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Research Article

Does the material recycling rate matter in the effect of the generated waste on environmental pollution? Panel smooth transition regression approach

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ABSTRACT

This study examined the effect of material recycling on the relationship between the waste amount and environmental pollution in EU-15 countries for the 1995–2019 period through panel smooth regression analysis by using the material recycling rate as the threshold variable. Based on the analysis results, the material recycling rate threshold level was estimated as 11.79. In these countries, if the material recycling rate is below the threshold level, the rise in the waste amount will increase environmental pollution. If the material recycling rate is above the threshold value, the rise in the waste amount will still increase environmental pollution, but the pollution increase rate will decrease. With the increase in the waste amount in the long term, environmental pollution can only be reduced by raising the material recycling rate. For the reduction of environmental pollution, which is one of the most prioritized issues in Europe in recent years, policy makers should take measures to increase the material recycling rate by taking the results of this study into consideration and pay attention to the implementation of these measures.

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INTRODUCTION

Urbanization and industrial advances accompanying the rapid increase in the world population directly increase the amount of solid, liquid, and gaseous waste [1–3]. In recent years, this has managed to focus the attention of environmental scientists and policy makers on the waste generated as a result of consumer goods [4, 5]. Waste is considered as any discarded or unwanted material [6–8]. Concerns about the disposal of the generated waste are increasing to include "upstream" environmental problems [6, 9]. This is because these wastes create hazards when released into the environment without recycling, proper treatment, and disposal procedures [2, 10, 11]. These hazards cause environmental problems such as greenhouse gas emissions (GHG), global warming, climate change, groundwater pollution, air pollution, and land degradation [12, 13]. It is said that the production amount of these wastes, which affect the environment in many ways, is increasing (across the world). This will cause a pile of garbage to occur and means that the damage done will increase gradually. Storage, composting, reuse, recycling, recovery and incineration are shown as ways to get rid of these piles [8, 14, 15].

Recycling waste is one of the primary methods of minimizing the damage of produced waste to the environment and the economy [8, 16, 17]. In the recycling process of the wastes produced, waste materials are primarily collected from land-

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fills. Afterward, they are separated according to their types (paper, plastic, glass, metal, etc.), compressed in volume, and transported to the facilities where they will be included in the production chain again [18]. As a result of recycling, less damage is done to the environment, both by recycling waste and by reducing the use of raw materials and energy. When products cannot be recycled or reused, new products must be produced in order to meet people's needs [19, 20]. And this will cause the raw material to be extracted and used. The damage to the environment, both when extracting raw materials and when producing a new product, will be much greater than when recycling products. In addition, while producing a new product, more energy is used than energy spent in the recycling phase [21–23]. Therefore, waste recycling plays a critical role in minimizing environmental damage.

Municipal solid waste (MSW) is the type of waste that has attracted the most attention recently regarding the recycling of solid waste. The production of MSW is said to be 1.2 kg per person per day worldwide, and this will increase to 1.42 kg by 2035. A large part of these wastes comprises "plastics-including rubber, paper and cardboard, glass, textiles, organic-animal and vegetal origin, wood, metals, minerals" which are called material wastes [24]. Therefore, policies should be produced and implemented to increase the material recycling rate.

By creating environmental policies by countries, it is aimed at recycling waste through taxes, incentives, and subsidies and reducing the damage to the environment [25, 26]. In this context, EU countries especially show the importance they attach to recycling with their decisions. The main goal of the decisions is to reduce the amount of waste, as well as to recycle or recover the majority of waste and reduce waste storage. Since the implementation of these decisions started, the amount of recycling has increased. Despite these increases, it is seen that the decrease in both the amount of waste produced, and the amount of waste stored is not at the desired level and even increases in some countries [27, 28]. As a result, it can be said that the damage to the environment cannot be reduced to the desired level. While this is the case in EU, where developed and developing countries take part in the developments to reduce the damage to the environment, it cannot be said that it will be different in the rest of the world. Based on all these, it is of great importance to investigate after which level the recycling rate in the amount of waste produced will reduce the damage to the environment.

Considering the study's contribution to the literature, three different contributions come to the fore. First contribution; The non-linear panel data analysis technique, which is not a frequently used method in this field, is the use of PSTR (Panel Smooth Regression Model) analysis. This model reveals the role of material recycling rate in the non-linear relationship between the amount of waste produced and environmental pollution (EP). Although there are similarities between them, the PSTR analysis developed by González et al. [29], differs from the PTR (Panel Threshold Regression) analysis developed by Hansen [30] in that the regression parameters change gradually, not sharply and abruptly.

Using quadratic models to model the non-linear relationship between the waste amount and ecosystem pollution is the second contribution. There is an important limitation to using this method. Using the square of the waste amount in the relationship between the amount of waste and EP; imposes a limitation that the effect of the amount of waste on EP increases and decreases in a monotonous or symmetrical way depending on the level of the amount of waste. In addition, the negative intervals found in the relationship may differ in absolute effect from the positive ones. Based on this, a regression model that calculates the threshold value is used to reveal how the increase in the amount of waste affects EP.

The third contribution is the inclusion of the EU-15 countries into the analysis. The EU-15 countries are the countries that signed the White Paper titled "An Energy Policy for the EU", which was adopted in 1995 and sets out the general principles and targets for the EU's internal energy market. The EU's energy policy objectives are based on striking a balance between competitiveness, energy supply security, and environmental protection. In this context, one of the main objectives is to reduce EP by reducing carbon dioxide (CO_2) emission levels. As the waste amount increases, EP increases as well. On the other hand, if the wastes are recycled instead of being randomly released to nature, stored, or incinerated, the damage to the environment can be minimized. In this regard, it is important to analyze the role of the material recycling rate in the non-linear relationship between the waste amount and EP in the countries of the White Paper titled "An Energy Policy for the EU."

This study aims to clarify whether the material recycling rate plays a decisive role in the relationship between the waste amount and EP in the EU-15 country group of the White Paper. To this end, in the first section of the study, the possible effects of the material recycling rate on the waste amount-environmental pollution relationship have been addressed. In the following sections, the interaction between the waste amount and EP covering the 1995–2019 period and whether there is a threshold for the material recycling rate in this relationship will be examined. In the last stage, the consistence of the empirical analysis findings with the existing literature will be evaluated.

LITERATURE REVIEW

With the developments such as industrialization, technological developments, urbanization and population growth in the world, the damage to the environment is increasing [26]. One of the most basic ways that increase the damage to the environment is the production of waste. The wastes produced are managed in different ways, such as being released to nature, storage, incineration and recycling. With this, waste management is becoming an increasingly important issue when considering the damage to the environment. It is stated that one of the ways to minimize the damage to the environment through waste management is recycling [31]. Many studies have been carried out in the literature to define, scope, increase and make recycling more efficient.

When the literature is examined, studies dealing with the relationship between waste reduction, recycling and EP from different aspects have been encountered. Classifying these studies by associating them with the environment in economic, socio-political, and technical terms is possible.

In a pioneering study, Leontief [32] mentioned the benefits of cross-industry applications for the analysis of environmental problems such as the release of pollutants into the atmosphere. Duchin [33] extended Leontief's study by considering the disposal and recycling of non-treatable waste the environment is exposed to. Nakamura [34], on the other hand, claims that while increasing recycling efforts contribute to the protection of unprocessed materials, total CO_2 emissions will go up due to the increased need for transportation to waste recycling centers. Along with increasing waste, the inability to manage waste in cities due to information, public participation rate, regulatory, financial, technical and institutional deficiencies creates more environmental problems [35]. In accordance with the principles of solid waste management (SWM), energy, economy, aesthetics and protection, it is the management of activities related to the collection, and proper transportation of solid wastes in an environmentally friendly environment, the separation of harmful wastes from harmless wastes and the disposal of harmful wastes [36]. The main objectives of SWM are to increase economic development by improving the environmental quality in densely populated urban areas and to raise awareness about the hygiene and health problems arising from harmful waste [37]. With the development of logistics operations and production technologies related to waste collection, transportation and recycling, the concern of protecting the environment and resources led many countries to specific applications [38].

In line with global trends, systems focus on sustainable issues with technologies based on 3R[2] [39]. Transitioning from a linear economy to a circular economy is an essential strategy to minimize waste in line with environmental sustainability [40]. While the first definitions of circular economy focused on 3R[1], Potting et al. [41] offered a more comprehensive circular design based on the 9R[2] principles. Recycling for the recovery of pure materials, which saves resources while minimizing EP, is one of the most fundamental approaches of SWM [42]. Recycling and composting minimize the use of resources and waste, ensuring that the value of products is preserved for a long time [43]. Therefore, the literature contains various studies on the advantages of recycling solid waste [18, 44–46]. The recycling system provides advantages such as improving the economy by creating new employment areas and gaining income from trade, as well as having positive effects on human and living health by reducing the EP [38, 42]. The importance attributed to recycling as a sustainable waste management strategy has revealed that the traditional collection and disposal methods have changed and should be improved. This is because recycling has the potential to extend the life of landfills and reduce waste transportation and disposal costs. There is increasing interest in turning waste into valuable resources that provide sustainable benefits, as it offers one of the most helpful solutions for waste management to protect waste both economically and ecologically [47, 48].

Studies dealing with the issue in economic terms show that recycling costs are generally higher than disposal costs. However, when negative and positive externalities are taken into account, it is seen that recycling has become more economically significant and efficient [49]. Brisson [50] proposed a model that equates the marginal costs of landfill disposal with those of recycling to find the optimal amount of recycling. Acuff and Kaffine [51] examined cost-reducing policies to reduce greenhouse gas-generating waste related to product manufacturing from diverse materials. The authors, who suggest that carbon pricing should be made for emission reduction, state that alternative approaches should be determined when these policies are unavailable. In this context, they compared waste reduction and recycling costs to show the benefits of greenhouse gas reduction. Franchetti and Kilaru [12] developed a model to estimate the impact of solid waste disposal and recycling on GHG. The model estimates the potential economic benefits and GHG of increased recycling. Friedrich and Trois [52] focus on the problem of the lack of a consistent framework in reporting and calculations of waste management in developing country cities. They state that the highest emissions are caused by methane gas, which is formed from garbage and landfills and mixed into the air. Jamasb and Nepal [53] stated that generating energy from waste is a renewable resource and investigated the effects of focusing on this on sustainability. They presented socio-economic benefit analyses of the selected waste management scenarios, discussing how recycling and waste-to-energy production are compatible.

As to studies addressing the subject in technical terms, Chen and Lo [54] evaluated MSW treatment scenarios, including landfill, waste-to-energy, and material recycling, to reduce GHG. The authors state that recycling will have a more significant impact on reducing GHG than converting waste into electricity. Batool and Chuadhry [55] summarize, as a result of their study, how the best available technologies (biogas recovery from landfills and use system and energy recovery from waste system in power plants) significantly reduce GHG and how smart urban SWM is. Chen [56] used data normalization to evaluate the environmental performance of waste-to-energy production technology and addressed urban waste and general industrial solid waste in terms of energy recovery and GHG.

When it comes to studies handling the issue in socio-political terms, King and Gutberlet [57] touch upon the socio-economic benefits of reducing GHG through recycling and resource recovery. The authors created a "GHG accounting calculator" that estimates the reduction to see

[1] 3R: reduce, reuse, and recycle.

[2] 9R: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover.

Table 1. Basic information about the variables

Variable	Variable description	Sources	Measure	Measure (used in this study)
Growth oil	GHG emissions from fuel Combustion-oil	International Energy Agency	Million tons of CO_2	Growth
Growth gen	Waste generated	Eurostat	Thousand tons	Growth
MatGen	Recycling-material	Eurostat	Thousand tons	% of waste generated
GDP	Gross domestic product	World Bank	Constant 2015 (billion Us Dollars)	
FDI	Foreign direct investment	World Bank	Net inflows (% of GDP)	
OP	Oil prices	U.S. Energy Information Administration	RBRTE- Europe brent spot price FOB (Dollars per barrel)	

if emissions reductions have occurred. Lee et al. [58] stated that recycling will reduce environmental damage in two ways. The first is reducing the amount of waste, as in other studies. Secondly, they emphasize that carbon emissions in the waste sector will also decrease. They say the government should develop alternative strategies, such as promoting waste-to-energy production. Razzaq et al. [44] examined the impact of recycling on economic growth and environmental quality in the context of the USA. They emphasized that recycling both creates economic value and reduces CO_2 emissions. Corsten et al. [59] argue that recycling in the EU is still effective in reducing CO_2 emissions but differs in quality. They indicate to decision-makers that they should consider the issue of high-quality and low-quality recycling when making policy. Nakamura and Kondo [60] developed a mathematical waste input-output model. They used that model to evaluate the effects of waste disposal and recycling options on garbage consumption, CO_2 emission, and industrial production level. That analysis is concerned with the supply (emission) and demand (recycling) of waste at the macro level, not taking into account regional aspects. It is reported that the existence of regional imbalances is one of the most important problems affecting waste recycling. Aydınbaş and Erdinç [61] revealed that there is a positive and significant relationship between the circular economy and GDP per capita, human capital index, renewable energy consumption and trade openness. In addition, as a result of the study, they stated that recycling, which is the most important part of the circular economy, is of great importance in ensuring economic growth.

This study, on the other hand, reveals the importance of material recycling rate in the relationship between the amount of waste summarized in the literature and EP from a different perspective. As the amount of waste increases, EP also increases. One way to prevent this situation is to ensure the recycling of waste. However, the fact that recycling efforts are not easy and progress slowly reveals the difficulty of the issue. This difficulty has been examined from the literature in terms of technical, economic and socio-political dimensions. Therefore, the answer to the question of "what proportion of recycling should be provided in order to reduce EP" is extremely important.

MODEL AND DATASET

This study examines the nonlinear relationship between EP (Co_2Oil) and the amount of waste generation (WasteGen) in the EU-15 country using the PSTR method in the period 1995–2019[3]. After comprehensive literature review, this study; Utilizing the theoretical framework established by Giovanis [62] and nonlinear panel data analysis, it examines the impact of material recycling rate on the relationship between waste and EP. Equation (1) contains the model;

$$ENV_{i,t}=\beta_0+\beta_1 \ Waste_{\mathrm{i,t}}+\varepsilon_{\mathrm{i,t}} \quad (1)$$

ENV is the EP; *Waste* represents the amount of waste generated; ε represents the error term; t = 1, 2, …, T represents time periods; i = 1, 2, 3…, N represents countries.

The basic information about the variables is given in Table 1. CO_2 emission representing EP was used as the dependent variable, and the total amount of waste generated was the independent variable. The waste recycling rate (MatGen) in the total amount of waste generated was included in the analysis as the threshold variable in this relationship. Additionally, GDP (gross domestic product), FDI (Foreign direct investment), and OP (Oil Prices) was used as control variables. Data on the amount of CO_2 emissions, which represent EP and originate from the combustion of fossil fuels, have been taken from the IEA (International Energy Agency) database. The data on the other two variables, the amount of waste generated and the recycling rate, were obtained from the EU Commission (ec-europa. eu).

Descriptive statistics for these variables are given in Table 2. Accordingly, the average of the variables in 15 countries, respectively; The CO_2 emission is 91.18, the total amount of waste produced is 14,552.07, recycling rate (3576.47) in the amount of waste produced is %24.57, GDP is 952.13, FDI is 6.70 and OP is 57.24.

[3] Data from the 1995–2019 period were included in the evaluation. This is mainly because there are great deficiencies in the data of the years before or after that period (at the time the data for the variables were obtained). While these deficiencies were seen in the years after the determined period in the dependent variable, they were seen before and after in the independent and threshold variables.

Table 2. Descriptive statistics

	CO_2Oil	WasteGen	MatGen	GDP	FDI	OP
Mean	91.18	14,552.07	3576.47	952.13	6.70	57.24
Std. Dev.	86.86	15,194.80	5485.77	983.78	4.78	31.31
Max.	339.12	53,966.00	25435.00	3597.32	234.25	111.63
Min.	6.53	291.00	54.00	42.95	-117.37	12.76
Obs.	348	348	348	348	348	348

Min., Max. and Std. Dev. respectively; minimum value, maximum value and standard deviation.

Table 3. Cross-section dependence

	CO_2Oil	WasteGen	MatGen	GDP	FDI	OP	Model
CD_{BP}	1,381.58***	935.49***	1501.42***	1852.08***	235.66***	2520.0***	998.52***
CD_{LM}	88.09***	57.31***	96.36***	120.56***	9.02***	166.65***	61.66***
CD	87.77***	56.98***	96.03***	120.23***	8.69***	166.32***	–
LM_{adj}	31.80***	17.34***	37.70***	41.00***	6.38***	50.20***	19.99***

CD_{LM}: Pesaran 2004 CD_{Lm} test, CD_{BP}: Breusch and Pagan 1980 test, LM_{adj}: Bias-adjusted CD test and, CD: Pesaran 2004 CD test. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

METHODOLOGY

PSTR analysis was used in the study. Panel threshold regression (PTR), developed by Hansen [30], is known as the first panel data analysis method that analyzes the nonlinear relationship between variables. PTR analysis assumes that the parameter change is abrupt when switching from one regime to another. Here, the regimes are separated according to the determined threshold value. From an economic point of view, changes are not always sudden [63]. This approach divides the countries in the panel into groups according to their material recycling rates in the relationship between the amount of waste and EP. It also estimates different parameters for groups. Therefore, it assumes apparent differences between countries with a low rate of material recycling and those with a high rate. Thus, it is accepted that a country with a low material recycling rate suddenly can turns into a country with a high material recycling rate. However, the change in the material recycling rate of a country takes place over time. In summary, the estimated parameters do not change abruptly but smoothly. Based on this result, it was deemed more appropriate to use the PSTR model, which allows the regression parameters to change gradually, not sharply and abruptly, from one regime to another [29].

In order to examine the role of material recycling rate in the relationship between the amount of waste and EP, the model in the first Equation (1) was taken as a basis. Based on this basis, in Equation (2), a constant PSTR model with two regimes has been constructed.:

$$ENV_{i,t}=\mu_i+\beta_0\ Waste_{i,t}+\beta_1\ Waste_{i,t} * g(q_{i,t};\gamma,\theta)+\varepsilon_{i,t} \quad (2)$$

The $ENV_{i,t}$ specified in the model represents EP (dependent variable), and $Waste_{i,t}$ represents the total amount of waste generated (independent variable). In addition, ε represents standard error, i countries, t time period, $q_{i,t}$ represents the threshold variable (recycling rate), and μ_i represents constant unit effects. The time period t in the equation is from 1 to T, the term i representing the countries is from 1 to N, and the $g(q_{i,t};\gamma,\theta)$ used as the transition function and takes values between 0 and 1.

Table 4. Pesaran and Yamagata (2008) Slope homogeneity test

Slope Homogenity Tests	Δ	p-value
Δ Test	19.733***	0.000
Δ_{adj} Test	21.530***	0.000

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

While performing the PSTR analysis, three stages are followed: testing the linearity, determining the number of regimes, and estimating [29, 64].

EMPIRICAL RESULTS

In this study, in which the nonlinear relationship between EP and the amount of waste for 15 EU countries is evaluated, cross-sectional dependence and unit root tests were performed; the results are presented in Tables 3 and 4, respectively.

As shown in Table 3, it has been determined that there is a cross-sectional dependence between EP and the amount of waste. This result requires applying one of the second-generation unit root tests, which considers the cross-sectional dependency.

As shown in Table 4, the presence of heterogeneity seen in the model. This result, which was realized at the 1% significance level in the Delta and Delta adjusted slope test developed by Pesaran and Yamagata [65], rejects the null hypothesis and takes heterogeneity into account.

Table 5. Pesaran (2007) CADF unit root test results

	Level values intercept-trend		Difference values intercept-trend	
	Statistics	p-values	Statistics	p-values
CO_2Oil	-2.327	0.488	-4.249***	0.000
WasteGen	-2.462	0.277	-3.113***	0.000
MatGen	-1.906	0.958	-3.073***	0.000
GDP	-2.398	0.373	-2.805**	0.022
FDI	-1.913	0.955	-3.896***	0.000
OP	2.610	1.000	1.700***	0.000

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Panel cointegration test results (Structural breaks & cross-section dependence)

Model	Zφ(N)	Zτ(N)
Mean shift	-2.182**	-2.711***
Regime shift	-5.806***	-5.491***

The distributions of the LM-based test statistics $Z\varphi(N$ and $Z\tau(N)$ are normal. Information criteria suggested by Bai and Ng (2004) is used to determine the number of common factors (max is 5). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

In Table 5, one of the second-generation unit root tests, the Pesaran CADF [66] test, was performed. According to the test results, it was determined that the series did not contain unit roots and were stationary at the first difference. Then, the LM-based cointegration test developed by Westerlund and Edgerton [67] was conducted to determine whether there is a long-term relationship between the series. The test results are given in Table 5.

As seen in Table 6, it was concluded that there is a cointegration relationship between the series. From this point of view, it has been determined that there are structural breaks in the cointegration equations of the series, and the results are given in Table 6.

According to the results in Table 7, it is seen that structural breaks generally occurred in 1997, 1998 and 2007. When these years are considered, the ruptures are associated with the Asian financial, Russian economic and global economic crises experienced in these years, respectively. With the determination of the structural break dates, the next step was the PSTR analysis. In the first step of the PTSR analysis, the linearity of the model is tested, and in the second step, it is decided how many threshold variables are in the model. The results of the tests performed are given in Tables 8 and 9, respectively.

The results in Table 8 show that the model is nonlinear and that the PSTR model with at least one nonlinear threshold variable is valid in the model.

According to the results in Table 9, it was determined that there was only one threshold variable in the model. In the last step, the relationship between EP and the amount of waste was estimated with the two-regime PSTR model.

As can be seen in Table 10, the smoothing value was 324.6962. This means that there is no sharp transition in

Table 7. Estimated breaks

Country	Mean shift	Regime shift
Austria	2009	1998
Belgium	2001	2001
Denmark	2013	1999
Finland	2013	2013
France	2000	2000
Germany	2006	2006
Greece	2012	2012
Ireland	2007	2007
Italy	2012	2012
Luxembourg	2008	2008
Netherlands	2008	2008
Portugal	2004	2004
Spain	2006	2006
Sweden	1998	1998
United Kingdom	2008	1998

The break dates are selected by means of the test approach suggested in Westerlund and Edgerton (2008) which follows the strategy of Bai and Perron (1998) to determine the location of structural breaks.

Table 8. Linearity test results

Threshold variables (MatGen)	
H_0 Linear Model H_1 PSTR Model at least one Threshold Variable	
LM	11.137 **
	(0.011)
LM_F	3.638 **
	(0.013)
LR_T	11.317***
	(0.000)

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 9. Non-linearity test results (PSTR model)

Threshold variables (MatGen)	
H_0 r=1 *vs* H_1:r=2	
LM	0.997
	(0.802)
LMF	0.310
	(0.818)
LRT	0.998
	(0.802)

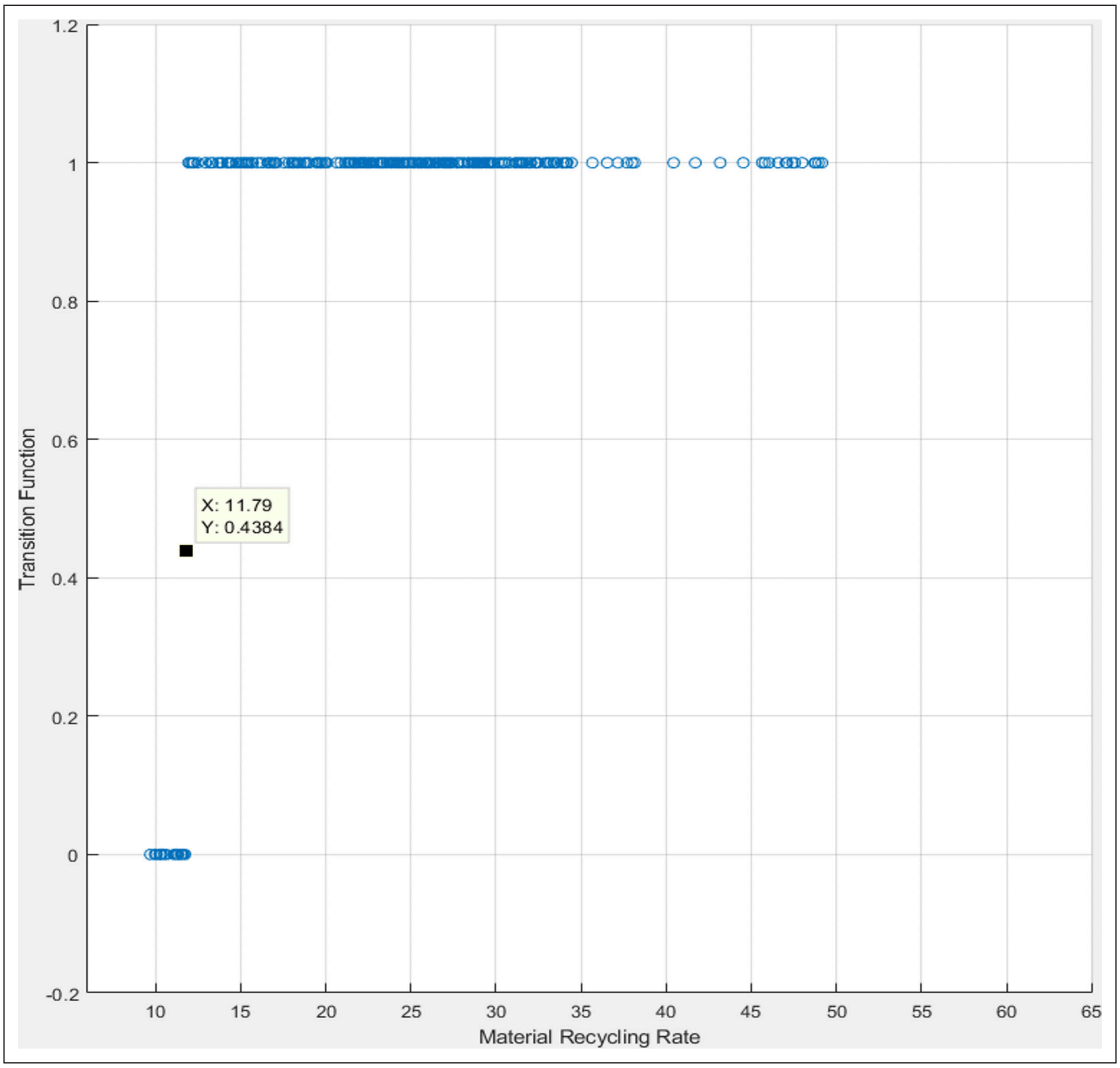

Figure 1. Estimated transition function of the PSTR model.

Table 10. Estimated PSTR model results

Threshold variables (MatGen)	Model
Waste$_1$	0.4941***
	(0.1069)
Waste$_2$	-0.3959**
	(0.1423)
Mean_Dummy$_1$	-3.6338
	(4.2830)
Mean_Dummy$_2$	1.9226
	(4.3020)
Regime_Dummy$_1$	-0.4857
	(0.5622)
Regime_Dummy$_2$	-0.5512
	(0.5541)
Location parameters, θ	11.7912
Slope parameters, γ	324.6962

The values in parentheses are standard deviation values. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

the relationship between the CO_2 emission change rate and the generated waste amount change rate, and the transition from one regime to the other is smooth. This is shown in Figure 1.

As indicated in Table 10, the threshold value for the material recycling rate was found to be 11.79%. The coefficient (β_0) estimated for the generated waste amount change rate in the first regime where the material recycling rate is below the threshold value was found to be statistically significant and positive (0.4941) at the 1% significance level. In the second regime where the material recycling rate is above the threshold value, the coefficient estimated for the generated waste amount change rate formed by the sum of (β_0+β_1) is statistically significant and still positive at the 5% significance level (0.0982). In other words, if the material recycling rate is below 11.79%, the CO_2 emissions amount increases as the generated waste amount increases. On the contrary, when the material recycling rate exceeds the threshold value, the increase in the generated waste amount does not reduce the CO_2 emissions amount but decreases its increase rate. In addition, considering the regime coefficients, it can be said that the effect is stronger in

Table 11. Results of PSTR with additional explanatory variable(s)

Threshold variables (MatGen)	Model A	Model B	Model C	Model D
$Waste_1$	0.4798***	0.4194***	0.2679***	0.2681**
	(0.1210)	(0.1148)	(0.0974)	(0.1038)
$Waste_2$	-0.3820**	-0.3217**	-0.2574**	-0.2622*
	(0.1524)	(0.1501)	(0.1285)	(0.1336)
$Mean\_Dummy_1$	-3.0871	-3.2344	-1.8945	-2.4721
	(4.4983)	(4.4260)	(4.2121)	(5.0590)
$Mean\_Dummy_2$	1.4147	1.6522	1.4778	2.1369
	(4.4888)	(4.4370)	(4.2529)	(5.1172)
$Regime\_Dummy_1$	-0.7685	-0.6925	-0.6359	-0.6100
	(0.6276)	(0.6293)	(0.5401)	(0.6089)
$Regime\_Dummy_2$	0.8238	0.7528	0.7809	0.7116
	(0.6208)	(0.6237)	(0.5313)	(0.6032)
GDP_1	0.0015			0.0018
	(0.0021)			(0.0021)
GDP_2	-0.0005			0.0004
	(0.0006)			(0.0006)
FDI_1		0.1490		0.0951
		(0.1634)		(0.1627)
FDI_2		-0.1660		-0.1100
		(0.1633)		(0.1629)
OP_1			-0.0308	-0.0315
			(0.0232)	(0.0284)
OP_2			-0.0245	-0.0254
			(0.0219)	(0.0281)
Location parameters, θ	11.6819	11.7907	11.7920	11.7915
Slope parameters, γ	8.9027	30.5722	333.1064	336.3252

The values in parentheses are standard deviation values. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. $Waste_1$: Coefficient below the threshold level; $Waste_2$: Coefficient above the threshold level.

the first regime, where the material recycling rate is below the threshold, than in the second regime, where it is above the threshold.

As the amount of recycled material in the generated waste decreases, the wastes are stored instead of being recycled, or they are incinerated to provide heat and energy. The use of waste in heat and energy production causes more GHG than waste recycling [54]. The storage of waste, on the other hand, causes visual pollution as well as increasing GHG [68]. For this reason, as the waste amount increases, EP also increases. On the other hand, as the share of the recycled material amount in the total waste increases, waste landfill and incineration and therefore the GHG resulting from these processes decrease [69]. In addition, not much greenhouse gas emission occurs during reuse or reuse by shredding (just combining different parts without any technical process) in the recycling of wastes. However, in some cases, it may be necessary to subject the materials to various processes. During these processes, harmful gases are released to the environment [70]. However, considering the resources used and the energy consumed during the first production of these materials, this causes less EP [54, 68, 69, 71, 72]. Therefore, although the increase in the waste amount still causes EP if the material recycling rate is above the threshold level, it can be said that it causes less EP than if the material recycling rate is below the threshold level.

In order to check the robustness of the model, control variables were added to the model both one by one and collectively. The results in Table 11 show that the material recycling rate threshold value at each stage is similar and the direction of the coefficient signs remains the same. This shows the robustness of the model. Additionally, when the control variables are examined, it is seen that they are insignificant below the threshold and above the threshold. This means that no comments can be made for the control variables within the scope of this relationship.

The results of the model obtained from the study can be summarized as follows;

a) A non-linear relationship was found between the total amount of CO_2 emissions and the total waste amount generated in 15 EU countries taken as EU-15 in the 1995–2019 period.

b) In this relationship, the threshold level for the material recycling rate was found to be 11.79%. Moreover, a significant and positive relationship was detected between the amount of CO_2 emissions and the waste amount generated when the material recycling rate was below the threshold. On the other hand, a significant and positive relationship was also detected when the material recycling rate was above the threshold, but the effect was lower than the case where the material recycling rate was below the threshold.

CONCLUSION

In the globalizing world, with industrialization and urbanization, resources are consumed unconsciously, and wastes are formed as a result of increased consumption. The problem of waste, which is increasing day by day, negatively affects the environment, like almost every part of the society, and increases EP. Recycling, which is defined as the reprocessing, reproduction, and reuse of previously collected materials, has an important place in today's world. From this point of view, the study examined the role of the material recycling rate in the relationship between EP and the waste amount in 15 EU countries that signed the White Paper titled "An Energy Policy for the EU" in the 1995–2019 period.

The material recycling rate threshold value for the analysis period covered by the study was found to be 11.79%. The effect of the material recycling rate on the environmental pollution-waste amount relationship differed depending on whether it was above or below the calculated threshold value. While the environmental pollution-waste amount relationship was positive and statistically significant in the case that the material recycling rate was below the determined threshold value, it was still positive and statistically significant when the material recycling rate exceeded the determined threshold value. However, although a positive relationship was also detected when the material recycling rate was above the threshold, the effect was lower than the case where the material recycling rate was below the threshold. The findings of the present study on the relationship between the waste amount and EP seem to be consistent with those of Giovanis [62], Lave et al. [71], and Mohareb et al. [69].

The results of this study emphasize that approaches indicating an asymmetrical relationship between the waste amount and EP can only be true when the material recycling rate is above the threshold value. In this context, the findings will be useful for policy makers on the necessity of keeping the material recycling rate above the threshold level in order to ensure low EP with the increasing waste amount. Thus, in the context of economic and environmental targets, it is thought that the target of low EP will not conflict with the target of reducing the waste amount, and the waste recycling rate will contribute to the reduction of EP by creating a suitable environment for the waste amount and the environment in the long term.

When the findings are considered in general, policy makers may implement the following policies for the effect of the waste amount on environmental sustainability in their countries:

- First of all, policy makers should ensure that waste management is established for the waste generated. The waste amount generated is important in reducing EP. However, it is not possible to reduce waste to zero. Therefore, waste management is of vital importance. Within the scope of waste management, the focus should be first on the collection of waste. Collecting waste will only contribute to the environment and sustainability through recycling. Otherwise, it will not be possible to go beyond creating a waste pile.
- Recycling activities may provide a cost disadvantage. The way to reduce this is to achieve efficiency in collection, separation, and recycling. In this way, it will be possible to save energy and resources used compared to the first production.
- After the solid wastes are collected, the majority of them are converted into energy by incineration. Considering that incinerated wastes cause more EP than recycling, policies should be established to reduce the rate of incineration of wastes and increase the recycling rate.
- Not much gas emission occurs during reuse or reuse by shredding (just combining different parts without any technical process) in recycling. However, in some cases, it may be necessary to subject the materials to various processes. During these processes, harmful gases are released to the environment. However, considering the resources used and the energy consumed during the first production of these materials, this may be more advantageous. For these reasons, policy makers paying attention to directing the collected waste to recycling can reduce both the damage to the environment resulting from the storage or incineration of wastes and the damage to the environment and consumption of resources for obtaining raw materials during the first production.

To conclude, in order to reduce EP in EU-15 countries, it should be aimed to increase the rate of material recycling in the waste amount, in addition to the above-mentioned policies.

In addition to all these results, there are various limitations in this study. The first limitation of this study is that it only examines the role of the material recycling rate in the relationship between carbon emissions and the amount of waste produced. Although material recycling includes many wastes, there are also missing some. Second, this relationship is limited only to the available country, year and data. Increasing data availability and quality in the future and choosing different country groups will better test the accuracy of the results. The third limitation is that the material recycling rate is considered as a whole for all sectors. However, in some sectors, a high recycling rate may be more important for the environment than in other sectors. Fourth, a limited number of control variables were used in the study. Increasing number of these variables may help to obtain more robust results. Future researchers can better support the results of our study by taking these limitations into consideration.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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