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FISCAL INSTRUMENTS FOR ENVIRONMENTAL SUSTAINABILITY: QUANTILE ANALYSIS OF ENVIRONMENTAL TAXES AND R&D IN G7 ECONOMIES

ÇEVRESEL SÜRDÜRÜLEBİLİRLİK İÇİN MALİ ARAÇLAR: G7 EKONOMİLERİNDE ÇEVRE VERGİLERİ VE AR-GE'NİN KANTİL ANALİZİ

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ABSTRACT

Amid rising environmental challenges, G7 countries face mounting pressure to meet carbon neutrality targets. Fiscal policies, shaping both economic and environmental outcomes, are key to addressing these challenges. This study examines the joint impact of environmental taxes (ET) and public environment-related R&D (PERD) expenditures on the Load Capacity Factor (LCF) in G7 nations from 1994 to 2018. Using Method of Moments Quantile Regression (MMQR), results show that ET consistently improves LCF across all quantiles, supporting the Sustainable Development Goals, particularly SDG-12 and SDG-13, by promoting behavioral change and industrial innovation. PERD, while less impactful at lower levels of sustainability, becomes increasingly effective in higher LCF quantiles—highlighting the importance of targeted R&D investments in renewable energy, sustainable agriculture, and carbon capture, aligned with SDG-7 and SDG-9. The GDP–LCF relationship confirms the Load Capacity Curve (LCC) hypothesis, while green innovation (GI) positively influences sustainability. Robustness checks (FMOLS, DOLS, CCR) confirm findings. The study calls for integrating revenue- and expenditure-based fiscal tools into unified sustainability strategies.

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ÖZ

Artan çevresel sorunlar nedeniyle G7 ülkeleri karbon nötr hedeflerine ulaşma konusunda artan bir baskıyla karşı karşıyadır. Hem ekonomik hem de çevresel sonuçlar üzerinde etkili olan mali politikalar, bu zorlukların ele alınmasında kilit öneme sahiptir. Bu çalışma, 1994-2018 yılları arasında G7 ülkelerinde çevre vergilerinin (ET) ve çevreyle ilgili kamusal Ar-Ge harcamalarının (PERD) Yük Kapasite Faktörü (LCF) üzerindeki etkisini incelemektedir. MMQR yöntemi kullanılarak elde edilen bulgular, ET'nin tüm kantillerde LCF'yi tutarlı bir şekilde iyileştirdiğini, davranış değişikliğini ve endüstriyel yeniliği teşvik ederek SKA-12 ve SKA-13'ü desteklediğini göstermektedir. PERD, düşük LCF düzeylerinde etkisizken, yüksek düzeylerde belirgin etkiler sunmakta ve SKA-7 ile SKA-9 hedefleriyle örtüşmektedir—bu da SKA-7 ve SKA-9 ile uyumlu yenilenebilir enerji, sürdürülebilir tarım ve karbon yakalama alanlarında hedeflenen Ar-Ge yatırımlarının önemini vurgulamaktadır. GSYİH-LCF ilişkisi Yük Kapasitesi Eğrisi (LCC) hipotezini doğrularken, yeşil inovasyon (GI) sürdürülebilirliği olumlu yönde etkilemektedir. Sağlamlık kontrolleri (FMOLS, DOLS, CCR) bulguları doğrulamaktadır. Çalışma, hem çevresel vergilerin hem de kamusal Ar-Ge harcamalarının entegre biçimde tasarlanmasının sürdürülebilirlik politikalarında etkili bir strateji oluşturduğunu ortaya koymaktadır.

Keywords: Environmental sustainability, Environmental taxes, Public environment-related R&D expenditures, Environmental policy, MMQR.

Anahtar Kelimeler: Çevresel sürdürülebilirlik, Çevresel vergiler, Çevreye yönelik kamusal Ar-Ge harcamaları, Çevre politikası, MMQR.

INTRODUCTION

Environmental sustainability has become a central concern in global policy discourse, with G7 countries facing increasing pressure to balance economic growth with ecological preservation. As major contributors to greenhouse gas emissions, these economies also hold the potential to lead global sustainability efforts. International agreements, such as the Kyoto Protocol (1997) and the Paris Agreement (2015), underscore the need for robust and innovative policy measures to mitigate climate change. Yet, the latest UNEP Emissions Gap Report (2023) indicates that current measures fall short of achieving the Paris goals, necessitating a strategic rethinking of existing policies. The United Nations SDGs, adopted in 2015, provide a global framework for addressing these environmental challenges. In particular, SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), SDG 7 (Affordable and Clean Energy), and SDG 9 (Industry, Innovation, and Infrastructure) emphasize sustainable practices, innovation, and climate mitigation—areas directly linked to fiscal policy interventions.

Fiscal policies, through their dual role in shaping economic and environmental outcomes, offer powerful tools to navigate these challenges. Among these, ET and PERD expenditures emerge as pivotal instruments. ET, grounded in the Pigovian tax principle, address negative externalities by aligning private costs with societal impacts (Ekins, 1999; Pearce, 1991). By incentivizing behavioral changes among consumers and producers, these taxes not only reduce unsustainable practices but also generate revenues that can be reinvested into green initiatives (OECD, 2019). In parallel, PERD aligns with Ecological Modernization Theory (Hajer, 1995; Jaffe et al., 2005), addressing market failures such as knowledge externalities and underinvestment in green technologies. By driving technological advancements, PERD complements ET, ensuring that behavioral shifts are supported by sustainable infrastructure and innovation. The interaction between these fiscal tools creates a framework that integrates immediate environmental benefits with long-term ecological balance. While ET drives short-term reductions in ecological footprint by discouraging harmful practices, PERD expenditures facilitate the development of green technologies necessary for sustainable growth.

Despite the growing body of literature on fiscal policies and environmental outcomes, significant gaps remain. Traditional metrics such as CO_2 emissions or EFP fail to consider the absorptive capacity of ecosystems, a critical dimension for sustainability. Recent works emphasize the importance of incorporating both ecological demand and supply perspectives (Adebayo et al., 2023; Dogan & Pata, 2022). Beside, existing studies predominantly use mean-effect methodologies, which overlook the heterogeneous impacts of fiscal policies across varying levels of sustainability. Moreover, most studies focus on either ET or PERD independently, neglecting their potential synergies (Bashir et al., 2020; Jiang et al., 2024; Zhang & Zheng, 2023).

To address these gaps, this study examines the combined effects of ET and PERD on LCF—a novel metric that uniquely integrates ecological demand (e.g., ecological footprint) with supply (bio-capacity)—in G7 countries from 1994 to 2018. This study employs Method of Moments Quantile Regression (MMQR) to capture the varied effects of fiscal instruments across countries with different sustainability levels. Unlike traditional regression models that focus only on average effects, MMQR enables the analysis of heterogeneous impacts across the full distribution of the dependent variable—LCF. This is crucial because the influence of fiscal tools is unlikely to be uniform across G7 nations with differing ecological and economic conditions. Moreover, MMQR is robust to heteroscedasticity and non-normality, both of which are present in the dataset, and provides more policy-relevant insights than mean-based approaches. For robustness, Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) methods validate the findings, while directional relationships are examined using the panel Granger non-causality test by Juodis et al. (2021), which accounts for cross-sectional dependence and heterogeneity.

By bridging theoretical and empirical insights, this research offers a comprehensive understanding of how fiscal tools jointly foster sustainability across varying levels of ecological performance, providing actionable recommendations for integrating revenue- and expenditure-oriented approaches in G7 economies. This integrated strategy is essential for advancing global efforts toward long-term ecological balance and achieving ambitious climate goals.

1. LITERATURE REVIEW

The relationship between fiscal policies and environmental sustainability has been widely studied, with ET and PERD identified as pivotal tools. ET, in particular, has garnered significant attention in recent years. By reducing resource use and addressing issues such as air emissions, water pollution, and wastewater management, ET supports climate goals (Sarpong et al., 2023). Grounded in the Pigovian tax principle, ET ensures polluters bear the financial cost of environmental damage (Ekins, 1999). These taxes incentivize behavioral change by increasing the cost of unsustainable practices, encouraging shifts towards sustainable alternatives (Harring & Jagers, 2013). ET drives innovation by prompting companies to develop cleaner technologies and more efficient processes to reduce their tax liabilities (Ambec et al., 2013; Ekins, 1999; Porter & Linde, 1995). Beyond addressing externalities, ET is both ethically imperative and economically effective, with revenues supporting green initiatives (OECD, 2019) or repairing pollution damage (Doğan et al., 2022; Pearce, 1991).

Empirical studies consistently validate ET's effectiveness in reducing emissions. Hashmi and Alam (2019) highlight significant CO_2 reductions in OECD countries, while Bashir et al. (2020) and Liu et al. (2023) confirm similar outcomes using alternative methodologies. Rafique et al. (2022)urbanization, and growing environmental issues (rising ecological footprint and less biodiversity and Bozatli and Akca (2023) show that ET effectively mitigate the EFP in OECD countries, broadening their relevance beyond carbon emissions. He et al. (2019) demonstrate ET's broader impact on reducing pollutants such as GHG, SO_x, NO_x, and SO_2 across OECD countries and Chinese provinces, with outcomes varying by industrial structure and tax scale. Ghazouani et al. (2021) show that ET, combined with renewable energy, significantly reduce GHG emissions in leading European economies. Esen et al. (2021) explore asymmetries in ET's effectiveness within the EU, emphasizing the need for tailored policies. In emerging markets, Sarpong et al. (2023) and Wolde-Rufael and Mulat-Weldemeskel (2021) confirm that ET support the transition to sustainable practices in emerging countries. Esen and Dündar (2021) find that energy taxes in Türkiye significantly reduce the carbon footprint in the long run, supporting their role as an effective environmental policy tool. Similarly, Sarıgül and Topcu (2021) show that environmental taxes reduce CO_2 emissions over time, although their effectiveness remains modest—highlighting the need for more targeted policy reforms to enhance environmental outcomes (see also Çelikkaya, 2017).

Within G7 countries, Doğan et al. (2022) and Zhang and Zheng (2023) demonstrate that ET reduce carbon emissions while driving cleaner production methods. Xie and Jamaani (2022) highlight ET's role, alongside green innovation (GI), in mitigating carbon emissions. Jahanger et al. (2024) extend this analysis by exploring ET's contribution to reducing the ecological footprint in G7 economies. Kartal (2024) provides a deeper insight by employing the LCF to measure environmental quality. The study finds that the effectiveness of ET varies across different countries, tax types, and levels of LCF, suggesting that a one-size-fits-all approach may not be effective. Despite their promise, ET face challenges, including resistance due to economic competitiveness concerns and potential regressive effects on lower-income populations (Ekins et al., 2011; Wier et al., 2005). Addressing these issues requires thoughtful policy design to balance economic and environmental objectives.

While ET effectively internalize pollution externalities and encourage emissions reductions, they may not suffice to drive the innovation needed for greener technologies (Jaffe et al., 2005). Building on the role of ET as a fiscal policy for sustainability, PERD emerges as a key strategy grounded in Ecological Modernization Theory (EMT). EMT suggests that technological innovation, spurred by strategic government interventions, can harmonize economic growth with environmental protection (Hajer, 1995; Mol & Sonnenfeld, 2000). As Jaffe et al. (2005) highlight, environmental technology faces challenges like knowledge externalities, where innovators cannot fully capture the benefits of their R&D due to its public good nature, leading to underinvestment. Adoption externalities, where the value of a technology increases with widespread use, further slow diffusion. Incomplete information exacerbates these issues; uncertainty in R&D returns and information asymmetry discourage investment in sustainability-critical technologies. These barriers underscore the importance of PERD in addressing innovation gaps and fostering greener technologies.

The few existing studies that focus solely on PERD expenditures—without considering revenue-oriented fiscal policies such as ET— accentuate relevant insights. S. Jiang et al. (2022) explore the impact of PERD and political risk index (PRI) on CCO2e in G7 countries, using advanced econometric techniques. Their findings reveal that PERD significantly reduces CCO2e by promoting green technologies, emphasizing the crucial role of PERD investments in enhancing environmental sustainability. Similarly, Jiang et al. (2024) investigate the impact of environmental and renewable energy-related R&D expenditures on CCO2e in G7 countries, emphasizing their critical role in promoting a sustainable environment. The study finds that increased environmental R&D spending, along with green innovation and renewable energy consumption significantly reduces trade-adjusted carbon emissions, highlighting the importance of a knowledge-based economy in achieving sustainable development goals. Ahmad and Satrovic (2023), in their study on the relationship between fiscal decentralization, financial inclusion, and environmental sustainability, contribute to the discussion by highlighting that environmental innovation, driven by the R&D budget allocated to ecological protection, has an enhancing effect on environmental sustainability, indicating that these investments diffuse beneficial environmental impacts.

While the impact of environmental fiscal policies on sustainability has been widely studied, the specific role of PERD expenditures remains relatively underexplored. Although total government R&D has been examined in the context of environmental outcomes (Adedoyin et al., 2020; Alam et al., 2021; Dogan & Pata, 2022; Fernández Fernández et al., 2018; Özen et al., 2024; Petrović & Lobanov, 2020; Shahzadi et al., 2022), the specific contributions of these public investments, as distinct from other influencing factors, have not been well disaggregated. This limited focus on PERD highlights a critical gap in the literature, suggesting a need for more targeted research to understand how government investments in PERD can complement other fiscal policies to drive sustainable development.

While most studies tend to focus on either ET or PERD in isolation, only a limited number of studies have explored the combined effect of both fiscal tools. This line of inquiry is particularly important, as the combined implementation of revenue-oriented and expenditure-oriented environmental policies can potentially enhance their effectiveness in achieving environmental goals. Safi et al. (2021) and Dahmani (2024) demonstrate that these tools, when used together, enhance environmental outcomes by leveraging their respective strengths—ET drives immediate behavioral change, while PERD fosters long-term innovation. This synergy is particularly significant in G7 economies, where robust fiscal frameworks and advanced innovation ecosystems enhance their combined effectiveness.

The above statements in recent environmental literature suggest that both PERD and ET reduce ecological degradation and contribute to sustainable development. However, significant gaps persist, as most research focuses on ET or PERD in isolation, often neglecting their potential synergy. PERD's role in fostering innovation and supporting long-term environmental goals is particularly underexplored, and its interplay with revenue-oriented policies like ET remains insufficiently examined. This study bridges these gaps by integrating ET and PERD in a unified framework, offering new insights into their combined effects on environmental sustainability in G7 economies. Another significant oversight in the existing literature is the neglect of the environmental supply side—specifically, the ecosystem's capacity to absorb environmental impacts. Traditional metrics, such as CO2 emissions or the EFP, focus primarily on the demand side, failing to account for the absorption capacity of ecosystems.

To address this, the study employs the LCF introduced by Siche et al. (2010), which integrates both the demand (EFP) and supply (bio-capacity) sides (Dogan & Pata, 2022; Pata, 2021), offering a more comprehensive assessment of environmental sustainability. More importantly, most of the studies reviewed focus on mean effects, typically using traditional regression techniques, which only capture the average impact of ET or PERD across all countries or time periods. Such approaches often overlook heterogeneous effects that vary across different levels of environmental outcomes. Using MMQR, this study takes a closer look at how the effects of ET and PERD differ across various levels of the LCF distribution.

2. DATA, MODEL CONSTRUCTION AND METHODOLOGY

2.1. Data and model construction

The research assesses the combined impact of ET and PERD on environmental sustainability in the G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) using panel data from 1994 to 2018. Although extending the dataset to include more recent years would enhance post-pandemic insights, the panel is limited to 1994–2018 due to data availability constraints—particularly for Canada, which lacks environmental tax data beyond 2018. To ensure full cross-country comparability and preserve a balanced panel, the analysis was restricted to this period. The dependent variable, LCF, sourced from the Global Footprint Network, measures environmental sustainability as the ratio of bio-capacity (ecological supply) to the ecological footprint (demand), expressed in global hectares per person, reflecting the balance between resource availability and usage. The key independent variables include ET, expressed as a percentage of total tax revenue, and PERD, measured as a percentage of total government R&D spending, both sourced from the OECD database. To control for economic activity, GDP per capita (constant 2015 US dollars) is included, along with its squared term (GDP^2) to test the LCC hypothesis, suggesting a non-linear growth-sustainability relationship. Green innovation (GI), measured as the percentage of environmental patents, serves as a control variable. All data series have been transformed into their natural logarithms to improve linearity, stabilize variance and mitigate the effects of outliers. Table 1 details the variables, their abbreviations, units, and sources.

Table 1: Description of the variables and sources

Variables	Symbol	Desciption	Source
Load Capacity Factor	LCF	Biocapacity/Ecological Footprint (Global hectares per person)	GFN
Environmental taxes	ET	Environmentally related tax revenue (% of GDP)	OECD
Public environmental R&D	PERD	Government budget allocations for R&D (total R&D)	OECD
GDP per capita	GDP	Per capita (Constant 2015 US dollars)	WDI
Green innovation	GI	Patents on Environmental Technologies (% of technologies)	OECD

Note: GFN=Global Footprint Network https://www.footprintnetwork.org/), OECD=Organization of Economic Coopera tion and Development (https://data-explorer.oecd.org/), WDI=World Development Indicator (https://databank.worldbank.org/source/world-development-indicators).

Table 2 presents the descriptive statistics of the study's variables. The results indicate significant skewness and kurtosis for all variables, deviating from the expected values of 0 and 3, respectively, for a normal distribution. This non-normality is further supported by the Jarque-Bera normality tests, which consistently reject the null hypothesis of normality at the 1% significance level for all variables. Given its robustness to non-normality and heteroscedasticity, the MMQR estimator is particularly well-suited for this analysis, offering reliable parameter estimates under these data conditions.

Table 2: Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max	Skew.	Kurt.	Jarque–Bera	Prob (J-B)
LCF	175	-1.033	0.807	-2.113	0.827	0.943	3.116	26.04	0.000
ET	175	1.694	0.311	1.007	2.226	-0.360	1.978	11.54	0.003
PERD	175	-3.943	0.688	-5.595	-3.021	-0.876	2.524	24.01	0.000
GI	175	2.263	0.298	1.635	2.759	-0.336	1.965	11.10	0.003
GDP	175	10.536	0.175	10.256	11.004	0.699	2.712	14.84	0.000
GDP^2	175	111.029	3.703	105.18	121.093	0.729	2.769	15.88	0.000

The empirical model used in this study is based on the following functional form:

$$LCF_{it} = a + \beta_1 ET_{it} + \beta_2 PERD_{it} + \beta_3 GI_{it} + \beta_4 GDP_{it} + \beta_5 GDP2_{it} + \epsilon_{it} \tag{1}$$

Where α represents the constant term; β_1, β_2, β_3, β_4 and β_5 are the coefficients of the respective variables; t and i indicate the time period and cross-sectional units, respectively; and ϵ_{it} is the error term. Environmental research, while extensively considering CO2 emissions and EFP in environmental evaluations, often overlooks the vital role of ecosystem absorption capacity. Focusing solely on consumption (the demand side) gives an incomplete picture. To address this gap, we use LCF introduced by Siche et al. (2010), offering a comprehensive measure that accounts for both EFP (the demand side) and bio-capacity (the supply side). Pata (2021) was the first to empirically analyze the determinants of LCF, using a linear model to explore the relationship between income and LCF. Building on this foundation, (Dogan and Pata (2022) further advanced the understanding by formally testing the LCC hypothesis. Their seminal study suggests that for the LCC hypothesis to hold, β_4 must be negative, and the coefficient of the squared-term β_5 should be positive. The turning point, where the quality of the ecosystem starts to improve, can be expressed as follows:

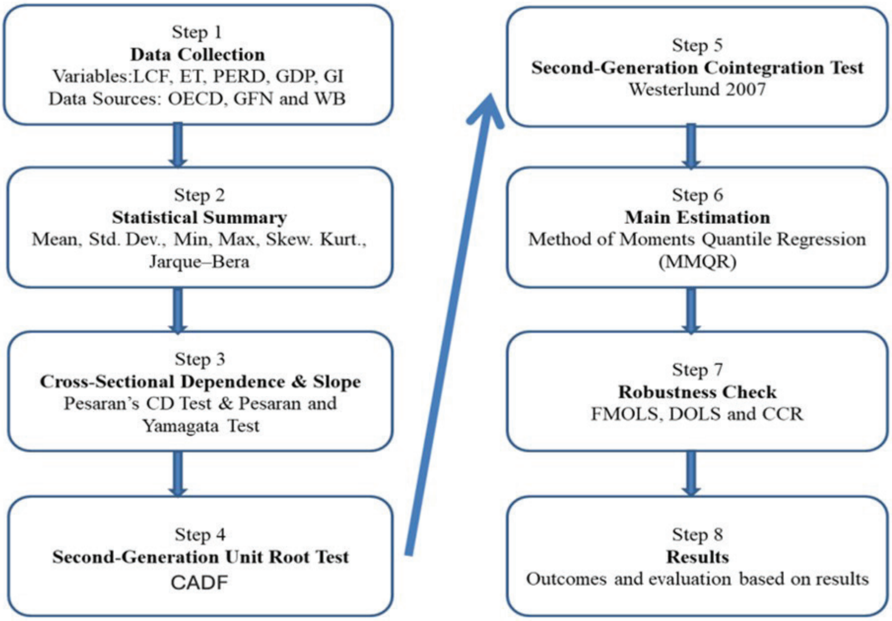
$$GDP\ {*}{=}{-}\ \beta_4/2\beta_5 \qquad (2)$$

In Eq. (2), exp (*GDP**) denotes the monetary threshold at which economic development begins to positively influence environmental conditions. When per capita income surpasses this turning point, further growth is expected to enhance environmental quality (Dogan & Pata, 2022).

2.2. Methodology

The current study seeks to establish the relationship between ET, PERD, GI, GDP, GDP^2 and LCF for G7 countries. To achieve this, a comprehensive econometric methodology is applied in two phases. In the first phase, preliminary tests of the panel data, including cross-section dependency, slope heterogeneity, and unit root tests, are performed to ensure the robustness of the data. In the second phase, the connection between these variables is examined within the context of the LCC hypothesis, using the MMQR approach. The econometric procedure is outlined in Figure 1, which provides an overview of the analysis framework and is further detailed in the subsequent sections.

Figure 1: Econometric procedure



The initial step in the analysis involves testing for cross-sectional dependence and slope heterogeneity in the panel data. Cross-sectional dependence is a critical concern in panel data analysis as it captures the interdependence between countries. The presence of cross-sectional dependence would indicate that shocks affecting one country may also influence others), which, if ignored, can lead to biased estimates (Phillips & Sul, 2007). To detect this, we apply Pesaran's (2004) Cross-Sectional Dependence (CD) test. The Pesaran (2004) CD test is based upon the average pairwise correlation coefficients of the residuals derived from individual regressions in a panel data setup. The test assesses whether the residuals from different cross-sections are correlated. The test statistic is expressed as follows:

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{\mathrm{i}=J}^{N-1}\sum_{J=\mathrm{i}+1}^{N}\hat{p}_{ij}\right) \tag{3}$$

Where N is the number of cross-sectional units, T is time and is the correlation coefficient of the residuals. While the null hypothesis of the test implies that there is no cross-sectional dependence, the alternative hypothesis is that there is cross-sectional dependence. If the CD statistic is significantly different from zero, it shows the presence of cross-sectional dependence in the data.

Another important step in panel data analysis is determining slope heterogeneity. To address this, we apply the slope heterogeneity test developed by Pesaran and Yamagata (2008). This test allows for assessing whether the slope coefficients differ significantly across cross-sections in a panel data model. The test equations are shown as follows:

$$\hat{\Delta}= \sqrt{N}\left(\frac{N^{-1}\tilde{S}-K}{\sqrt{2K}}\right) \tag{4}$$

Where: N is the number of cross-sectional units (countries), K is the number of regressors and presents the modified Swamy (1970) statistic. The adjusted test statistic is given by:

$$\hat{\Delta}_{adj}= \sqrt{N}\left(\frac{2k(T-K-1)}{T-1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S}-2K\right) \tag{5}$$

Where T is the number of time periods. In the Pesaran and Yamagata (2008) delta test, the null hypothesis (H_0) suggests that the slope coefficients are homogeneous across the cross-sections, whereas the alternative hypothesis (H_1) posits that the slope coefficients exhibit heterogeneity.

The next step in the methodology involves testing the stationarity of the data. To account for cross-sectional dependence, this study applies Pesaran's (2007) Cross-sectionally Augmented Dickey-Fuller (CADF) test. The CADF test extends the standard ADF test by including cross-sectional averages, improving reliability in panels with common shocks. The CADF regression is specified as:

$$\Delta Z_{it} = a_i + \beta_i Z_{i,t-1} + \gamma_i \bar{\bar{Z}}_{t-1} + \sum_{j=0}^{p} \theta_{ij} \Delta \bar{\bar{Z}}_{t-j} + \sum_{j=0}^{p} \vartheta_{ij} \Delta Z_{t-j} + \epsilon_{it} \tag{6}$$

Where $\bar{\bar{Z}}_{t-1}$ and $\Delta\bar{\bar{Z}}_{t-j}$ are cross-sectional averages of the levels and first differences, respectively. The null hypothesis H_0:βi=0 indicates the presence of a unit root, while the alternative H_1:βi<0 suggests stationarity. This test is well-suited for our panel of G7 countries, where cross-sectional dependence is likely. By applying this test, we can confidently assess whether the variables of interest are stationary, allowing us to move forward with the econometric modeling process.

After confirming the stationarity of the variables, the next step is to test for the existence of a long-run relationship among the variables. For this purpose, we employ the Westerlund (2007) cointegration test. This method is advantageous since it accounts for cross-sectional dependence and heterogeneity across individual units, making it particularly practical in studies with interdependent countries like the G7. The test is built on error-correction models, with the null hypothesis (H_0) assuming no cointegration and the alternative (H_1) assuming cointegration for at least one unit in the panel, providing both group and panel-based statistics to assess long-run equilibrium relationships.

In the second phase of the analysis, the MMQR, developed by Machado and Silva (2019), is applied to examine the effects of ET and PERD on the LCF across different quantiles. MMQR's key advantage lies in its ability to capture the variation in the effects of explanatory variables across different quantiles, revealing distributional asymmetries that traditional linear methods often overlook. Additionally, MMQR is robust to nonlinearity and non-normality, making it ideal for data that deviate from the assumptions of linear regression models. By incorporating fixed effects, MMQR also accounts for unobserved heterogeneity across countries, thus reducing bias from omitted variables. Furthermore, it addresses the issue of non-crossing quantile estimates, ensuring the validity of the model across the entire distribution of LCF, a feature missing in simple quantile regression. These features make MMQR especially well-suited to the structure of our data—characterized by non-normality and heteroscedasticity, as confirmed by descriptive statistics and diagnostic tests—and to the policy-oriented aim of identifying how fiscal instruments perform under varying environmental conditions.

Following the methodology of Machado and Silva (2019), which has also been employed by Afshan and Yaqoob (2023), Ahmad and Satrovic (2023), Alola et al. (2023), Jahanger et al. (2024) and Xie and Jamaani (2022)the load capacity factor (biocapacity/ecological footprint in studies related to the LCC hypothesis, the estimated model of 'conditional quantiles' $Q_y(\tau|X)$ is specified as follows:

$$Y_{it} = a_i + X'_{it}\beta + (\theta_i + Z'_{it}\gamma)U_{it} \tag{7}$$

Where Y_{it} is the vector of the dependent variable (LCF), X_{it} is the matrix of independent variables variables (ET, PERD, GI, GDP and GDP^2) and (a,β,θ,γ) are the parameters to be estimated where a_i and θ_i show individual fixed effects. Z_{it} represents the k-vector of known differentiable components of X'_{it} with element where $Z_l= Z_l(X_{it})$, l=1,2,3...k and $P(\theta_i+Z'_{it}>0)=1$. U_{it} is stochastic error term which is unrelated to X_{it} and it is normalized to account for moment conditions as follows:

$$E(U_{it}) = 0\,, E(|U_{it}|) = 1 \tag{8}$$

The model's conditional quantile representation is expressed in its final form as follows:

$$Q_y(\tau|X) = \left(a_i + \theta_i q(\tau)\right) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \tag{9}$$

Where $a_i+\theta_i\, q(\tau)$ is the scalar coefficient that represents the distributional effect at quantile (τ). The parameter estimation in MMQR is based on Hansen's (1982) one-step Generalized Method of Moments (GMM) estimator, which ensures robust and efficient estimates. Therefore, this method effectively takes into account potential endogeneity issues and heteroskedasticity, making it particularly suitable for capturing distributional heterogeneity in the panel data.

For robustness check, this study incorporates three alternative estimation techniques: FMOLS developed by Phillips and Hansen (1990), DOLS introduced by Stock and Watson (1993), and CCR proposed by Park (1992). These methodologies are widely used to address endogeneity, serial correlation, and cross-sectional dependence in panel data settings. FMOLS corrects for potential endogeneity and serial correlation by adjusting the covariance matrix of the errors, while DOLS includes leads and lags of the differenced regressors to control for endogeneity. CCR, on the other hand, modifies the traditional OLS approach to accommodate non-stationary time series data by incorporating transformations that provide consistent estimates. By applying these three techniques, we ensure that the results are robust across various estimation methods and are not sensitive to the particularities of any one approach.

In addition, this study employs the panel Granger non-causality test developed by Juodis et al. (2021) to investigate the direction of causality between variables. The test corrects for Nickell bias using the Half-Panel Jackknife (HPJ) method and allows for heterogeneity, cross-sectional heteroskedasticity, and dependence. While the test is designed for panels with larger cross-sectional dimensions—where its $\sqrt{NT}$ convergence rate yields greater statistical power—its application to individual variable pairs, combined with bias correction and bootstrap variance estimation, enables valid inference even in settings with limited units (e.g., N = 7) and moderate time periods (e.g., T = 24), albeit with reduced power (Xiao et al., 2023). In such contexts, it ensures better size control and more reliable inference than alternative methods such as Dumitrescu and Hurlin (2012), under cross-sectional dependence, where the latter tends to exhibit size distortions.

3. RESULTS AND DISCUSSION

This section presents the findings from the empirical analysis of the panel data. It begins with diagnostic tests to validate the robustness and reliability of the model, followed by econometric estimations. The analysis starts with testing for cross-sectional dependence (CSD), a crucial step for ensuring accurate panel data estimations. Table 3 reports the results of the Pesaran (2004) CD test, which strongly rejects the null hypothesis of cross-sectional independence for all variables. Correlation coefficients, ranging from 0.34 to 0.95, further confirm the presence of significant cross-sectional dependence. These findings indicate that shocks in one G7 country may affect others, highlighting the interconnectedness of these economies.

Table 3: CSD test analysis

Variables	CD-test	mean abs (ρ)
LCF	9.551***	0.52
ET	6.506***	0.48
PERD	-2.407**	0.34
GI	21.673***	0.95
GDP	18.131***	0.79
GDP^2	18.110***	0.79

Note: *** and ** shows the significance level at 1% and 5%, respectively.

Table 4 gives the results of the (Pesaran & Yamagata, 2008) slope homogeneity test, indicating a rejection of the null hypothesis of homogeneity, as both the delta and adjusted delta statistics are significant. This implies that the slope coefficients differ across the cross-sections, reflecting heterogeneity in the relationship between the variables across the G7 countries.

Table 4: Slope homogeneity test

Slope homogeneity tests	Stat.	p-value
Delta	6.975	0.000
adj.	8.220	0.000

H_0 for suggests that the slope coefficients are homogeneous

Table 5 presents the results of Pesaran's (2007) CADF unit root tests for LCF, ET, PERD, GI, GDP, GDP^2. All variables in levels have p-values above 0.05 (ranging from 0.063 to 0.940), indicating non-stationarity, while their first differences yield p-values below 0.01 (ranging from 0.000 to 0.008), confirming stationarity. Variable-specific lag lengths (2–4 for levels, 0–2 for first differences) were selected to address serial correlation and yielded consistent results. As all variables are I(1), panel cointegration was tested using Westerlund's (2007) approach, which accounts for both cross-sectional dependence and heterogeneity across units.

Table 5: Unit root test (CADF)

Variable	P-value (Level)	Stationary at Level?	P-value (1st Diff.)	Stationary at 1st Diff.?	Order of Integration
LCF	0.065	No (borderline)	0.008	Yes	I(1)
PERD	0.940	No	0.000	Yes	I(1)
GI	0.063	No (borderline)	0.001	Yes	I(1)
GDP	0.342	No	0.006	Yes	I(1)
GDP^2	0.350	No	0.007	Yes	I(1)

Table 6 presents the results of Westerlund's (2007) bootstrap panel cointegration test, confirming a long-term equilibrium relationship among the variables. The significance of both the group-based (Gt) and panel-based (Pt) statistics, coupled with the robust p-values (indicating that the cointegration relationship is robust to potential heteroscedasticity and autocorrelation issues), strongly supports this conclusion. This suggests that the cointegration relationship is not only present within specific groups of panels but also across the entire panel. Therefore, based on the evidence from Westerlund's test, we can confidently assert the presence of a long-run equilibrium relationship among the variables.

Table 6: Westerlund (2007) bootstrap panel cointegration

Statistics	Value	Z-value	P-value	Robust P-value
Gt	-4.540	-4.382	0.000	0.000
Ga	-9.684	2.749	0.997	0.12
Pt	-11.001	-3.646	0.000	0.000
Pa	-10.428	1.541	0.938	0.040

Table 7 presents the MMQR estimation results, capturing the quantile-specific effects of ET, PERD, GI, and GDP on LCF across its conditional distribution. This approach moves beyond traditional mean-based methods, enabling an in-depth analysis of how fiscal policies impact environmental sustainability at different quantiles of LCF. To enhance robustness, bootstrapped standard errors (1,000 replications) were employed in the MMQR estimation, addressing potential cross-sectional dependence in the data. Quantile estimates are reported at 10-percentile intervals from the 10th to the 90th percentile and labeled Q1 through Q9 accordingly. These trends are visually illustrated in Figure 2, offering a clear depiction of the varying effects across the distribution.

Table 7: MMQR estimation results

Var.	Location	Scale	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
ET	0.321***	-0.004	0.328***	0.326***	0.324***	0.323***	0.321***	0.320***	0.318***	0.316***	0.315***
	(0.06)	(0.35)	(0.07)	(0.63)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.08)	(0.09)
PERD	0.048**	0.021**	0.013	0.025	0.033	0.041*	0.048**	0.056***	0.064***	0.073***	0.082***
	(0.02)	(0.01)	(0.28)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.23)
GI	0.181***	0.014	0.157***	0.165***	0.171***	0.176***	0.180***	0.186***	0.192***	0.198***	0.203***
	(0.02)	(0.01)	(0.29)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.27)
GDP	-22.548***	-4.732*	-14.79*	-17.43**	-19.15***	-20.92***	-22.39***	-24.31***	-26.09***	-28.08***	-29.946***
	(4.88)	(2.72)	(7.77)	(6.76)	(6.06)	(5.47)	(4.99)	(4.62)	(4.32)	(4.32)	(4.73)
GDP^2	1.064***	0.224*	0.697*	0.822**	0.903***	0.987***	1.056***	1.147***	1.232***	1.325***	1.413***
	(0.23)	(0.13)	(0.37)	(0.32)	(0.29)	(0.26)	(0.23)	(0.22)	(0.20)	(0.20)	(0.22)
Cons	118.02***	25.10*	76.87*	90.90**	100.02***	109.40***	117.21***	127.39***	136.85***	147.38***	157.26***
	(25.70)	(14.34)	(40.90)	(35.56)	(31.90)	(28.81)	(26.31)	(24.38)	(22.83)	(22.86)	(25.02)
Obs.	175	175	175	175	175	175	175	175	175	175	175

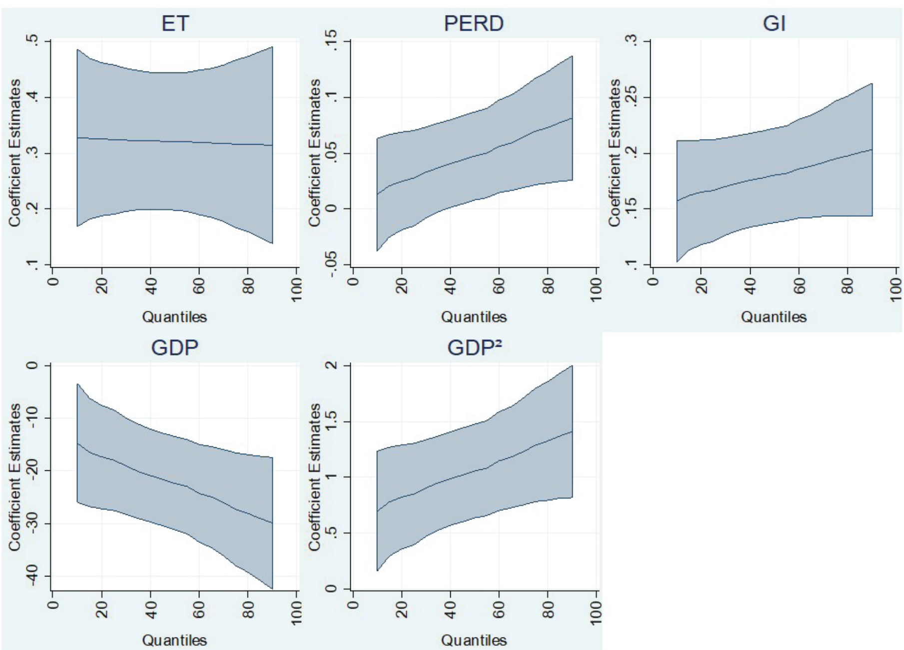
Note: ***, **, * present the significance level at 1%, 5% and 10% respectively. Q1 to Q9 correspond to the 10th to 90th percentiles of the conditional distribution of the LCF, in 10-percentile increments.

MMQR results reveal a consistently positive and significant impact of ET on LCF across all quantiles (0.328 in Q1 to 0.315 in Q9), confirming its effectiveness in promoting environmental sustainability regardless of the LCF level. These findings extend prior studies (Dahmani, 2024; Doğan et al., 2022; Jahanger et al., 2024; Safi et al., 2021, 2021; Xie & Jamaani, 2022; Zhang & Zheng, 2023), which primarily document the role of environmental taxes in reducing emissions and ecological degradation across indicators such as CO_2, GHG, and CCO_2e in G7 economies. The robust and uniform effect observed here supports Pigouvian tax theory, which posits that internalizing environmental externalities through taxation incentivizes polluters to reduce harmful emissions. From a policy standpoint, the stability of ET's impact implies that environmental tax reform can be pursued as a baseline policy instrument in both high- and low-performing countries. To maximize effectiveness and political feasibility, environmental tax policies should be designed with sectoral targeting, aligned with emissions profiles, and integrated into broader fiscal strategies. Revenue recycling mechanisms—such as channeling tax proceeds into clean energy subsidies or reducing labor taxes—can improve fairness and public acceptance (OECD, 2017; Safi et al., 2021). These findings reaffirm ET's central role in achieving SDGs 12 and 13, providing a clear justification for its continued and expanded use.

Surprisingly, the effects of PERD become more pronounced in higher quantiles of the conditional LCF distribution. While the coefficients are statistically insignificant at lower quantiles (Q1–Q3), they begin to increase in magnitude and significance from Q4 onward, rising from 0.041 to 0.082. This suggests that PERD's effectiveness in promoting environmental sustainability amplifies as the ecosystem's condition improves (higher LCF levels). While consistent with prior research (Dahmani, 2024; Jiang et al., 2024; Safi et al., 2021; Shahzadi et al., 2022) highlighting PERD's crucial role, our findings emphasize that this effect is particularly pronounced in more developed environmental contexts. This pattern aligns with Ecological Modernization Theory. However, as Mol and Spaargaren (2000) argue, innovation and clean technologies are effective only when embedded in modernized industrial, institutional, and economic systems—an insight that supports the finding that PERD becomes more impactful at higher levels of environmental performance. Given the inherently long-term nature of R&D impacts, these results call for a sequenced approach to PERD investment—prioritizing high-capacity environments where the adoption and diffusion of green technologies can mature and scale. In lower-performing contexts, investments in capacity-building and institutional development may be a necessary precursor to effective R&D funding, in line with the objectives of SDG-7 and SDG-9.

GI, included as a control variable, consistently shows a positive and significant impact across all quantiles, with coefficients increasing from 0.157 to 0.203 as we move to higher quantiles. These findings emphasize the critical role of technological advancements in promoting environmental sustainability, particularly in countries already on a sustainable path. The results for GDP and GDP² strongly validate the LCC hypothesis, revealing a U-shaped relationship between economic growth and environmental sustainability. GDP exerts a negative and significant impact on LCF across all quantiles, (from -14.79 in Q1 to -29.94 in Q9), suggesting that economic growth initially leads to environmental degradation as observed in Figure 2. However, the positive and significant coefficients for GDP², ranging from 0.697 in Q1 to 1.413 in Q9, suggest that beyond a certain threshold, further economic growth enhances sustainability. This non-linear relationship aligns with the EKC framework and is consistent with studies such as Afshan and Yaqoob (2023) the load capacity factor (biocapacity/ecological footprint and Dogan and Pata (2022).

Figure 2: MMQR parameter plots



To assess the robustness of our findings, we conducted additional analyses using FMOLS, DOLS, and CCR estimators. The results presented in Table 8 generally support our initial MMQR findings, with ET, GI, GDP, and GDP² consistently exhibiting statistically significant impacts on LCF across all estimation methods. While PERD's effect is consistent only in the FMOLS estimator the overall findings reinforce the importance of these factors in influencing environmental sustainability. Notably, the magnitudes of the coefficients from FMOLS, DOLS, and CCR are generally smaller than those obtained from MMQR. This may be attributed to the fact that MMQR, specifically designed for quantile-specific analysis, is more sensitive to capturing the heterogeneous effects of variables across different quantiles of LCF. In contrast, while robust to endogeneity and autocorrelation, FMOLS, DOLS, and CCR may not be as effective in pinpointing the precise magnitude of effects at specific quantiles.

Table 8: Results of FMOLS, DOLS and CCR estimations

Dependent variable: LCF	**FMOLS**	**DOLS**	**CCR**
ET	0.11***	0.07**	0.11***
PERD	0.01**	-0.54	0.00
GI	0.09***	0.36***	0.09***
GDP	-3.01***	-13.29***	-12.68***
GDP²	0.09***	0.59***	0.55***

Note: ***, **, * present the significance level at 1%, 5% and 10% respectively.

To further examine the direction of causality among the variables, we applied the HPJ Granger non-causality test. The results reveal that ET, GI, GDP, and GDP² significantly Granger-cause the LCF, indicating that fiscal and macroeconomic factors play a predictive role in environmental sustainability. In contrast, no causality is found from PERD to LCF, suggesting that its effects may be long-term rather than immediate, as evidenced by its significance in higher LCF quantiles in the MMQR results. Notably, LCF Granger-causes GI, implying that environmental improvements may also stimulate green innovation. However, no reverse causality is detected from LCF to ET, PERD, GDP, or GDP². These results reinforce the robustness of the main quantile regression findings and underscore the importance of fiscal instruments—particularly environmental taxes and innovation policies—in driving ecological balance within the G7 economies.

Table 9: HPJ Granger Non-Causality test results

Causality Flow	Wald stat	p-value	Decision
H_0: ET does not Granger-cause LCF	8.4311***	0.0037	Reject H_0
H_0: PERD does not Granger-cause LCF	0.0528	0.8182	Accept H_0
H_0: GI does not Granger-cause LCF	33.728***	0.0000	Reject H_0
H_0: GDP does not Granger-cause LCF	10.344***	0.0013	Reject H_0
H_0: GDP^2does not Granger-cause LCF	10.804***	0.0010	Reject H_0
H_0: LCF does not Granger-cause ET	0.0776	0.7806	Accept H_0
H_0: LCF does not Granger-cause PERD	0.2099	0.6469	Accept H_0
H_0: LCF does not Granger-cause GI	7.2500***	0.0071	Reject H_0
H_0: LCF does not Granger-cause GDP	0.2057	0.6501	Accept H_0
H_0: LCF does not Granger-cause GDP^2	0.1931	0.6604	Accept H_0

Note: ***, **, * present the significance level at 1%, 5% and 10% respectively.

Overall, the findings emphasize the importance of a dual-track fiscal approach in the G7: one that leverages both revenue-based instruments, such as ET, and expenditure-based measures, particularly PERD. The consistent and significant impact of ET across all quantiles reaffirms its foundational role in driving sustainability, while the increasing effectiveness of PERD at higher LCF levels highlights the importance of institutional readiness. Hence, an integrated policy mix that adapts to varying environmental capacities is vital for sustaining long-term ecological outcomes.

CONCLUSION

In the 21st century, as environmental degradation becomes increasingly apparent, the role of environmental fiscal policies in sustainability has gained prominence, particularly for G7 countries, which are both significant contributors to global challenges and positioned to lead sustainability efforts. This study evaluates the combined effects of ET and PERD revenue and expenditure-oriented policies on achieving carbon neutrality objectives in G7 economies.

Using MMQR and the comprehensive LCF metric, which incorporates bio-capacity and damage, this research captures the asymmetric effects of these policies across different levels of ecological performance. The inclusion of GI as a control variable and GDP to test the LCC hypothesis further enriches the analysis. Robustness checks confirm the reliability of the results. Notably, the study's findings reveal that ET consistently increases LCF across all quantiles, demonstrating its effectiveness in driving sustainability. Therefore, it can be inferred that they are effective tools in promoting behavioral change and stimulating innovation and efficiency in industries aligning with SDG-12 and SDG-13. PERD, while insignificant at lower quantiles, becomes significant and increasingly effective at higher levels of ecological performance, highlighting the need for targeted R&D investments in renewable energy, sustainable agriculture, and carbon capture technologies, aligning with SDG-7 and SDG-9.

In conclusion, this research provides robust evidence of the positive impact of both revenue-oriented and expenditure-oriented fiscal policies on environmental sustainability. These findings emphasize the need for G7 countries to strengthen ET systems and expand PERD budgets, fostering innovation and green sector growth. Additionally, the research confirms the LCC hypothesis, showing that economic development and sustainability can coexist, provided early-stage development is managed to avoid excessive degradation.

This study provides robust insights into the effectiveness of fiscal policies, such as ET and PERD, in promoting environmental sustainability in G7 countries. However, its scope is limited to these advanced economies and macro-level analysis, potentially overlooking dynamics in other regions or microeconomic contexts. Additionally, the dataset's time coverage ends in 2018 due to data constraints in some G7 countries—particularly the absence of post-2018 environmental tax data for Canada—limiting the ability to assess post-pandemic fiscal developments. Future research should incorporate more recent data when available and explore micro-level instruments for targeted policy guidance. It should also extend the analysis to a broader range of countries, including emerging economies like Türkiye, which faces challenges in balancing economic growth with emissions reduction. As Türkiye pursues its 2053 net-zero emissions target, insights from the G7 experience can inform how fiscal tools such as carbon pricing and innovation-driven public investment, might be adapted to its climate policy framework.

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ÇEVRESEL SÜRDÜRÜLEBİLİRLİK İÇİN MALİ ARAÇLAR: G7 EKONOMİLERİNDE ÇEVRE VERGİLERİ VE AR-GE'NİN KANTİL ANALİZİ

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Giderek derinleşen çevresel krizler ve iklim değişikliği tehdidi, küresel ölçekte politika yapıcıları sürdürülebilir kalkınma konusunda daha kararlı adımlar atmaya zorlamaktadır. Küresel sera gazı emisyonlarının önemli bir bölümünden sorumlu olan G7 ülkeleri, karbon nötr hedeflerine ulaşma konusunda hem ulusal hem de uluslararası baskı altındadır. Bu bağlamda, maliye politikaları—ekonomik büyümeyi yönlendirmenin yanı sıra çevresel etkileri şekillendirme gücüne de sahip araçlar olarak—sürdürülebilirliğe yönelik çözüm arayışlarında önemli bir yer tutmaktadır. Bu çalışma, çevresel vergiler (ET) ile çevreye yönelik kamusal Ar-Ge harcamalarının (PERD) birlikte çevresel sürdürülebilirlik üzerindeki etkilerini incelemektedir. Çalışmada sürdürülebilirlik göstergesi olarak hem ekolojik talebi hem de arzı kapsayan ve çevresel baskıyla ekosistemin taşıma kapasitesini oranlayan yenilikçi bir ölçüt olan Yük Kapasitesi Faktörü (LCF) kullanılmıştır.

Çalışma, 1994–2018 dönemine ait G7 ülkelerine ilişkin panel verileri temel alarak, ET ve PERD'nin LCF üzerindeki etkilerini MMQR (Momentlere Dayalı Kantil Regresyon) yöntemiyle analiz etmektedir. MMQR yöntemi, geleneksel ortalama etkili modellerin ötesine geçerek değişkenlerin farklı sürdürülebilirlik düzeylerinde (kantillerde) nasıl farklı etkiler gösterdiğini ortaya koyar. Elde edilen bulgulara göre, çevresel vergiler tüm kantillerde LCF'yi anlamlı ve pozitif yönde etkilemektedir. Bu sonuçlar, ET'nin yalnızca kısa vadeli davranışsal değişiklikleri tetiklemekle kalmayıp, aynı zamanda endüstriyel yeniliği teşvik ederek daha uzun vadeli yapısal dönüşümlere zemin hazırladığını göstermektedir. Böylece, ET'nin SKA-12 (Sorumlu Üretim ve Tüketim) ve SKA-13 (İklim Eylemi) gibi sürdürülebilir kalkınma hedefleriyle uyumlu bir politika aracı olduğu doğrulanmaktadır.

Öte yandan, PERD harcamalarının etkisi daha heterojendir. LCF'nin düşük olduğu kantillerde anlamlı bir etkisi gözlemlenmeyen PERD, çevresel performans arttıkça yani yüksek LCF düzeylerine ulaşıldıkça pozitif ve giderek güçlenen bir etki göstermektedir. Bu durum, kamu Ar-Ge yatırımlarının çevresel sürdürülebilirlik üzerindeki etkisinin zaman içinde veya belirli bir eşiğin

aşılmasından sonra daha belirgin hale geldiğini ortaya koymaktadır. PERD'nin bu etkisi, SKA-7 (Temiz ve Erişilebilir Enerji) ile SKA-9 (Sanayi, Yenilikçilik ve Altyapı) hedefleriyle doğrudan örtüşmektedir. Yenilenebilir enerji, sürdürülebilir tarım ve karbon yakalama teknolojileri gibi alanlarda yapılan kamu Ar-Ge yatırımları, sürdürülebilirliğe geçiş sürecinde olan gelişmiş ekonomiler için stratejik önem taşımaktadır.

Çalışmada kontrol değişkeni olarak yer verilen yeşil inovasyon (GI) tüm kantillerde LCF üzerinde pozitif ve anlamlı bir etkiye sahiptir. Bu bulgu, teknolojik ilerlemenin çevresel sürdürülebilirliğe katkısını doğrulamakta ve yenilikçiliğin çevresel politikaların başarısında kritik bir rol oynadığını göstermektedir. Ayrıca, kişi başına düşen gelir (GDP) ile LCF arasındaki ilişkinin U şeklinde olması, Yük Kapasitesi Eğrisi (LCC) hipotezini desteklemektedir. Başlangıç aşamasındaki ekonomik büyümenin çevresel tahribata yol açtığı, ancak belirli bir gelir eşiği aşıldıktan sonra büyümenin sürdürülebilirliği artırdığı sonucuna ulaşılmıştır. Bu, erken kalkınma süreçlerinin dikkatle yönetilmesi ve çevresel mali araçlarla desteklenmesi gerektiğine işaret etmektedir.

Elde edilen bulgular FMOLS, DOLS ve CCR gibi farklı regresyon teknikleriyle test edilmiş ve sonuçların sağlamlığı doğrulanmıştır. Ayrıca Dumitrescu-Hurlin panel nedensellik testi ile yapılan analizlerde, çevresel vergiler ve yeşil inovasyon ile LCF arasında çift yönlü, PERD'den LCF'ye ise tek yönlü nedensel ilişkiler saptanmıştır. Bu bulgular, gelir yönlü ve harcama yönlü mali araçların birbirini tamamladığını ve birlikte kullanıldığında çevresel sürdürülebilirliğe güçlü katkılar sunduğunu göstermektedir.

Sonuç olarak, bu çalışma G7 ülkelerinde hem çevresel vergilerin (gelir yönlü araçlar) hem de kamusal Ar-Ge harcamalarının (harcama yönlü araçlar) birlikte ve bütüncül biçimde uygulanmasının çevresel sürdürülebilirliği artırmada etkili olduğunu ortaya koymaktadır. Politika yapıcılara, bu iki aracı entegre şekilde kullanarak hem kısa vadeli çevresel iyileştirme hem de uzun vadeli yapısal dönüşüm sağlamaları önerilmektedir. Ayrıca, ekonomik kalkınmanın sürdürülebilirlikle çelişmek zorunda olmadığı, aksine doğru tasarlanmış mali politikalarla bu ikisinin bir arada var olabileceği vurgulanmaktadır.