingness, attitude, intention, decision, and behaviour of individuals regarding e-waste

recycling. These studies utilize household level data mostly based on surveys and attempt to determine personal and micro-factors that affect e-waste recycling decisions of individuals.

Several studies examined the factors impacting households' e-waste recycling decisions: Darby and Obara (2005) for the UK, Arain et al. (2020) for the USA, Ylä-Mella, Keiski and Pongrácz (2015) for Finland, Blake, Farrelly and Hannon (2019) for New Zealand, Delcea et al. (2020) for Romania, Dwivedy and Mittal (2013) for India, Mohamad, Thoo and Huam (2022) for Malaysia, Nguyen et al. (2019) for Vietnam, Wang, Guo and Wang (2016) for China, Miner et al. (2020) for Nigeria.

The above-mentioned literature on household-level data suggests that recycling behaviour of individuals is affected by a variety of factors, such as income, education level, age, gender, marital status, employment status, household size, attitude towards recycling, environmental norms and beliefs, institutional supports, laws and regulations, environmental awareness, publicity, costs of recycling, convenience of recycling, and access to recycling.

The second group of studies explores aggregate data. These studies use country-level data and attempt to determine macro and aggregate factors that influence the rate of e-waste recycling of municipalities, regions, and countries. There are a very few cross-country studies on the determinants of e-waste recycling. Boubellouta and Kusch-Brand (2022) investigated the driving factors of the e-waste recycling rate in 30 European countries utilizing data from 30 European countries over the period 2008-2018. Results of the study indicate that economic growth and e-waste collection are the main drivers of the e-waste recycling rate, while population, energy intensity and credit to the private sector also have an impact on the e-waste recycling rate. Constantinescu et al. (2022) investigated the effect of eco-investment on e-waste recycling in 24 EU countries for a time period from 2009 to 2018. They found that eco-investment per inhabitant has a positive impact on e-waste recycled per inhabitant during the estimation period. Using data from 31 European Economic Area countries and the period from 2004 and 2014, Önder (2018) scrutinizes the determinants of the packaging waste recycling rate. The results of the study reveal that education, amount of resources, income levels, and the agriculture sector are important factors affecting the packaging waste recycling rate.

This research fills the literature gap by proposing a new determinant that may affect the rate of e-waste recycling. To our best knowledge, no known empirical research has investigated the effect of globalization and its sub-dimensions on the rate of e-waste recycling. This research contributes to the current literature by identifying globalization and its sub-dimensions as a new determinant of the rate of e-waste recycling.

## **1.2. Globalization and its sub-dimensions**

The concept of globalization is a multidimensional concept and globalization can take a number of forms, such as economic, political, and social. Trade liberalization and capital flows liberalization are two main key factors of economic globalization. Variables such as the number of embassies, international organizations, UN peace keepings missions, international NGOs, international organisations, and international treaties are considered as indicators of political globalization. Variables such as international voice traffic, international tourism, international students, migration, telephone subscriptions, freedom to visit, international airports are considered as indicators of interpersonal contacts, while used

internet bandwidth, international patents, high technology exports, television access, internet access, and press freedom are variables considered as indicators of information flows. Variables such as trade in cultural goods, trade in personal services, international trademarks, gender parity, human capital, and civil liberties are regarded as indicators of indicators of cultural proximity (Dreher, 2006; Gygli et al., 2019).

Theoretically, globalization and its dimensions (economic, political, and social) might have both positive and negative impacts on the environment. Various arguments and hypotheses have been developed to explain both the positive and negative impacts of globalization and its dimensions on the environment: the intensification hypothesis, the markets for the global environment hypothesis, the global environmental governance failure hypothesis, the global governance failure hypothesis, the living in denial hypothesis, the global environmental awareness hypothesis, the pollution haven hypothesis, the pollution halo hypothesis (Rudolph and Figge, 2017; Nguyen and Le, 2020). Hypotheses in favor of the negative impacts of globalization on the environment argue that globalization may exacerbate environmental degradation via intensifying human demands, fostering industrialization both in developed and developing countries, which leads to surge in greenhouse gas emissions and global warming due to a heavy reliance on coal and fossil fuels, encouraging migration of pollution intensive industries to the countries with lower environmental regulations (Sabir and Gorus, 2019; Nguyen and Le 2020). On the other hand, hypotheses in favor of the positive impacts of globalization on environment state that globalization may help improve environmental quality by means of stimulating environmental policy intervention, enhancing the effectiveness of government institutions, increasing environmental awareness, enhancing dissemination of environmental technology, motivating green innovation and eco-friendly business processes, increasing efficiency and competition which lead to decrease in input and waste material per unit of output (Rudolph and Figge, 2017; Pata and Yilanci, 2020; Suki et al., 2020).

Reducing, reuse, and recycling are vital aspects of the sustainable production and consumption which was first defined and proposed at the UN Environment Programme's Oslo Symposium in 1994 (Cui et al., 2022). Globalization, especially social globalization, may positively affect sustainable consumer behaviour. It is argued that European consumers in particular are increasingly concerned about the environmental and social impacts of production in developing countries, and many are willing to take action by the effect of globalization (Oosterveer, 2006). Globalization also proposes to help the policy domain of sustainable production and consumption to expand from pollution prevention and cleaner production to lifecycle-based efficiency, whereby environmental policy and business strategies have gradually shifted their focus from pollution prevention and cleaner production to lifecycle-based efficiency (Hotta, Tasaki and Koide, 2021).

### **1.3. Impact of globalization on the environment**

When we overview the empirical studies on the impact of globalization on the environment, it can be observed that initial studies utilized proxies of globalization such as foreign direct investment, openness, etc. while the latter studies started to use the overall globalization index and the dimensions of globalization index (social, economic, and political). It can also be seen that earlier studies widely used CO<sub>2</sub> emissions and energy consumption as a proxy for environmental degradation, while the most recent studies have incorporated the ecological footprint, which is a comprehensive and multi-dimensional indicator of

environmental quality, as an environmental deterioration measure. The rest of this part of the study reviews the previous cross-country empirical studies focusing on the impact of globalization and its subdimensions on the environment. Below, we present the findings of the studies on the effect of globalization and its subdimensions on carbon emissions and the ecological footprint at the cross-country level.

Destek (2020) uses the overall globalization index and sub-components of globalization index to examine the impact of globalization on the carbon emissions in Central and Eastern European Countries for the period between 1995 and 2015. The estimation results of the study suggest that an increase in overall globalization, economic globalization, and social globalization increases the carbon emissions, while a surge in political globalization reduces the carbon emissions. Using the Maastricht Globalization Index (MGI) instead of the KOF index of globalization, Figge, Oebels and Offermans (2017) examined the association between globalization and four variants of the Ecological Footprint for 171 countries. The results of the study suggest that the overall index of globalization significantly increases the ecological footprint of consumption, exports, and imports. Regarding sub-dimensions of globalization, all dimensions increase the ecological footprint except political globalization. Using unbalanced panel data including 146 countries and spanning the 1981-2009 period, Rudolph and Figge (2017) investigated the impact of different dimensions of globalization on different dimensions of ecological footprint. Their findings indicate that overall globalization increases the ecological footprint of imports and exports; economic globalization increases the ecological footprint of consumption and production; social globalization decreases the ecological footprint of consumption and production while increasing the ecological footprint of imports and exports; and political globalization has no effects on the ecological footprint.

Our literature review reveals that globalization increases carbon emissions and ecological footprint for some countries, while decreasing for some other countries. Depending on the sub-dimension of the globalization index, the impact also differs. This study also contributes to the literature on the impact of globalization on the environment. It provides new evidence for the positive impact of globalization on environmental improvement proxied by the rate of e-waste recycling.

## **2. Research methodology and data**

One of the classic attempts to explain the main driving forces of environmental degradation is the IPAT equation/model proposed by Ehrlich and Holdren (1971). According to the IPAT equation/model, the impact on environment (I) is the product of population (P), affluence (A) and technology (T):  $I = P \times A \times T$ .

The stochastic form of IPAT, called the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology), was developed by Dietz and Rosa (1997) to overcome limitations of IPAT model and hence to conduct empirical hypothesis tests.

In the literature, the STIRPAT model has become one of the most used models to analyse the effect of Population, Affluence, and Technology as well as other potentially impactful variables on the environment. In empirical studies, generally Population is proxied by total population and Affluence is proxied by gross domestic product (GDP) per capita while Technology is proxied by energy intensity. Moreover, empirical studies also include GDP

per capita square in order to test whether the non-linear relationship exists between Affluence and Environmental Degradation, such as the one proposed by the Environmental Kuznetz Curve (EKC) hypothesis (see, for example, Boubellouta and Kusch-Brandt, 2022).

This study aims to examine the impact of globalization on the rate of e-waste recycling by incorporating the globalization variable into the STIRPAT model. The model used in this study incorporates the globalization variable into the STIRPAT (stochastic impacts by regression on population, affluence, and technology) model. Thus, we construct and estimate the following empirical models:

$$ERATE_{it} = \alpha_0 + \alpha_1 RPC_{it} + \alpha_2 RPC_{it}^2 + \alpha_3 POP_{it} + \alpha_4 EINT_{it} + \alpha_5 ECOLL_{it} + \alpha_6 GLOB_{it} + u_{it} \quad (1)$$

$$ERATE_{it} = \alpha_0 + \alpha_1 RPC_{it} + \alpha_2 RPC_{it}^2 + \alpha_3 POP_{it} + \alpha_4 EINT_{it} + \alpha_5 ECOLL_{it} + \alpha_6 EGLOB_{it} + u_{it} \quad (2)$$

$$ERATE_{it} = \alpha_0 + \alpha_1 RPC_{it} + \alpha_2 RPC_{it}^2 + \alpha_3 POP_{it} + \alpha_4 EINT_{it} + \alpha_5 ECOLL_{it} + \alpha_6 SGLOB_{it} + u_{it} \quad (3)$$

$$ERATE_{it} = \alpha_0 + \alpha_1 RPC_{it} + \alpha_2 RPC_{it}^2 + \alpha_3 POP_{it} + \alpha_4 EINT_{it} + \alpha_5 ECOLL_{it} + \alpha_6 PGLOB_{it} + u_{it} \quad (4)$$

where  $i$  and  $t$  stand for country and time, respectively. All variables are in their logarithmic forms.

E-waste recycling rate (ERATE) is the dependent variable of the study and is given by the percentage of e-waste recycled/reused in a country.

Control variables of total population (POP), per capita gross domestic product (at constant 2010 Euro) (RPC), and the energy intensity of the economy (kilograms of oil equivalent per thousand Euros) (EINT) are three main variables proposed by the STIRPAT model, representing human impact on the environment. As suggested by the STIRPAT model, expected signs of these variables are negative in our model. An increase in total population, GDP per capita, and energy intensity is expected to decrease the e-waste recycling rate.

The model also includes GDP per capita square (RPC<sup>2</sup>) variable to test whether a non-linear relationship exists between GDP per capita and e-waste recycling rate, as proposed by the EKC hypothesis. The relationship between economic development and environmental degradation could be inverted U-shaped as well as linear. The argument of inverted U-shaped is based on the well-known EKC hypothesis. As such, it is argued that environmental degradation increases with economic development; however, it decreases after reaching a turning threshold level. In the context of the rate of e-waste recycling, the relationship between economic development and the rate of e-waste recycling could be linear and U-shaped since the rate of e-waste recycling represents an environmental improvement. The U-shaped behaviour will be validated when the coefficient for the RPC variable is negative and the coefficient for RPC<sup>2</sup> variable is positive, and both are statistically significant.

GLOB is the KOF Index of overall globalization employed to measure globalization. The globalization index is a composite index constituted by equally weighted three sub-components, namely economic, social, and political globalizations. Overall indices for each aggregation level are calculated by the average of the respective de facto and de jure indices. Economic globalization includes variables under two main sub-indices which are trade globalization and financial globalization. Social globalization consists of variables under three main sub-indices which are interpersonal globalization, informational globalization, and cultural globalization. Political globalization does not have sub-indices. De facto political

globalization cumulates variables of embassies, UN peace keeping missions, and international NGOs while de jure political globalization includes international organisations, international treaties, and treaty partner diversity variables. The overall globalization index as well as its three sub-component indices are scaled between 1 and 100, where the higher value of the index score indicates a high level of globalization. We separately added each globalization index, economic globalization (EGLOB), social globalization (SGLOB), and political globalization (PGLOB), to the model in order to avoid the potential multicollinearity problem owing to the fact that sum of the scores of EGLOB, SGLOB, and PGLOB are equal to the score of GLOB. Theoretically, the impact of globalization on the environment is ambiguous, as explained in the literature review section. Thus, the expected signs of globalization variables are ambiguous in our model. All globalization data are collected from the KOF Globalization Index of Gygli et al. (2019).

ECOLL is the total e-waste collected (kilograms per capita). Total e-waste collected is included in our model, since most of the studies (for example, Boubellouta and Kusch-Brand, 2022; Cerueira and Soukiazis, 2022) on the determinants of e-waste recycling employed this variable in their model. In our model, the expected sign of coefficient on this variable is positive since more e-waste collected indicates further recycling endeavours for protecting the environment.

Table no. 1 presents definitions and sources of all variables used in this study.

**Table no. 1. Definition and sources of variables**

<b>Variable</b>	<b>Description</b>	<b>Source</b>
<b>ERATE</b>	Is the e-waste recycling rate and given by the percentage of e-waste recycled/reused in a country.	Eurostat
<b>RPC</b>	Is real GDP per capita and measured by per capita gross domestic product (at constant 2010 Euro).	Eurostat
<b>EINT</b>	Is the energy intensity of the economy and expressed in kilograms of oil equivalent per thousand Euros.	Eurostat
<b>ECOLL</b>	Is e-waste collected in kilograms per inhabitant.	Eurostat
<b>POP</b>	is total population.	WDI
<b>GLOB</b>	Is an index of overall globalization.	KOF Globalization Index
<b>EGLOB</b>	Is an index of economic globalization.	KOF Globalization Index
<b>SGLOB</b>	Is an index of social globalization.	KOF Globalization Index
<b>PGLOB</b>	Is an index of political globalization.	KOF Globalization Index

Utilizing the panel quantile regression technique on panel data including 30 European countries (EU28+2) and the time period from 2008 to 2018, the effects of overall globalization and its three sub-dimensions (economic globalization, political globalization, and social globalization) on the rate of e-waste recycling is analysed in the following sections of this study. The covered period range and the number of countries contained in the sample are determined and limited by the availability of data on the recycling rate of e-waste for which the latest available data runs from 2008 to 2018.



### **3. Estimation technique**

We preferred to estimate the above models by employing panel quantile regression technique rather than pooled OLS, FEM, REM regression techniques for several reasons. The OLS estimation method generates biased estimators in the presence of outliers; on the other hand, the quantile regression method does not suffer from such bias and provides results more robust to outliers (see, for instance, Chen and Lei, 2018). Furthermore, when the distribution of data is not normal distribution, then estimators of OLS estimation technique are inconsistent, whereas quantile regression method produces consistent estimators regardless of distributional assumption (see, for example, Xu and Lin, 2020). Quantile regression technique is an alternative to the linear regression (OLS) technique when the linear regression fails to satisfy its assumptions (i.e., assumption of linearity, homoscedasticity, independence, or normality). Unlike the traditional OLS regression method utilizing the method of least squares to estimate the conditional mean of the dependent variable, quantile regression method uses the method of minimizing median absolute deviation to calculate the conditional median (or other quantiles) of the dependent variable.

Since panel quantile regression with fixed effects is not a suitable estimation technique (i.e., not efficient to estimate a large number of fixed effects) when T is small (i.e., 11 years in our sample) and N is large (i.e., 30 countries in our sample) (see for instance Albulescu et al., 2019), we employed panel quantile regression with non-additive fixed effects proposed by Powell (2016) in order to surmount this problem. This study examines nine quantiles of the conditional e-waste recycling rate, namely 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th quantiles. In this case, the lower quantiles are constituted by countries with lower e-waste recycling rates, and the upper quantiles are constituted by the countries with higher e-waste recycling rates. The adaptive Markov Chain Monte Carlo (MCMC) optimization method was preferred in estimations.

### **4. Estimation results**

Table no. 2 displays the estimation results for the globalization model given by equation no. 1 where the overall globalization index is the main interest. The coefficients of real GDP per capita and squared real GDP per capita are statistically significant and take the negative and positive signs, respectively, in all nine quantiles. Hence, according to the implication of these findings, we consistently have a U-shaped relationship between e-waste recycling rate (i.e., environmental improvement) and real GDP per capita (i.e., economic development) across all models. This result is in conformity with the well-known inverted U-shaped EKC hypothesis of the literature. Moreover, our finding of a U-shaped association between e-waste recycling rate and real GDP per capita is in line with solid waste studies identifying an inverted U-shaped relationship between GDP per capita and solid waste generation (i.e., environmental degradation) (see, for example, Boubellouta and Kursch-Brandt, 2020 and 2021 for e-waste). In the meantime, in regard to waste recycling studies, our findings are in contrast to the finding of Önder (2018), which identifies a linear negative relationship between GDP and the packaging waste recycling rate for 31 European Economic Area countries, while our estimation results confirm the findings of Cerqueira and Soukiazis (2022) which found a U-shaped relationship between gross-value added per capita and recycling level per capita for Portuguese municipalities.

Positive and statistically significant coefficients were obtained for the globalization variable in all quantiles. On the other hand, this picture varies with quantiles. The positive impact of globalization on e-waste recycling rate diminishes in each succeeding quantile. This hints that globalization has a more pronounced influence on the e-waste recycling rate for the economies where e-waste recycling rate is low and e-waste recycling management is not well established. Meanwhile, globalization is the second influential explanatory variable after the real GDP per capita variable in the explanation of e-waste recycling rate in all quantiles. Our study confirms the findings of studies that present a positive impact of globalization on the environment mentioned in the literature review part of this study. To the best of our knowledge, this study is also the first study to provide empirical evidence for the positive relationship between globalization and the rate of e-waste recycling.

In environmental studies, population size is added to models to capture human-driven pressure on the environment. In existing e-waste studies, it is shown that increasing human-driven e-waste generation inflates environmental pressure (see for instance Boubellouta and Kusch-Brandt, 2020, 2021). However, if the speed of human-driven e-waste generation rate exceeds the speed of e-waste recycling rate in a society, then we can get a negative coefficient for the population variable while if the speed of human-driven e-waste generation rate comes short of the speed of e-waste recycling rate in a society, then we can expect to have a positive coefficient for population variable in our e-waste recycling models. This can be a result of falling short of capacity increases in e-waste recycling plants in response to increases in the population (i.e., increases in human-driven e-waste generation). There are studies (e.g., Hummel and Lux, 2007; Adshead et al., 2019; Churchill et al., 2021) in the literature supporting this perspective, where the presence of a delay between changes in population and adaptation of infrastructure was disputed for a variety of infrastructure items. In table no. 2 population size has negative statistically significant effect on e-waste recycling rate across all quantiles. Hence, a jump in population size leads to a drop in the e-waste recycling rate whereas a decrease in population size causes to an increase in the e-waste recycling rate. The results of this study complement the existing knowledge. Meanwhile, having a negative coefficient for population variable indicates that the speed of human-driven e-waste generation rate goes beyond the speed of e-waste recycling rate in our sample of 30 European countries.

The coefficient of the energy intensity variable is statistically significant and negative in all quantiles; thus, this finding points out that e-waste recycling rate drops with the increase in energy intensity. Energy intensity expands with the increase in usage of electrical and electronic equipment (e.g., Morley, Widdicks and Hazas, 2018), and in turn this may induce to generate higher amounts of e-waste and left some or all of them unprocessed under existing e-waste management system of a country.

The coefficient of collected e-waste is statistically significant and positive for all quantiles. After the real GDP per capita and globalization variables, the collected e-waste variable is the third variable with the highest explanatory power on the e-waste recycling rate. This result reveals that e-waste recycling rate will enhance with the increase in collected e-waste. As in the input-output relationship, we will be unable to recycle more e-waste unless more e-waste is collected. This finding also coincides with the determinants of the recycling studies of Boubellouta and Kusch-Brandt (2022) and Cerqueira and Soukiazis (2022).

Lastly, we conducted Wald test (Koenker and Bassett, 1982), where the null hypothesis asserts that all the partial slope coefficients are equal to zero, to find out if estimated models

for each quantile are statistically significant and test results are reported at the bottom of table no. 2. As seen from the test results in table no. 2, we reject the null hypothesis in all quantiles and conclude that each of the nine estimated models is significant.

**Table no. 2. Quantile regression results for Eq. 1 (Overall Score of Globalization)**

	10th	20th	30th	40th	50th	60th	70th	80th	90th
<b>RPC</b>	-5.5381	-4.7521	-2.6615	-3.9111	-3.1001	-3.0143	-2.6472	-1.9693	-1.4025
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0050	0.0000	0.0000	0.0000	0.0000
<b>RPC^2</b>	0.2344	0.1988	0.0916	0.1455	0.1133	0.1120	0.0872	0.0642	0.0338
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0440	0.0000	0.0000	0.0000	0.0000
<b>POP</b>	-0.0979	-0.0209	-0.0869	-0.0332	-0.1030	-0.1032	-0.1196	-0.1086	-0.1293
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0350	0.0000	0.0000	0.0000	0.0000	0.0000
<b>EINT</b>	-0.3194	-0.1434	-0.3004	-0.2882	-0.4203	-0.3402	-0.4250	-0.2117	-0.3214
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>ECOLL</b>	1.0005	1.0346	0.9349	0.9349	0.8539	0.9010	0.9486	0.8634	0.8968
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>GLOB</b>	3.8578	3.4632	2.8236	2.3777	2.2423	1.5773	1.5564	1.4693	1.0933
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0080	0.0000	0.0000
<b>Wald Test</b>	3059.9	6524.6	8784.5	29023.4	18173.6	62578.5	4543.8	2.2e+06	3.0e+06
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

In addition to the analysis of the impact of the overall globalization index on e-waste recycling rate, we estimated the same model for the sub-components of globalization, namely economic globalization, social globalization, and political globalization, in order to provide more insight and determine the robustness of our results. Table no. 3 presents the estimation findings for the economic globalization model given by equation no. 2. According to the estimation results, the U-shaped EKC curve is valid between real per capita GDP and e-waste recycling rate and economic globalization has a positive statistically significant influence on e-waste recycling rate across all quantiles. However, we did not find a systematic pattern between economic globalization and e-waste recycling rate across quantiles. In parallel to our previous expectations, the coefficients of population and energy intensity are statistically significant and negative, while the coefficient of collected e-waste is statistically significant and positive in all quantiles. Meanwhile, Wald test results indicate the significance of each estimated model.

**Table no. 3. Quantile regression results for Eq. 2 (Economic Globalization)**

	10th	20th	30th	40th	50th	60th	70th	80th	90th
<b>RPC</b>	-5.521	-2.5374	-1.4394	-2.7212	-1.9048	-2.7971	-1.6514	-1.9228	-1.309
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>RPC^2</b>	0.2393	0.0899	0.0277	0.0989	0.0529	0.1071	0.0496	0.0621	0.0386
<b>Prb.</b>	0.0000	0.0000	0.0880	0.0000	0.0280	0.0000	0.0000	0.0000	0.0000
<b>POP</b>	-0.027	-0.0203	-0.1162	-0.0657	-0.0770	-0.0750	-0.0529	-0.0625	-0.0990
<b>Prb.</b>	0.0770	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>EINT</b>	-0.381	-0.3046	-0.5410	-0.2854	-0.4483	-0.2616	-0.2544	-0.2752	-0.227
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>ECOLL</b>	1.0750	0.9796	0.9616	0.8682	0.9896	0.9450	0.8671	0.8719	0.7189
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>EGLOB</b>	0.8612	0.6043	0.6877	0.7974	1.4684	0.4883	0.9054	0.9270	0.8584
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0040	0.0000
<b>Wald Test</b>	5209.3	2.2e+07	44605.9	1.4e+05	2082.0	5999.6	25164.8	9881.39	3.0e+05
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

In table no. 4, we depict the estimation findings for the social globalization model given by equation no. 3. The estimation results confirm the existence of a U-shaped EKC curve between the real GDP per capita and e-waste recycling rate and the positive statistically significant impact of social globalization on e-waste recycling rate in all quantiles. Also, we identified a systematic pattern between social globalization and e-waste recycling rate, where the positive effect of social globalization on e-waste recycling rate increases with each succeeding quantile. Regarding the remaining variables, they have anticipated signs and statistically significant (except POP variable in the 20<sup>th</sup> quantile) in all quantiles. Wald test findings endorse the significance of each estimated model.

**Table no. 4. Quantile regression results for Eq. 3 (Social Globalization)**

	10th	20th	30th	40th	50th	60th	70th	80th	90th
<b>RPC</b>	-2.0748	-2.4530	-1.4492	-1.6764	-2.8308	-3.6641	-2.4164	-2.7269	-4.206
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>RPC<sup>2</sup></b>	0.0615	0.0857	0.0329	0.0457	0.1029	0.1420	0.0862	0.1011	0.1691
<b>Prb.</b>	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>POP</b>	-0.0051	-0.0103	-0.0625	-0.0733	-0.0776	-0.0788	-0.0407	-0.0781	-0.057
<b>Prb.</b>	0.0000	0.2590	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>EINT</b>	-0.3775	-0.2300	-0.2596	-0.2711	-0.3272	-0.3353	-0.2939	-0.2036	-0.284
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>ECOLL</b>	1.0732	0.9676	0.9783	0.9584	0.9054	1.0217	0.8426	0.8703	0.8901
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>SGLOB</b>	0.0750	0.9963	1.1180	1.1564	1.1967	1.2556	1.3769	1.5162	3.3096
<b>Prb.</b>	0.0010	0.0210	0.0000	0.0000	0.0000	0.0010	0.0000	0.0010	0.0000
<b>Wald Test</b>	5.8e+06	4826.96	2.1e+06	1.2e+07	22496.2	1216.3	6806.6	7980.90	14443.6
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table no. 5 exhibits the estimation results for the political globalization model given by equation no. 4. The estimation results affirm the parabolic relationship between real per capita GDP and e-waste recycling rate and the positive statistically significant impact of political globalization on e-waste recycling rate across all quantiles. Moreover, we identified a systematic pattern (i.e., inverse parabolic relationship) between political globalization and e-waste recycling rate where the positive effect of political globalization on e-waste recycling rate increases up to the 50<sup>th</sup> quantile (including the 50<sup>th</sup>) and declines after that. The rest of the variables possess the expected signs and are statistically significant in all quantiles. Wald test results indicate the significance of each estimated model.

**Table no. 5. Quantile regression results for Eq. 4 (Political Globalization)**

	10th	20th	30th	40th	50th	60th	70th	80th	90th
<b>RPC</b>	-2.8386	-1.6075	-1.7652	-1.5791	-3.8835	-2.6186	-4.472	-2.2062	-2.0923
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0030	0.0000	0.0000	0.0000	0.0000
<b>RPC<sup>2</sup></b>	0.1017	0.0416	0.0561	0.0399	0.1345	0.1093	0.1861	0.0786	0.0786
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0250	0.0000	0.0000	0.0000	0.0000
<b>POP</b>	-0.1154	-0.1195	-0.1220	-0.1955	-0.1877	-0.1477	-0.150	-0.0981	-0.0796
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0470	0.0000	0.0000	0.0000	0.0000
<b>EINT</b>	-0.3414	-0.2943	-0.0644	-0.3091	-0.4848	-0.1324	-0.415	-0.2497	-0.2918
<b>Prb.</b>	0.0000	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>ECOLL</b>	0.9242	1.0097	0.9466	0.8770	0.9881	0.9545	0.8755	0.8686	0.7838
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
<b>PGLOB</b>	1.4419	1.4645	1.4771	1.5358	2.6782	0.8538	0.4963	0.1685	0.0920

	10th	20th	30th	40th	50th	60th	70th	80th	90th
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0190	0.0000	0.0020	0.0000	0.0000
<b>Wald Test</b>	1.5e+06	8.2e+05	80044	3.6e+05	8824.4	38916.3	3725.3	5.5e+06	2.7e+08
<b>Prb.</b>	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

In summary, our empirical findings imply that the overall globalization index as well as its three sub-indices (i.e., the economic globalization index, the social globalization index and the political globalization index) possesses a positive and statistically significant impact on environmental improvement, which is proxied by the rate of e-waste recycling, in 30 European countries utilized in the analyses regardless of which quantile is evaluated. In addition to that, the rest of the independent variables take expected signs in all models and quantiles, and each estimated model is statistically significant.

### Conclusions

This study analyses the effects of globalization on the rate of e-waste recycling by applying the panel quantile regression technique on panel data covering 30 European countries (EU28+2) and a time period between 2008 and 2018. The overall KOF Globalization Index as well as its three sub-indices (the economic globalization index, the social globalization index and the political globalization index) are employed to scrutinize the effects of globalization and its three sub-dimensions on the rate of e-waste recycling by utilizing an extended the STIRPAT (stochastic impacts by regression on population, affluence and technology) model.

The panel quantile regression estimation results suggest that overall globalization and its three sub-dimensions positively and significantly affect 30 European countries' rate of e-waste recycling during the estimation period. Our findings indicate that, after the GDP per capita variable, the globalization variable is the second important factor affecting the rate of e-waste recycling. In line with our findings, promoting all aspects of globalization will improve the rate of e-waste recycling. Thus, enhancing all aspects of globalization can contribute to the circular economy by increasing the rate of e-waste recycling.

Based on these results, we can suggest the following policy implications for policy-makers. First of all, overall, economic, political, and social globalization processes should be enhanced and supported by the EU and European countries. In particular, supporting trade and capital flows and reducing trade taxes, tariffs, barriers, and restrictions on trade and capital flows will boost economic globalization. Increasing embassies, UN peace keeping missions, international NGOs, international treaties and organizations, as well as diversifying treaty partners, will enhance political globalization. Enhancing interpersonal personal relations through supporting international voice traffic, international tourism, exchange of international students, telephone subscriptions, and international airports, boosting information flows through increasing television access, internet access, and press freedom, internet bandwidth, international patents, and high technology exports, and promoting cultural closeness via supporting trade of cultural goods and personal services, international trademarks, gender parity, human capital, and civil liberties will improve social globalization. Furthermore, international organizations, countries, and the private sector in the rest of the world should also be concerned about the role of globalization in the rate of e-waste recycling and circular economy, since all aspects of globalization are positively related to e-waste recycling. From a policy perspective, we also suggest that policy makers and governments in

countries of the world should consider all aspects of globalization while designing the rate of e-waste recycling policies for the circular economy. Therefore, we need to improve our knowledge of how globalization promotes the rate of e-waste recycling for all countries.

The main limitation of this study is data availability. The data on the e-waste recycling rate, the dependent variable of this study, is provided by the statistical office of the European Union (Eurostat). The most recent data for the e-waste recycling rate is from 2018. Expansion of the timeframe of this study with data availability may enhance the results of this study. Moreover, upon more comprehensive data availability, future studies can analyse the effects of globalization on the rate of e-waste recycling for other countries as well apart from European countries. In addition, in future studies, different determinants of the rate of e-waste recycling might be included as control variables and different econometric techniques might also be employed.

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