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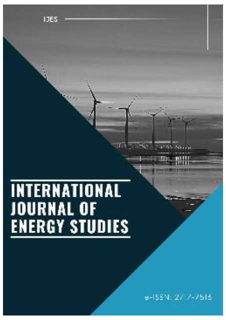

Research Article

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Impacts of the environmental taxes on ecological footprint: Panel threshold Rregression analysis for G7 countries

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Highlights

- Environment-related technology reduce ecological footprint
- Environmental taxes, renewable energy, and green investment reduce ecological footprint
- The impact of green investments on the ecological footprint increases at higher environmental taxes levels
- The environemntal tax is an important policy strategy to improve environmental quality

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ABSTRACT

In this study, the effects of green investment, environmental tax, environmental-related technology, renewable energy consumption, and economic growth on the ecological footprint were examined with annual data for the G7 countries during the period of 2000-2021. In addition, the impact of green investments on the ecological footprint at a threshold of different environmental tax levels was investigated. For this purpose, OLS, Fixed Effect, Random Effect, FGLS, Driscoll-Kraay random effect, and Panel Threshold Regression Analysis were applied in the study. According to the results, increases in environmental-related technology, renewable energy, environmental taxes, and green investment reduce the ecological footprint. Therefore, these variables can be considered as the main drivers of reducing environmental degradation for G7 countries. A 100% increase in environmental taxes reduces the ecological footprint per capita by approximately 5%. Another implication of this study is that the impact of green investments on the ecological footprint increases at higher environmental tax levels. Therefore, the effective use of environmental taxes helps improve environmental quality by encouraging green investments. In this context, market regulatory instruments such as environmental tax is an important policy strategy to improve environmental quality.

Keywords: Green investment, Environmental taxes, Renewable energy, Ecological footprint, G7

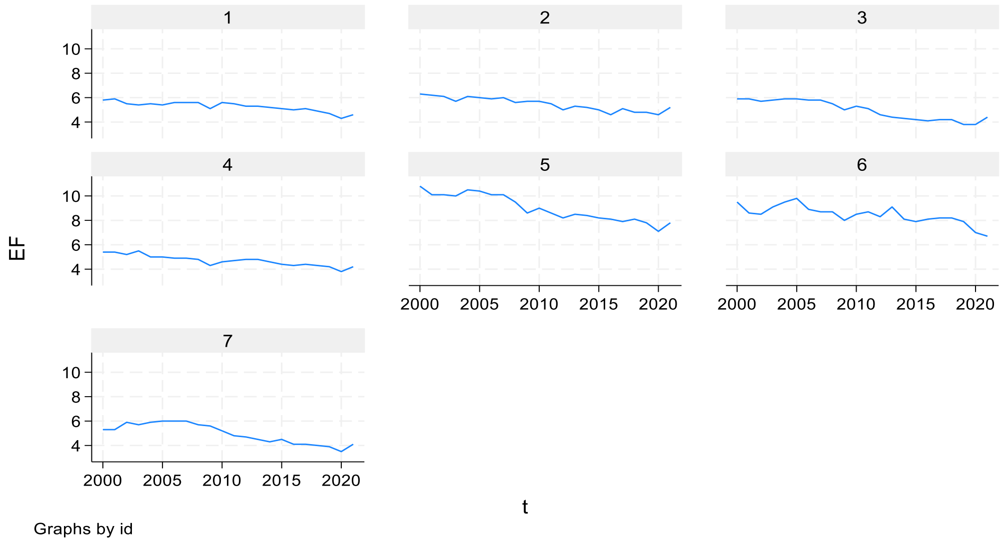
1. INTRODUCTION

Sustainable development aims to achieve the 17 goals in the 2030 Agenda for Sustainable Development, which shapes European Union (EU) policy [1]. In this context, it aims to balance economic growth, social inclusion and environmental protection by 2030. EU member states have the primary responsibility for achieving sustainable development at the national, regional and local levels. This responsibility includes taking steps to integrate the Sustainable Development Goals (SDGs) into national policies and allocate resources to support their achievement [2]. In this context, energy, sustainable development, and the environment are deeply interconnected [3]. Sustainable development depends on transitioning to cleaner energy sources, improving energy efficiency, and integrating environmental protection into energy systems. Achieving this balance is essential for meeting global development goals while minimizing environmental harm.

The ecological footprint (EF) represents an effective indicator of the SDGs [4]. Since CO2 emissions (CO2e) as an indicator of environmental pollution does not provide a sufficient analysis, the number of studies using the EF, which considers water and soil pollution in addition to air pollution, has increased significantly recently. Therefore, EF is used as an environmental predictor in empirical studies investigating the linkage between economic growth, environment, and the other variables. Consequently, much evidence has been put forward that there is a relationship between EF and economic development [5].

The impact of economic growth on environmental degradation is initially negative due to the increase in excessive consumption of natural resources, then, this effect turns positive by accelerating investments in green innovation and technology. This process also includes the transition from non-renewable energy sources to renewable energy. In this context, the transition from energy derived from traditional sources such as fossil and coal to renewable energies is an innovative approach to achieving environmental, economic and social sustainability [6]. Renewable energy is emerging as an alternative to fossil fuels for sustainable development and environmental protection. Rising energy demand, climate change, and environmental concerns have accelerated the development and expansion of renewable energy sources. Resources such as solar, wind, biomass, hydroelectricity, and geothermal power play a significant role in energy production. Innovations in wind power, energy storage, and smart grids are not only reducing costs and increasing efficiency, but are also reshaping economic ecosystems. As these technologies scale, they create self-reinforcing adoption cycles that challenge traditional energy paradigms [7]. Green investments (GI), are one of the most important components for ensuring the sustainability of the low-carbon economy and involve allocating financial assets to sustainable practices and

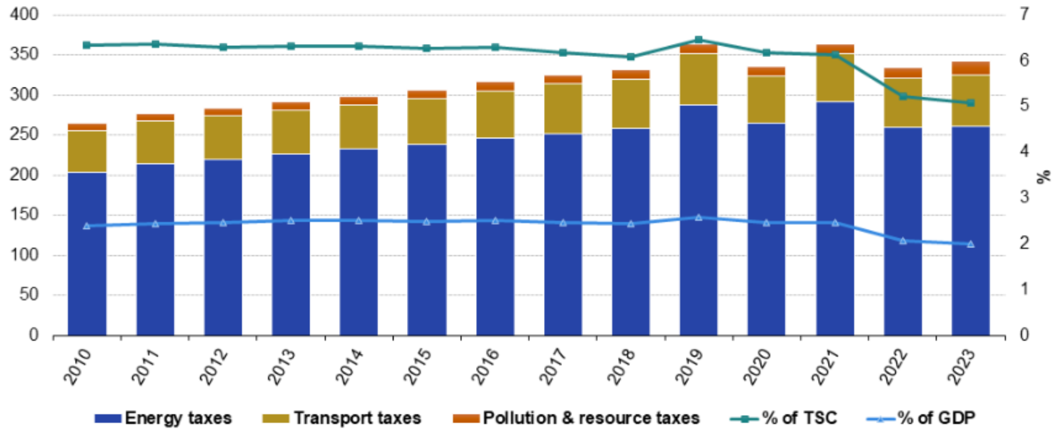
environmentally friendly projects. GI have significant impacts in areas such as combating climate change, creating new jobs, innovation, technology, and economic development. According to analysis by the European Commission, an average of €764 billion was invested annually in the EU to reduce carbon emissions between 2011 and 2020. This corresponds to approximately 5.1% of the EU's GDP (Gross Domestic Product) in 2023. Furthermore, the Commission estimates that an additional €477 billion in GI will be needed each year, equivalent to 3.2% of GDP in 2023 [8].
Environmental technologies (ETC) play a crucial role in solving environmental problems and achieving sustainable development. Technological innovation can help achieve environmental goals more cost-effectively, resulting in welfare gains [9]. These technologies are applied in a wide range of sectors such as energy, agriculture, and tourism to improve environmental quality [10]. Technological innovation is important to advance renewable energy supply and ensure ecological sustainability [11]. These technologies include waste management, pollution control, water and air purification, and renewable energy solutions and incorporate innovative formulations and engineering methods to increase efficiency and sustainability. The global ETC market size was valued at USD 589.20 billion in 2024 and is projected to rise to USD 973.90 billion by 2032 [12].
The G7 countries accounted for approximately 40% of the global economy, 30% of global energy demand, and 25% of global energy-related CO2e in 2020 [13]. In this respect, this countries are playing a leading role in global efforts to transition from fossil fuels to renewable energy. The renewable energy transition in G7 countries is driven by a combination of increased investment, technological innovation, strict environmental regulations, financial sector development, and supportive policy frameworks. At the COP28 climate change conference, world leaders, including all G7 members, agreed to triple global renewable energy capacity by 2030 [14]. In other words, G7 countries aim to source 60% of their energy from renewable sources by 2030. In June 2021, G7 leaders pledged to lead other countries in transitioning to net-zero emissions by 2050. Additionally, G7 countries have committed to phasing out or reducing coal-fired power plants and implementing policies that increase the use of renewable energy, hydrogen and carbon capture technologies [13]. Figure 1 shows the EF for the period 2000-2021 in G7 countries. The downward trend in EF since 2000 has increased slightly due to the impact of the covid-19.



Source: Author. 1. Germany 2. France 3. Italy 4. Japan 5. the United States 6. Canada 7. the United Kingdom

Figure 1. Ecological Footprint in G7 Countries

The increasing importance of environmental issues on the agenda brings with it the need to evaluate the effects of various environmental policy instruments [15]. Policy makers aim to improve environmental quality through many policies. In this context, environmental taxes (ET) are an important policy tool. Environmental policies, especially fiscal policies through taxes, aim to balance economic growth with ecological sustainability [16]. ET are a policy tool designed to improve environmental quality by imposing a price on individuals, companies, or industries that cause environmental pollution. In addition, ET can promote the integration of green finance and environmental investment, governments should accelerate the environmental tax reform process and raise it to a reasonable level to encourage the transformation of companies' environmental investments [17] ET based on [18] are designed to internalize negative externalities by making polluters pay for the social costs of their actions. The primary goal of the Pigou tax system is to minimize environmental degradation rather than eliminate it [19]. ET are classified as energy taxes, transportation taxes, resource taxes and pollution taxes. In 2023, total ET revenue in the EU amounted to €341.5 billion, representing 2% of EU GDP and 5.1% of total EU government revenue from taxes and social contributions (TSC) [16] (see Figure 2). ET have three functions: redistribution, incentive, and fiscal. Redistribution involves dividing the funds obtained and allocating them to environmental funds. The fiscal function ensures the accumulation of funds for the state budget. The incentive function involves the rational and economical management of resources by institutions [20].



Source: [16].

Figure 2. The Structure of Environmental Taxes in the EU

The main purpose of this study measured to impact of the green investment, technological innovation (patents), renewable energy consumption, environmental taxes, and economic growth on the ecological footprint G7 countries from 2000 to 2021. In this context, this study investigated the main drivers for reducing environmental degradation and the impact of green investments on the ecological footprint at a threshold of different environmental tax levels. There are insufficient studies covering G7 countries on REC, ETC, ET, and GI, which are expected to reduce the EF. In addition, the number of studies measuring the impact of ET on environmental quality is quite low. Therefore, this study is expected to contribute to the literature by examining how these variables affect environmental quality in G7 countries.

This research consists of the following sections: The second part includes the literature review. The third part presents research gap in the environmental studies. The fourth part includes the data, model and methodology. The fifth part presents outcomes of the study. The last part includes the conclusion and policy directions.

2. LITERATURE REVIEW

After [21] considered the EF as an important indicator of environmental degradation, comprehensive research have begun linkage between environment, energy, growth and technology. The studies examining the effects of GI, GDP, ET, REC and ETC on EF are presented under five subheadings. Then sixth subheading includes about environmental studies that used panel threshold approach.

2.1. Ecological Footprint and Green Investment

Industries with GI increase financial and ecological efficiency compared to traditional sectors [22]. In this context, many studies have proven that GI reduces EF. In their study applying the Method of Moments Quantile Regression (MMQR) approach for Organisation for Economic Co-Operation and Development (OECD) countries in the period 1990-2019, [22] showed that GI and renewable energy consumption (REC) reduce the EF, but these effects are more pronounced from the middle and upper percentiles. [23] found that GI had a significant negative impact on the EF in 45 BRI countries in covering the period 1995-2020. [24] concluded that GI and production capacities improved environmental quality by reducing the EF in 42 BRI countries for the period 2000-2018. On the other hand, [5] found a significant and positive short and long-term relationship between GI, natural resources, green technology investment, and economic development with the EF in China using the NARDL approach from 2000 to 2018. [25] demonstrated the validity of an inverted U-shaped relationship between green finance and EF in 11 East Asian and Pacific countries between 2000 and 2023. [26] showed that green technology innovation reduced the EF while simultaneously promoting green growth in 17 emerging economies during the period 2003-2021.

Green investments, which have positive impacts on the natural environment, are practices that facilitate the allocation of financial resources to projects or companies that focus on sustainable practices, environmentally friendly technologies and the protection of natural resources. The studies in the literature generally contain findings that green investments increase environmental quality.

2.2. Ecological Footprint and Economic Growth

Some studies have evaluated the effect of economic growth on EF as linear, while others have tested the Environmental Kuznets Curve (EKC) hypothesis. [27] revealed a positive correlation between EF and real income in 27 highest emitting countries. [3] found that economic growth increased the EF in MENA countries from 1990 to 2016. Simlarly, [4] concluded that economic growth increases the EF in Mexico, Indonesia, Nigeria, and Türkiye (MINT) from 1990 to 2018. The EKC hypothesis assumes an inverted U-shaped relationship between economic growth and environmental quality. According to this hypothesis, initially economic growth negatively affects environmental welfare, but later it increases environmental quality. While some studies support the EKC hypothesis, others have stated that the EKC hypothesis is not valid. For example, [28] confirmed the EKC hypothesis, which states that the relationship between economic growth and environmental footprint is inverted U-shaped, in 11 newly industrialized countries for the period 1977-2013. [29] proved that the EKC is confirmed for the G7 countries. Similarly, [30] confirmed the EKC hypothesis in four fossil fuel dependent South Asian countries for the period 1990–2016. [31] used a spatial dynamic panel data model within the EKC framework in EU countries for the period 2000-2017 and showed that REC has a negative impact on CO2e and that the relationship between economic freedom and CO2e is U-shaped. Finally, a significant positive spatial lag coefficient is found for CO2e, indicating that a country's CO2e is positively correlated with its neighbors. On the other hand, [32] found that the EKC hypothesis was more valid in upper-middle and high-income countries than in other countries in their study conducted for 144 countries during the 1988-2008 period. [33] demonstrated that the EKC is not valid for the period 1980-2014 across 24 OECD member countries.

The studies that evaluate the linear impact of economic growth on environmental quality have proven that economic growth is mostly a factor that reduces environmental quality. On the other hand, the studies that investigating the non-linear relationship between economic growth and environmental quality through the EKC hypothesis have reached mixed results. Accordingly, the EKC hypothesis is supported in some country groups, while it is not supported in others. Some studies have demonstrated that the results differ according to the income levels of country groups.

2.3. Ecological Footprint and Environmental Taxes

Some studies have shown that ET are a very useful tool in reducing environmental pollution [1]. However, studies have reached different conclusions regarding the impact of ET on the EF. [15] found that the ratio of revenues from ET to GDP in the EU-15 countries over the period 1995-2016 significantly reduced ecological deficits after exceeding a certain threshold level. [19] found that ET and REC reduced the EF in OECD countries for the period 1994 to 2018. [34] showed that green innovation, REC, and ET significantly improved environmental quality by reducing the EF in Italy during the period 1994-2019. [1] applied new nonlinear percentile-based approaches to the EU-5 countries for the period from 1995/Q1 to 2021/Q4. It was found that energy-related ET only had a decreasing effect in the lower and middle percentiles in Germany and in the lower percentiles in Italy. Transport-related ET had no effect on the EF in any country, while the total ET had a decreasing effect only in Germany. However, [35] showed that ET do not have long-term effects on the EF and CO2e in Türkiye. On the other hand, [36] found that ET reduce the EF after exceeding a certain threshold in China.

Briefly, studies in the literature mostly conclude that ET improves environmental quality. When considered alongside green innovation and renewable energy, there is evidence that ET has a very positive impact. While there are some exceptions, ET is believed to be an important policy tool for improving environmental quality.

2.4. Ecological Footprint and Renewable Energy

The literature highlights the impact of REC on improving environmental quality by reducing environmental pressure [19]. [37] conducted the study using the PMG-ARDL method in 16 EU countries from 1997 to 2014, and concluded that REC improves environmental sustainability. [38] found that both renewable and non-renewable energy use had a positive impact on economic growth in 26 OECD countries between 1996 and 2014. The key difference between the two energy types is that non-renewable energy use increases greenhouse gas emissions, while renewable energy use reduces them. In this context, the use of renewable energy sources is of great importance. [39] analyzed the impact of renewable energy production, globalization, and agricultural activities on the EF and CO2e for the BRIC countries using Fourier cointegration and causality tests for the period 1971-2016. While renewable energy production significantly reduces environmental pollution in Brazil and China, it does not affect environmental pressure in Russia and India. Therefore, these countries need to diversify their current renewable energy production policies to achieve their sustainable development goals. According to [40], natural resource rents, REC, and urban population in BRICS countries during the period 1992-2016 improve environmental quality by reducing the EF. [33] found that increasing REC reduced the EF in 24 OECD member countries for the period 1980-2014. [41] showed that REC reduces environmental degradation in terms of both the ecological and carbon footprints in OECD covering the period 1980-2016. [30] concluded that REC decreased EF in four South Asian countries for the period 1990-2016. [42] found that increasing renewable energy production capacity and technical innovation reduces EF in five Southeast Asian countries during the period 1985-2016. However, some studies have reached different conclusions regarding the impact of REC on EF. For example, [3] conducted that renewable energy does not contribute significantly to environmental quality for MENA countries.

In summary, studies in the literature emphasize that renewable energy improves environmental quality by reducing gas emissions and should be used as a leading policy tool in improving environmental quality. Increasing the use of renewable energy sources is critical to achieving low ecological footprints, improved air quality and sustainability goals. As a result, although the impact of renewable energy use varies sectorally or regionally, the general opinion is that it improves environmental quality.

2.5. Ecological Footprint and Environmental-Related Technology

Technological innovations can both reduce resource demand and increase productivity by enabling more efficient use of natural resources, energy, and land [43]. Although the number of studies investigating the impact of ETC on environmental degradation is limited, it is generally observed that this relationship is negative. [44] found that ETC and REC support sustainable development for 20 OECD countries from 1990 to 2015. [45] confirmed the role of REC and ETC in reducing environmental degradation for BRICS countries during the period 1992-2020. [46] concluded that environmental technological innovation reduced the EF for China during the period 1980-2021. [43] found that developments in ETC in 19 European countries between 1995 and 2020 reduced the EF more in the middle and high percentiles with the MMQR approach. [47] investigated the impact of renewable energy supply, green energy investment, environmental taxes, and economic growth on green technology innovation in six selected Association of Southeast Asian Nations (ASEAN-6) countries over the period 1995-2018. The empirical findings indicate that the effects of green energy and green investment on green technology innovation are positive in the short and long term, but stronger in the long term. Furthermore, economic growth and environmental taxes have positive effects on green technology innovation.

However, there are also studies that conclude that technological development deteriorates environmental quality. [48] found that technological innovation reduced CO2e in G6 countries while increased in MENA and BRICS countries for the period 1990-2016. According to [49] energy-based R&D expenditures increased CO2e in selected OECD countries period of the 2003-2015. [50] found that technological innovation and economic growth reduce environmental quality in India in the long-run for the period from 1980 to 2018. [51] implemented ARDL analysis for Pakistan during the period 1992-2018 and concluded that economic growth, technological innovation, and trade openness increased EF in Pakistan.

In summary, studies evaluating the impact of technological innovations on environmental quality have reached different conclusions. According to some studies, technological innovations improve environmental quality by reducing resource demand and enabling more efficient use of natural resources. The other studies proved that technological innovations have negative impacts on environmental quality because they have not reached the desired level or have not yet reached productivity-generating capacities.

2.6. Panel Threshold Regression Analysis in Environmental Studies

Since the 1990s, numerous studies have been conducted that include linear relationships revealing the relationships between the economy, energy, and the environment. However, panel threshold regression models that include structural breaks and transitional regime changes have begun to be used [52]. [53] conducted panel threshold analysis for 31 developing countries. They found that economic growth has a negative effect on CO2e in low-growth regimes, but a positive effect with a higher marginal effect in high-growth regimes. Therefore, U-shaped relationship is confirmed instead of the EKC hypothesis. [54] investigated the relationship between environmental regulations and CO2e in 30 provinces of China from 2004 to 2015, using energy intensity and foreign direct investment as threshold variables. They found that environmental regulations have a threshold effect on CO2e, and that there are differences between regions. Unlike the western region, environmental regulations in the central region reduce CO2e due to the effects of energy intensity and foreign direct investment.

[55] used the panel threshold method for OECD and non-OECD countries. They found that inverted U-shaped relationship between technological progress and CO2e in OECD countries, and an N-shaped relationship in non-OECD countries. Furthermore, when economic development exceeds a certain threshold, the effect turns from positive to negative. Although technological progress increases CO2e in middle- and low-income countries, its marginal effect diminishes. [56] applied a dynamic panel threshold model for 97 countries between 1995 and 2015. The results showed that when countries exceed a certain renewable energy consumption threshold, renewable energy consumption has a negative and significant impact on carbon emissions. [57] examined the impact of innovation on CO2e using a fixed-effect panel threshold model for 29 selected EU countries between 2000 and 2019. The results show that innovation has a significantly negative impact on CO2 per capita. [58] examined the role of environmental taxes in the impact of renewable energy consumption on economic growth for 27 EU countries. The research findings show that the impact of renewable energy consumption on growth varies depending on the level of environmental taxes implemented. When environmental taxes exceed the threshold, renewable energy consumption has a greater impact on reducing economic growth. Therefore, environmental taxes should be set at optimal levels, and investments should be made in renewable energy sources. [59] investigated the effects of green policies and green fiscal policies on CO2e using panel threshold regression analysis for 16 countries (Germany, Austria, Belgium, Czechia, Spain, Switzerland, Italy, France, Luxembourg, Hungary, Poland, Portugal, Slovakia, Slovenia, Greece, and Turkey). In a regime of high green (environmental) policy stringency, an increase in urban

population and an increase in environmental technology patents reduce CO2e, while an increase in the share of the service sector increases CO2e.

In conclusion, the findings of the panel threshold regression analysis applied within the scope of environmental studies include that policy instruments such as renewable energy, environmental taxes and environmental technologies improve environmental quality after a certain threshold level.

3. RESEARCH GAP

The current study differs from the literature in several aspects. First, there is no study in the literature that examines green investments, renewable energy, environmental technologies, and environmental taxes together in terms of environmental quality for G7 countries. Therefore, including these variables in the model creates a more holistic framework. In this context, the interaction between innovation, environment, growth, investment, energy, and taxes as a market regulator will provide an important perspective. Second, in addition to traditional regression models, a panel threshold regression model is used to reveal the effects of changes in green investments at a specific stage of environmental taxes on environmental quality. Such an analysis has not been conducted for G7 countries or different countries/country groups. Therefore, it is expected that this study will provide a significant contribution to environmental studies.

4. DATA, MODEL AND METHODOLOGY

To estimate the impact of green investment (GI), technological innovation (patents) (ETC), renewable energy consumption (REC), environmental taxes (ET), and economic growth (GDP) on the ecological footprint (EF), panel data of the all countries were selected to cover the period 2000-2021. Table 1 includes definition, measurement scale, and source of the variables. According to this table, EF was obtained from [60]; ETC variable was obtained from the [61]; GDP, REC, and ET variables were obtained from [62], GI variable was obtained from [63].

The present study used the EF as a comprehensive indicator of environmental degradation. The econometric model is given as follows:

$$EF_{it} = \alpha_0 + \alpha_1 ETC_{it} + \alpha_2 GDP_{it} + \alpha_3 REC_{it} + \alpha_4 ET_{it} + \alpha_5 GI_{it} + \gamma_i + \delta_t + \varepsilon_{it} \quad (1)$$

where, i represents the cross sections and t shows the time period covered for empirical analysis. The parameter α_0 represents the intercept term. EF_{it} is dependent variable. $ETC_{it}, GDP_{it}, REC_{it}, ET_{it},$ and GI_{it} are independent variables. α_1, α_2, α_3, α_4, and α_5 slope coefficient, which measures the marginal effect of the independent variables on ef. The term γ_i captures the country specific unobservable effects while δ_t captures the temporal effects. The term ε_{it} is the error term. Logarithm (ln) of all variables except ET and GI are taken. Because the mean values of the ET and GI variables converge to the logarithmic form values of the other variables.

In this study, Ordinary Least Squares (OLS), Fixed Effects (FE), Random Effects (RE), Feasible Generalized Least Squares (FGLS), [64], and Panel Threshold Regression Analysis were applied. For this purpose, firstly the slope heterogeneity of the variables and multicollinearity among the variables were tested. Then, econometric analysis methods were applied and the results were supported with post-estimation tests.

In addition, the panel threshold regression model was applied to investigate the effects of green investments on the ecological footprint of different levels of environmental taxes. In this context, the fixed effect panel threshold model developed by [65] and modified by [66] was used in this study. This method estimates the effect of the threshold variable on the dependent variable, which behaves differently depending on the regime change. In other words, the threshold variable has different coefficients to affect the dependent variable depending on the regime [67]. In this study, [57] was taken as a reference in following the panel threshold regression steps.

This model is as follows:

$$\begin{cases} EF_{it} = \alpha_{0i} + \beta_1^T X_{it} + \varepsilon_{it} x, & q_{it} < \gamma \\ EF_{it} = \alpha_{0i} + \beta_2^T X_{it} + \varepsilon_{it} x, & q_{it} \geq \gamma \end{cases} \quad (2)$$

where, q_{it} is the threshold variable, and γ is the threshold level. Model (2) can be regarded as a special case of the threshold model with either $q_{it} < \gamma$ or $q_{it} \geq \gamma$ for all $i = 1, ...,$ and $t = 1, ..., T$ [57]. In this research $X_{it} = [GDP_{it}, REC_{it}, ET_{it}, GI_{it}]$ and q_{it} is ET_{it}.

If there is more than one regime, a double threshold model as follows:

$$EF_{it} = \alpha_i + \beta_1^T X_{it}(q_{it} < \gamma_1) + \beta_2^T X_{it}(\gamma_1 \leq q_{it} < \gamma_2) + \beta_3^T X_{it}(q_{it} \geq \gamma_2) + \varepsilon_{it} \quad (3)$$

where, γ_1 and γ_2 are the thresholds that divide the equation into three regimes with coefficients β_1, β_2 and β_3 [57].

Table 1. Data Description and Measurement Units

Variables	Definition	Measurement scale	Source
EF	Environmental degradation	Ecological Footprint (per person)	Ecological Footprint Network
ETC	Technological innovation	Environmental-related technology (patents)	OECD
GDP	GDP per capita	constant 2015 US$	World Bank
REC	Renewable energy cons.	% of total final energy consumption	World Bank
ET	Environmental tax	percent of GDP	World Bank
GI	Green investment	Nuclear, renewables and other (quad Btu)	IEA

Table 2 shows the summary statistics of the variables. In this table, the variables with the highest and lowest standard deviations are GI and GDP, respectively. Moreover, based on the JB outcomes, it can be seen that all variables except ET have a nonnormal distribution at a 1% significance level.

Table 2. Summary Statistics

Variable	Mean	SD	Min	Max	JB	JB Prob.
EF	1.7715	0.2780	1.2528	2.3795	11.15	0.0038
ETC	7.5574	1.1029	5.6559	9.2878	14.56	0.0007
GDP	10.5849	0.1758	10.2911	11.0508	10.53	0.0052
REC	2.1724	0.6922	0.3365	3.1739	13.5	0.0012
ET	1.8710	0.7991	0.21	3.6	3.643	0.1618
GI	3.7847	4.4364	0.19	16.195	101.1	0.0000

Table 3 shows that Variance Inflation Factor (VIF) values are less than 10, thus, there is no multicollinearity between the independent variables. Table 4 includes [68] and [69] tests results. Accordingly, the null hypothesis that the panel series are homogeneous was rejected and analyses related to the heterogeneous panel procedure were applied.

Table 3. Results from VIF Analysis

Variable	VIF	1/VIF
GI	2.69	0.372338
GDP	2.56	0.391076
ET	2.20	0.455425
ETC	1.71	0.584245
REC	1.15	0.868329
Mean VIF	2.06	

Table 4. Slope Heterogeneity Test

[68]		[69]	
Delta	5.690 (0.000)	Delta	1.969 (0.049)
adj	6.891 (0.000)	adj	2.384 (0.017)

Note: () shows the p-values.

5. RESULTS AND DISCUSSION

Table 5 presents the OLS, FE, RE, FGLS, and Driscoll-Kraay panel regression results. Firstly, the Hausman test, applied to decide between fixed-effect and random-effect tests, shows that the fixed-effect model is valid. The F test was used to decide between the OLS and fixed-effect tests. Accordingly, the H_0 hypothesis, that unit effects equal zero, was rejected. Therefore, the classical model was rejected and the fixed-effect model was accepted. Accordingly, 75% of the change in the EF is explained by the independent variables. Furthermore, according to this model, increases in ETC, REC, ET, and GI reduce the EF. Among these variables, REC exhibits the best performance in reducing the EF. A 100% increase in REC reduces the EF by 21%. ET are secondly effective in reducing the EF. A 100% increase in ET reduces the EF by 10%. The roles of ETC and GI in reducing the EF are approximately 5% and 2%, respectively.

In addition, FGLS and [64] were conducted as robustness checks. According to the heteroskedasticity test, the error terms have constant variances depending on the values of the independent variables. The Wooldridge test detected first-order autocorrelation in OLS methods. To eliminate this problem, the FGLS estimator, which produces robust results in the presence of autocorrelation, was selected. However, the Breusch-Pagan/Cook-Weisberg test indicates the no presence of heteroskedasticity. According to the Hausman test statistic, the Driscoll-Kraay random effect model is suitable. FGLS and [64] support that ETC, ET, and REC are beneficial for environmental quality.

Table 5. Results of the Panel Regression Analysis

Variable	OLS	FE	RE	FGLS	Driscoll-Kraay
ETC	-0.1623***	-0.0448*	-0.0829***	-0.0104***	-0.0829***
	(0.000)	(0.081)	(0.000)	(0.000)	(0.002)
GDP	-0.1217	-0.0235	-0.0312	0.5002***	-0.0312
	(0.213)	(0.847)	(0.811)	(0.000)	(0.824)
REC	-0.0448***	-0.2129***	-0.1954***	-0.1140***	-0.1954***
	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)
ET	-0.2485***	-0.0972***	-0.1413***	-0.0070***	-0.1413***
	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)

GI	0.0356***	-0.0164**	0.0095	0.0276***	0.0095**
	(0.000)	(0.024)	(0.152)	(0.000)	(0.026)
_cons	4.7133***	3.0653**	3.3810**	-2.4776*	3.3810**
	(0.000)	(0.015)	(0.013)	(0.066)	(0.032)
R2	0.7813	0.7524	0.7189		0.3096
F test//Wald test	105.75***	86.30***	299.82***	151.55***	369.52***
Wooldridge Test	32.876 (0.001)				
Heteroskedasticity	1.38 (0.240)				
Obs.	154	154	154	154	154

Note: i) ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. ii) () shows the p-values. iii) Hausman test statistic: 119.12 (0.000). iv) Driscoll-Kraay Cluster-Robust Hausman test statistic: 0.67 (0.9843).

Table 6 contains the threshold effect test results. This table includes RSS, mean squared error (MSE), F statistic (F-stat), probability value of F statistic (Prob), and critical values at 10%, 5%, and 1% significance levels (Crit10, Crit5, andCrit1, respectively) [66]. The F statistic is significant at 5% with a value of 16.95 and the double model is valid.

Table 6. The Triple Threshold Effect Test Outcomes

Threshold	RSS	MSE	F-stat	Prob	Crit10	Crit5	Crit1
Single	0.5280	0.0040	20.95	0.0500	17.9285	20.8492	32.8594
Double	0.4679	0.0035	16.95	0.0367	13.5747	16.0384	22.4947
Triple	0.4308	0.0033	11.37	0.6833	21.0012	23.9969	33.3383

Table 7 shows the threshold estimators (environmental taxes) and their confidence intervals. Th-1 represents the predictor in single-threshold models, while Th-21 and Th-22 represent two predictors in the double-threshold model. According to double model, the regime change point is 2.4700. Figure 3 shows the threshold confidence interval. The critical value at the 95% confidence level is shown with a dashed line.

Table 7. Threshold Estimators (Environmental Taxes) and Their Confidence Intervals

Model	Threshold	Lower	Upper
Th-1	2.4700	1.6300	2.4800
Th-21	2.4700	1.6200	2.9100
Th-22	3.0700	2.7300	3.0900
Th-3	1.6000	1.3700	1.6200

Table 8 shows the results of the fixed-effects threshold estimation. Accordingly, the impact of GI on the EF increases at higher ET levels. Table 9 shows the elasticity of the EF regarding GI at different ET levels. In other words, as ET increase, GI have an increasing potential to reduce the

EF. Additionally, a 100% increase in ET reduces the EF by approximately 5%. GDP and REC also reduce the EF.

Table 8. The Result of the Fixed-Effect Threshold Estimation

EF	Coefficient	Std.Err.	t	P>t	[95% conf. interval]	
GDP	-0.4060669	0.1177918	-3.45	0.001	-0.6389332	-0.1732007
ET	-0.0465013	0.0245151	-1.90	0.060	-0.094966	0.0019634
REC	-0.1876043	0.013661	-13.73	0.000	-0.2146111	-0.1605974
_cat#c.GI						
0	-0.0142156	0.0067466	-2.11	0.037	-0.0275531	-0.000878
1	-0.1006377	0.0183865	-5.47	0.000	-0.1369866	-0.0642888
2	-0.3581821	0.0622752	-5.75	0.000	-0.481296	-0.2350682
_cons	6.634345	1.234961	5.37	0.000	4.192912	9.075777
sigma_u	0.39464935					
sigma_e	0.05760746					
rho	0.97913694					
F test that all u_i=0: F (6, 141) = 242.55						Prob > F= 0.0000

Table 9. The Result of Estimating the Fixed Effect Environmental Taxes Threshold

ET	$\delta_{EF,GI}$
ET<2.47	-0.01422
2.47<ET<3.07	-0.10064
ET>3.07	-0.35818

Figure 3 shows that LR statistic of two thresholds (using critical value of 7.35 at 95% CI) [70]. The likelihood ratios at 2.47 and 3.07 reach their minimum at the 5% level. The confidence interval confirms that the double-threshold model of ET is correctly identified as a threshold variable.

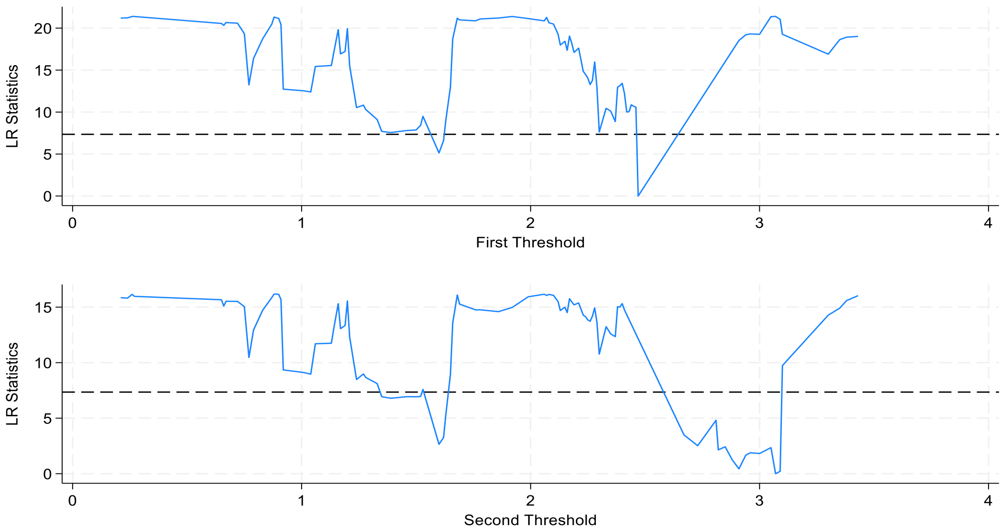


Figure 3. The Threshold Confidence Interval for the First and the Second Threshold

6. CONCLUSIONS AND POLICY SUGGESTIONS

Increasing investment in renewable energy and ETC, stringent environmental regulations, green investment, and technology development are vital to reducing carbon emissions and achieving carbon neutrality in G7 countries. G7 countries lead to other countries in improving environmental quality through setting targets, stringent environmental policies, and technological innovation. In this respect, it is important to evaluate the practices carried out to improve environmental quality in these countries. In addition, understanding the impact of technological innovation, renewable energy, GI and ET on achieving environmental goals is important for policy makers.

Studies in the literature have recently focused on examining the EF as a broad measure of environmental impact. In this context, this paper investigates the impact of the GI, ETC, REC, ET, and GDP on the EF G7 countries from 2000 to 2021. According to the results, ET, REC, ETC, and GI have significant effects on improving environmental quality. These explanations are presented in Graph 4. In addition, the impact of GI on the EF increases at higher ET levels. At levels where the ratio of ET to GDP exceeds 3%, the reducing effect of GI on EF increases to 35%. This means that at high levels of ET a 100% increase in GI reduces EF by 35%. Therefore, the effective use of ET helps improve environmental quality by encouraging GI. When ET are determined at optimum rates, it encourage GI and increase the availability of green technologies. If ET exceed a certain level, the efficiency and support rates of companies' environmental investments may decrease. Therefore, estimating ET thresholds is important to determine the appropriate proportional levels of ET. The effectiveness of ET varies depending on many factors, including development, tax structure, firm size, and institutional arrangements. The combined application of ET with public finance or different targets strengthens the impact on green investments.

These results are consistent with the studies finding that ET reduce EF. [15] for EU-15, [19] for OECD countries, [34] for Italy achieved similar results. The results also support studies that find a negative impact of REC on the EF. [37] for 16 EU countries, [37] for BRICS, [33] for 24 OECD countries, [41] for OECD countries, and [30] for four South Asian countries found similar results. The studies proving the impact of ETC on reducing the EF are as follows: [44] for 20 OECD countries, [45] for BRICS, [43] for 19 European countries, and [46] for China. According to fixed effect regression results, the increase in GI reduces EF which is supported by the studies of [22] for OECD and [23] for 45 BRI economies.

Finally, as interconnected strategies REC, ETC, ET, and GI are clearly compatible with achieving SDGs in G7 countries. The increased use of renewable energy sources consistently leads to lower emissions and improved environmental quality. Investment in green technology and eco-innovation is linked to significant reductions in emissions and EF, supporting long-term sustainability. ET, which are policy instruments designed to reduce environmental damage, aim to support green innovation and improve environmental quality. ET are also important in terms of increasing investment in renewable energy. Transferring revenue from ET to R&D and sustainable technologies further improves environmental quality. The effectiveness of these measures depends on policy design, implementation and the economic context of each country. In this respect, the G7 countries offer a more holistic framework.

This study points to an increase in environmental sustainability associated with increased green investments at higher environmental tax levels. Future studies may examine the relationship between environmental tax thresholds and environmental technologies or renewable energy. Furthermore, the impact of environmental taxes on economic growth and sustainability through the financial sector may be investigated. Different results to be obtained through analyses for developing and strengthening country groups, especially BRICS+, will contribute to the enrichment of the literature. Furthermore, this study does not include results regarding the heterogeneous effects of countries. Therefore, by applying country-specific time series or panel analysis techniques that emphasize heterogeneous effects, the sensitivity of variables to environmental taxes can be determined and policy inferences can be made on a country-specific basis.

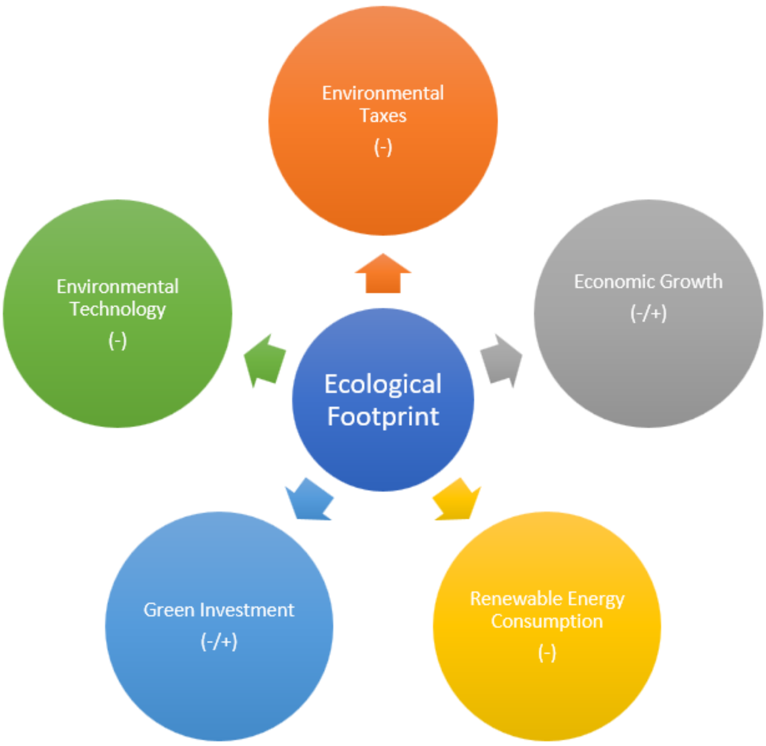


Figure 4. Effect of the Variables on Ecological Footprint

NOMENCLATURE

The abbreviations are given in the text

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Gülbahar Atasever: Writing, Methodology, Econometric Analysis, Review & Editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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