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# How do transportation-based environmental taxation and globalization contribute to ecological sustainability?

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## ABSTRACT

Environmental taxation strategies are recognized as powerful instruments for enhancing environmental quality through emissions reduction globally; however, the ecological effects of green taxes in the transportation sector (ETT) have been largely overlooked. To fill this literature void, we undertake a novel attempt to evaluate the effectiveness of ETT and globalization in attaining ecological sustainability in the presence of energy intensity and real GDP per capita. We employ second-generation Westerlund cointegration, pooled mean group autoregressive distributed lag and fully modified ordinary least squares econometric strategies on data from the Group of Seven (G7) countries from 1994 through 2016. We found long-term stability among the under-analysis variables. Notably, we revealed that while ETT shows a neutral effect in the short run, it promotes ecological sustainability in the long run. Likewise, increased globalization is also uncovered to foster ecological sustainability from the long-term perspective, though its neutral impact existed in the short term. In addition, energy intensity is found to increase ecological footprint consumption (EFCO); nevertheless, the phenomenon of the Environmental Kuznets Curve is valid for the G7 countries, suggesting a long-term ecological recovery in response to higher economic growth. Concerning causality directions, all variables established a bidirectional relationship with EFCO except for globalization, displaying a unidirectional link stemming from globalization to EFCO. From the normative policy perspective, ETT fiscal policy toolbox can prove a breakthrough instrument in mitigating environmental emissions, contributing to ecological quality. Also, in the face of enhanced globalization, exchanging green investment endeavors and trade in green and environmentally friendly products can achieve the ecological sustainability agenda of sustainable development.

## 1. Introduction

According to the United Nations, the main issue of our generation is climate change, and humankind is at a critical crossroads (UN, 2021). Enormous hazards from human activities are predicted to arise without drastic improvements in climate mitigation tactics (Ahmad et al., 2022; Bhujabal et al., 2021; Chandio et al., 2022). For economic development, social bonding, and sustainable environments, a country's power provision must be accessible and used efficiently (Dash et al., 2022; Khan et al., 2021). Warranting the availability of sustainable and green power has become a top issue within the global policymaking framework due to the serious consequences of an overreliance on fossil fuels, leading to

the production of greenhouse gas emissions (GHGEs) and an unavoidable threat of depleting natural resources (Intergovernmental Panel on Climate Change, 2022). In this context, a number of countries have placed particular emphasis on renewable power production and low-carbon transitioning (Ahmad and Satrović, 2023; Damrah et al., 2022b; Jabeen et al., 2021). The development of practical low-carbon transformation methods has been greatly aided by a variety of economic incentives and long-run energy agenda, particularly among the United States and European Union members (EU) (Haldar and Sethi, 2022; Satrović et al., 2022; Verbić et al., 2021). The EU nations took the lead in the world in 2019 while pledging to have net-zero GHGEs well before 2050 (OECD, 2021). Keeping this in view, the "Fit for 55 policy"

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agenda was issued by EU governments in 2021. To realize such a breakthrough transformation, different mitigation tools, such as environmental taxation and technological advancements, have been introduced to cap the environmental degradation process (Chen et al., 2020; Tchorzewska et al., 2022; Wu et al., 2020a). This study delves into the environmental taxation<sup>1</sup> instrument of fiscal authorities employed to protect the *public good*<sup>2</sup> (i.e., ecological sustainability) and avoid the *public bad* (i.e., ecological degradation).

Environmental taxation in the transportation sector (ETT) is crucial from the standpoint of the supply or conservation of public goods on account of several factors. Place and time are crucial aspects of this approach. For public goods like localized air quality, authorities might choose to implement city toll bands or other tools to enhance ETT and distinguish fuel consumption aversion by place, time, seasonality, and probably as per the air quality index (Hussain et al., 2022). From a different perspective, mitigation and technologies might be crucial factors (Balsalobre-Lorente et al., 2018). In this context, authorities might seek greener automobiles instead of just ETT to improve air quality. On top of that, ETT is used since it inhibits the magnitude of transport activities and encourages fuel-efficient actions, frequently known to achieve some degree of ecological objectives globally (Mathiesen et al., 2011).

The cruciality of ETT might also be linked to the role of globalization — enhanced global interconnectivity attributable to the exchange of commodities and services, technologies, financial resources, data, culture, and individuals across international borders — in ecological sustainability. Enhanced globalization would mean amplified mobility of tradable products, resources, and individuals, leading to increased transportation activities and deteriorated ecological quality (Satrovic and Adedoyin, 2022). On the one hand, international trade may increase both production- and consumption-based environmental pollution (Yang et al., 2021). However, trade in environmentally sustainable products may improve ecological quality (Can et al., 2021). Moreover, foreign investments may deteriorate the environmental quality of host nations, given the lax ecological regulations in place (Doytch, 2020; Mohanty and Sethi, 2022). In contrast, under strict ecological regulations such as environmental taxation, foreign enterprises would contribute to the ecological quality of the host countries via technological transfer (Liu et al., 2021). Besides, globalization may involve exchanging management practices to improve the service quality of the host nations and add to labor productivity (Pascali, 2017). Herein, in addition to ETT, globalization might extend distinguished contributions to sustainable environments.

The existing body of knowledge sheds light on the role of environmental taxation and globalization from heterogeneous perspectives to provide diverse conclusions. We divide the previous literature into the following debates:

### 1.1. Environmental taxation in transport and ecological sustainability

According to the *first debate*, while no research has been noticed to consider the impact of ETT on ecological quality, some studies analyzed

<sup>1</sup> Environmental taxes are imposed on activities that are detrimental to the earth's well-being. They are vital to preventing climate disruption and are built on a straightforward rule: people who produce environmental emissions should be charged for their actions.

<sup>2</sup> “Public good” is something having the following two properties: (i) non-rivalrous — the level of satisfaction that a person derives from consuming something (for instance, improved ecological quality) is not lessened when other people derive the same level of satisfaction from it. (ii) Non-excludable — something which is difficult to exclude or prohibit people from consuming or charging them for its use. Whereas, the public bad is the identical conception with the opposite nature (for example, ecological degradation, environmental emissions, etc.) (Samuelson, 1954).

the contributions of overall environmental taxation on various environmental indicators. For instance, Hussain et al. (2022) employed a cross-section adjusted ARDL (CARDL) modeling setup to examine the role of environmental taxation and energy consumption on transport emissions in the OECD region during 2000–2020. They found that while the transportation industry boosted carbon emissions, environmental taxation mitigated those emissions. Wu et al. (2020b) used the generalized method of moments (GMM) strategy to China's provincial data over the 2006–2015 period to investigate and reveal that environmental laws significantly mitigated carbon emissions. Esen et al. (2021) used a panel smooth regression technique (PSRT) on data from 15 European Union (EU) countries from 1995 through 2016 to analyze the influence of environment-related taxation on environmental sustainability. They figured out an ecological quality improvement driven by environmental taxation. Utilizing the method of moments quantile regression (MMQREG) approach to data from European countries from 1995 through 2020, Alola et al. (2023) inspected the benefits of environmental taxation to ecological quality. The authors concluded that environmental taxes proved helpful for the four European countries under analysis in supporting their ecological sustainability objectives. Depren et al. (2023) analyzed the quarterly data from Nordic countries from 1994 through 2020 by employing a panel quantile regression (PQREG) to scrutinize the influence of environmental taxation on carbon emissions. The authors observed mixed effects of environmental taxation on those emissions. Considering the sample of EU nations during 1995–2019, Dogan et al. (2023) investigated the influence of environmental taxation on renewable energy utilization. They found an adverse effect of the former on the latter. Within a computational general equilibrium framework (CGEF), Chen et al. (2022) investigated and found that environmental taxes improved the air quality of 30 Chinese provinces and observed significant differences across multiple regions. Rafique et al. (2022) applied the panel ARDL approach to data from 29 OECD member states from 1996 through 2016 and unveiled a negative contribution of environmental taxation on ecological footprint consumption (EFCO). Analyzing the data of mining and manufacturing companies over the 2008–2014 period, Tchorzewska et al. (2022) empirically spotlighted that the higher level of environmental tax companies invested more in green technological advancement as compared to those facing lower taxes. Sun et al. (2020) applied the CGEF to data from 11 sectors of the Chinese economy in 2015 and found that environmental taxation increased the exportation of EFCO while reducing the net importation of the same.

### 1.2. Globalization and ecological sustainability

The *second debate* considered the globalization—ecological quality nexus to yield heterogeneous outcomes depending on the selection of methodology and sampled data. For instance, studying the panel of 27 OECD economies from 1970 to 2017, Yang et al. (2021) investigated the contributions of globalization and the aging phenomenon to EFCO, revealing that globalization improved the quality of ecological systems of the region. In their study, Ahmad et al. (2021b) analyzed the role of financial globalization, economic progress, and urbanization on the EFCO of the Group of Seven (G7) nations from 1980 through 2016. The authors discovered that financial globalization mitigated environmental pollution. As a contrarian, Langnel and Amegavi (2020) examined the relationship among energy use, globalization, and EFCO by using the ARDL technique on data from Ghana over the 1971–2016 period. The authors concluded with the ecological adversity caused by globalization during the sampled period. Damrah et al. (2022a) applied the MMQREG technique to data from the top nine oil-producing nations during 1999–2018 to assess and uncover the environmentally favorable indirect effects of globalization. Ortiz et al. (2022) considered data from 101 global economies from 1995 through 2015 to apply the Spatial Durbin Model (SDM). They examined and spotlighted the environmental improvement effects of globalization for the sampled countries. A study

by Alvarado et al. (2022) empirically tested the influence of globalization and urbanization on the ecological quality of 95 global economies from 1995 through 2018 by utilizing an augmented mean group (AMG) and dynamic common correlated model (DCCM). They revealed an insignificant but ecological degradation reduction effect of globalization. Similarly, Deng et al. (2022) used the panel threshold modeling on 107 global countries' data to analyze and find the environmental pollution enhancement effects of social globalization over the 1980–2018 period. Employing a Fourier ARDL approach, Pata (2021) inspected and found a positive association between globalization and ecological quality in the case of BRICS (Brazil, Russian Federation, India, China, and South Africa) economies from 1971 through 2016. Ahmed et al. (2021) made use of an asymmetric ARDL approach to the Japanese time series over the 1971–2016 period to analyze the influence of economic globalization and financial development on EFCO. The authors discovered that the rise in both variables deteriorated the ecological quality of Japan. In their work, Jabeen et al. (2023) evaluated the effects of economic opening and financial development on EFCO in the Belt and Road Initiative members and found that both variables degraded the environmental quality of the sampled region. Nevertheless, Ahmad and Wu (2022a) applied the PQREG method to data from 20 OECD countries over the 1990–2017 period to single out the role of globalized economies, ecological progress indicators, and green development on EFCO. The authors found mixed outcomes across different model specifications.

### 1.3. Research gaps, objectives, and contributions

Despite significant momentum gained by the existing body of evidence, it offers certain crucial research gaps bridged by this work. First, to our knowledge, none of the previous works considered how ETT contributes to ecological sustainability. This gap is extremely important because the transportation sector has an important role in promoting the environmental adversities of a country since it consumes a significant amount of natural resources involving petroleum products. Therefore, the application of environmental taxation to this sector would have the scope of mitigating some of those adversities. Environmental taxation may serve as a rationing device to induce human behaviors of economic agents (firms and households) to reduce the consumption of natural resources by lessening the use of the energy-intensive mode of transportation. Second, none of the scholars are so far known to investigate the combined influence of ETT and globalization on ecological sustainability. This gap is of utmost importance because globalization enhances the trade of goods and services, which involves the transportation sector. Thus, pricing the transportation emissions becomes highly relevant to the international economies involving international economic activities such as foreign investments, international trade, and investment portfolios.

To bridge the aforementioned research gaps, this study aims to examine whether the combined consideration of ETT and globalization can lead to ecological sustainability in the G7 economies over the 1994–2016 period. In this regard, we offer the following significant contributions: Firstly, we include twin proxies of ETT (i.e., environmentally related tax revenue from transport as a percentage of GDP as well as a percentage of total tax revenues) to investigate their robust contribution to ecological quality. Secondly, combined with ETT, we introduce a comprehensive globalization factor to delve into the ecological consequences of international economies. Thirdly, we build our theoretical arguments on Grossman and Krueger (1991) EKC framework by integrating the ETT, globalization, and energy intensity in the model. Finally, we apply model panel data econometric tools robust to cross-section dependency and slope heterogeneity. Our research findings will extend the theoretical understanding of global researchers and will guide the leaders of the international economies to implement guided and robust economic-ecological policies. The following foundations aspire us to select G7 as a study sample: These countries comprise a

forum with the seven most industrialized countries integrated into the world economy that seeks to answer to the current environmental problems. Efforts to create pollution reduction initiatives unambiguously illuminated a high degree of integration between G7 countries.

The structure of the remaining study is as follows: Section 2 deals with theoretical modeling. Section 3 is based on data and methods. Section 4 explains the regressions and findings. Section 5 discusses the main results. Section 6 concludes the study involving policies, limitations, and future research avenues.

## 2. Theoretical foundation and hypotheses development

We establish the theoretical foundation of environmental taxation from the perspective of public goods, inspired by the seminal work of Samuelson (1954), arguing that market-based tools (e.g., taxes, quotas) can provide an optimal solution to ecological problems. To illustrate, a basic concept is that economic agents (i.e., households and firms) want to reduce expenditures as much as possible. Assuming pollutant emissions are taxed evenly, each gram weighted by harm, economic agents shall continue to mitigate those emissions until their marginal cost equals the implemented taxation rate on marginal emissions. We can express it through Eq. (1) as follows:

$$ETT_{el} = Cost_e^h = Cost_e^i \tag{1}$$

where  $Cost_e^h$  is the demonstration of the marginal cost of reducing environmental emissions for each household  $h$  or firm  $i$ . Eq. (1) herein indicates the cost-effective availability or maintenance of public goods (e.g., ecological sustainability). Despite the cost-effectiveness characteristic, such costs to households, firms, and different sectors require the availability of ecological benefits to all these stakeholders to nullify their individual and societal costs. Thus, for an optimal welfare solution for public goods, the taxation on environmental emissions should be equal to the cumulative benefits gained by all stakeholders in the form of marginal benefits ( $Benefit_{el}$ ).

$$ETT_{el} = \sum_{h=1}^n Benefit_e^h = n_i Benefit_{el} \tag{2}$$

where  $Benefit_e^h$  is indicative of the local marginal benefits for a household in the G7 member country in terms of breathing the less polluted air, while  $n_i Benefit_{el}$  depicts the cumulative form of those benefits for the whole region or country.

After establishing that the market-based solutions provided by ETT would be optimal for the allocation, provision, and protection of public goods like ecological sustainability, we move forward to build the theoretical setup for our environmental-economic modeling to test the contributions of ETT to ecological quality. To this end, we augment Grossman and Krueger's, 1991) EKC framework by including ETT, globalization, and energy intensity as determinants of ecological footprint consumption (EFCO). We propose the following modified version of EKC:

$$EFCO = f(PCGR, PCGR^2, ENIN, ETT, IGL) \tag{3}$$

where  $PCGR$  captures the linear and  $PCGR^2$  denotes the squared form of real GDP per capita (GDPCR),  $ENIN$  is the energy intensity and  $IGL$  stands for globalization index. The present study made use of two proxies for  $ETT$ , namely environmentally related tax revenue from transport (% GDP) –  $TTG$  (included in Model 1 as Eq. (4)), and environmentally related tax revenue from transport (% total tax revenue) –  $TTT$  (included in Model 2 as Eq. (5)). We converted all variables of interest into natural logarithms and split the functional form Eq. (3) into the following regression equations (Eqs. (4) and (5)):

$$\begin{aligned} Model1: LEFCO_{it} \\ = \alpha + \beta_1 LPCGR_{it} + \beta_2 L^2PCGR_{it} + \beta_3 LENIN_{it} + \beta_4 LTTG_{it} + \beta_5 LIGL_{it} + \epsilon_{it} \end{aligned} \tag{4}$$

Model2:LEFCO<sub>it</sub>

$$= \alpha + \beta_1 LPCGR_{it} + \beta_2 LPCGR_{it}^2 + \beta_3 LENIN_{it} + \beta_4 LTTT_{it} + \beta_5 LIGL_{it} + \varepsilon_{it} \quad (5)$$

where  $L$  represents a natural log of the sampled variables. G7 countries are indicated by  $i = 1, 2, \dots, 7$ , while time variable is represented by  $t = 1, 2, \dots, 23$ ;  $\varepsilon_{it}$  depicts the error term and  $\alpha$  stands for intercept. The long-run elasticities of  $PCGR$ ,  $PCGR^2$ ,  $ENIN$ ,  $TTG$ ,  $TTT$  and  $IGL$  respectively, are denoted by  $\beta_1 - \beta_6$ . The EKC hypothesis of the inverted U-shaped nexus between  $GDPGR$  and  $EFCO$  will be affirmed if  $\beta_1 > 0$  (i.e.,  $\frac{\partial LEFCO_{it}}{\partial LPCGR_{it}} > 0$ ) and  $\beta_2 < 0$  (i.e.,  $\frac{\partial LEFCO_{it}}{\partial LPCGR_{it}^2} < 0$ ) in both models. This association is driven by the influencing mechanism stating that for lower economic development scales, economic progress deteriorates the ecological quality; however, after reaching a certain development level, the economic progress starts to reduce the ecological burden of developed economies through energy conservation, energy efficiency improvement, and energy transition to clean energy modes (Ahmad et al., 2021a; Ru et al., 2018). Moreover, because the increase in the units of energy used to produce one unit of GDP is theorized to increase the EFCO (Aftab et al., 2021; Chandio et al., 2019; Mushtaq et al., 2022),  $\beta_3$  is expected to be positive (i.e.,  $\frac{\partial LEFCO_{it}}{\partial LENIN_{it}} > 0$ ).

Including ETT proxies in the model is the most critical theoretical contribution. ETT can serve as a rationing device to mitigate environmental pressures by radically or gradually transforming the behavior of economic agents (producers and consumers) depending upon the degree of such pricing (Esen et al., 2021). It has also been argued that environmental taxation induces firms to increase R&D investments and lessen their financial constraints, improving firm productivity levels, which helps them mitigate firm-level environmental emissions to secure sustainable environments (Liu et al., 2022). In response to environmental taxation costs, producers would start manufacturing green vehicles, and consumers would intend to purchase and avail of green and sustainable transport. In this regard, Tchorzewska et al. (2022) empirically argued that firms facing the low level of environmental taxes show less aptitude to invest in cleaner and green technologies, while those having liability to bear higher taxation demonstrate the opposite tendency to cut the taxation cost of their emissions. Thus, we hypothesize the following association:

**Hypothesis 1.** An increase in ETT is expected to accelerate ecological sustainability (i.e.,  $\frac{\partial LEFCO_{it}}{\partial LETT_{it}} < 0$ ).

Finally, incorporating globalization as a determinant of EFCO in the model is extremely vital as it may contribute to ecological quality through different channels. Increased globalization involves escalating international economic activities such as foreign direct investment and international trade. These activities may improve the ecological quality domestically if environmental regulations are stringent. In this context, foreign enterprises may bring cleaner and green technologies and environmentally-friendly machinery to the host nations (Yang et al., 2021). However, if host economies follow the race to the bottom approach to fulfill economic drive and open their corridors for polluting firms, globalization would resultantly degrade the ecological sustainability of those economies (Ahmad and Wu, 2022a; Dorninger et al., 2021). Besides, it has been claimed that globalization is indirectly responsible for climate change. In other words, globalization has affected the main sources of carbon dioxide emissions, namely industry, transport, and deforestation. The existence of these sources is not reliant on globalization, but their development strongly relies on globalization (OECD, 2013; Satrovic et al., 2020). Therefore, we deduce the following hypothesis:

**Hypothesis 2.** Increased globalization is expected to either foster or

deteriorate ecological sustainability (i.e.,  $\frac{\partial LEFCO_{it}}{\partial LIGL_{it}} < 0$  or  $> 0$ ).

### 3. Data and methodology

This section explains the data involving data sources, data definitions, correlations, and a statistical summary of the study variables. Moreover, it documents the panel data econometric methods employed to analyze our data.

#### 3.1. Data

This study uses balanced annual panel data for the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom, United States) covering the 1994–2016 period. The geographical location of G7 members is shown in Fig. 1. The choice of the analysis period is limited to 23 observations in this study as the data for environmentally related tax revenue from transport are available from 1994 onwards, while data for EFCO are available until 2016. The EFCO data for all G7 countries were collected from the GFN (2019). The  $GDPGR$  and Squared  $GDPGR$  data were sourced from the WB (2021) and Macrotrends (2021). Energy intensity data are from the WB (2021) and IEA (2021). Further, ETT data were collected from the (OECD, 2020), while those on globalization were retrieved from the database by Gygli et al. (2019). A more detailed description of the variables is depicted in Table 1.

Table 2 documents the descriptive statistics of all the inspected data by country, while the data trends can be viewed in Fig. 2. The average EFCO in the sample is 6.35 (gha per capita). Table 2 further reports that the United States and Canada are respectively in first and second places in EFCO, with Japan and Italy having the least average EFCO per capita among the sample of interest.

In terms of the  $GDPGR$ , the average value for G7 countries is 40,792.48 (constant 2010 US\$). The United States and Japan are respectively in first and second places in  $GDPGR$ . However, Italy and the United Kingdom have the lowest average  $GDPGR$ . Regarding the energy intensity, Table 2 lists the average value of 5.29 (MJ/\$2011 PPP GDP). On average, Canada shows the highest proportion of units of energy used to produce one unit of GDP, followed by the United States. In contrast, the United Kingdom ranks among the G7 countries with the lowest units of energy used to produce one unit of GDP, followed by Italy. Japan has the highest average environmentally related tax revenue from transport (% GDP), followed by Italy, while the lowest values are reported for Canada (0.25) and the United States (0.28). Turning to the second ETT proxy, Table 2 reports the average value of 1.25, with Japan (2.03) and the United Kingdom (1.61) ranking among the G7 countries with the highest environmentally related tax revenue from transport (% total tax revenue). In addition, Canada and France have the lowest average environmentally related tax revenue from transport (% total tax revenue) among the sampled countries. The United Kingdom reports the highest average globalization index, while Japan ranks among the G7 countries with the lowest globalization index.

Table 3 offers the matrix of correlations, displaying that EFCO is positively correlated with  $GDPGR$  and energy intensity at the 1% significance level. Over the sample period among the G7 countries, the EFCO is negatively correlated with both proxies of ETT. We also revealed the negative but statistically insignificant correlation between globalization and EFCO.

Further, Table 3 also reveals that  $GDPGR$  is positively correlated with energy intensity at the 1% significance level. In contrast, it is negatively correlated with environmentally related tax revenue from transport (% GDP) at the 1% significance level. Moreover, the correlation matrix reports negative and positive, respectively, impacts of environmentally related tax revenue from transport (% total tax revenue) and globalization on  $GDPGR$  that are not statistically significant. Table 3 illuminates the negative correlation coefficient between energy intensity and environmental taxation at the 5% significance level; energy intensity

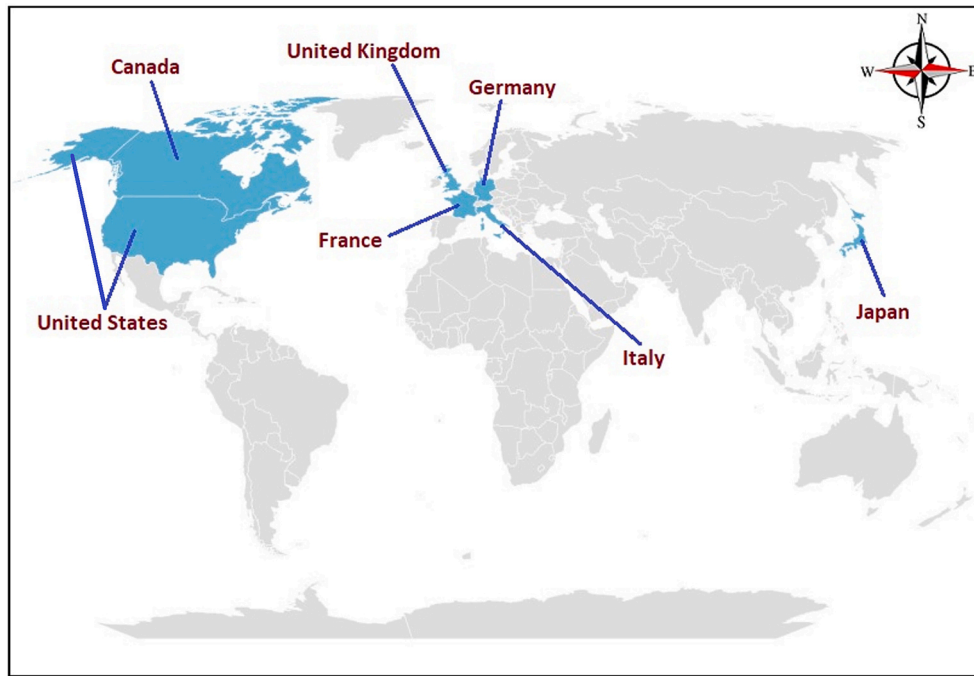


Fig. 1. Geographical location of G7 member countries. Source: Authors' drawing using Microsoft Excel and Paint.net.

Table 1 Information about the variables.

Variable	Variable label	Unit of measurement	Source
Ecological footprint consumption	EFCO	global hectare – gha per capita	(GFN, 2019)
Real GDP per capita	PCGR	constant 2010 US\$	(WB, 2021); (Macrotrends, 2021); authors' calculations
Real GDP per capita squared	PCGR <sup>2</sup>	constant 2010 US\$ squared	(WB, 2021); (Macrotrends, 2021); authors' calculations
Energy intensity	ENIN	MJ/\$2011 PPP GDP Mega Joule/constant 2011 US\$ at purchasing power parity	(WB, 2021); (IEA, 2021); authors' calculations
Environmentally related tax revenue from transport	TTG	% GDP	(OECD, 2020)
Environmentally related tax revenue from transport	TTT	% total tax revenue	(OECD, 2020)
Globalization index	IGL	index	(Gygli et al., 2019)

Notes: GFN: Global Footprint Network, IEA: International Energy Agency, WB: World Bank, OECD: Organisation for Economic Co-operation and Development.

and globalization at the 1% significance level. We reported a negative correlation coefficient between globalization and environmental taxation at the 1% significance level. Moreover, Fig. 3 presents the scatter matrix plot to provide the correlation matrix consistent with our results in Table 3.

### 3.2. Estimation methods

To examine the data from G7 economies, we applied second-generation unit root, cointegration, and parameter estimation strategies capable of handling modern panel data econometric issues.

Considering the high degree of integration among G7 countries, panel data are presumed to be subject to cross-sectional dependency (CRSD) problems. In the presence of CRSD, first-generation methods could give biased empirical results. Therefore, we opt for second-generation empirical strategies, which are robust to the CRSD issue. To empirically test the existence of CRSD, this study employs Breusch and Pagan (1980) test, and Pesaran (2015) cross-section dependence (CD) and Pesaran (2004) scale-adjusted tests. The CD statistics can be formalized as Eq. (6):

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left( \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) N(0, 1) \tag{6}$$

where  $T \rightarrow \infty$  and  $N \rightarrow \infty$ , and  $\hat{\rho}_{ij}$  captures the correlation coefficient. Additionally, the null hypothesis supports the absence of CRSD, while the alternative one assumes its existence. Before testing for unit root and cointegration, it is useful to check for CRSD, as overlooking this issue can lead to biased and misleading results.

After the CRSD tests, the next step of our analysis is to evaluate the stationary properties of our variables. To overcome the issue of CRSD, the application of the most relevant stationary testing becomes inevitable. Herein, we check for the stationary properties by using Im et al. (2003) cross-section adjusted (CRIPS) test of Pesaran (2007) that incorporates the issue of CRSD. The null hypothesis in the case of the CRIPS test is that all cross-sections  $i$  have a unit root ( $c_1 = \dots = c_N = 0$ ) while the alternative one is that  $c_i < 0$  for at least some cross-section. Our CRIPS test is based on the t-ratio of the OLS estimate of  $b_i$  in the cross-section adjusted Dickey-Fuller (CRADF) regression in Eq. (7):

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + \varepsilon_{it} \tag{7}$$

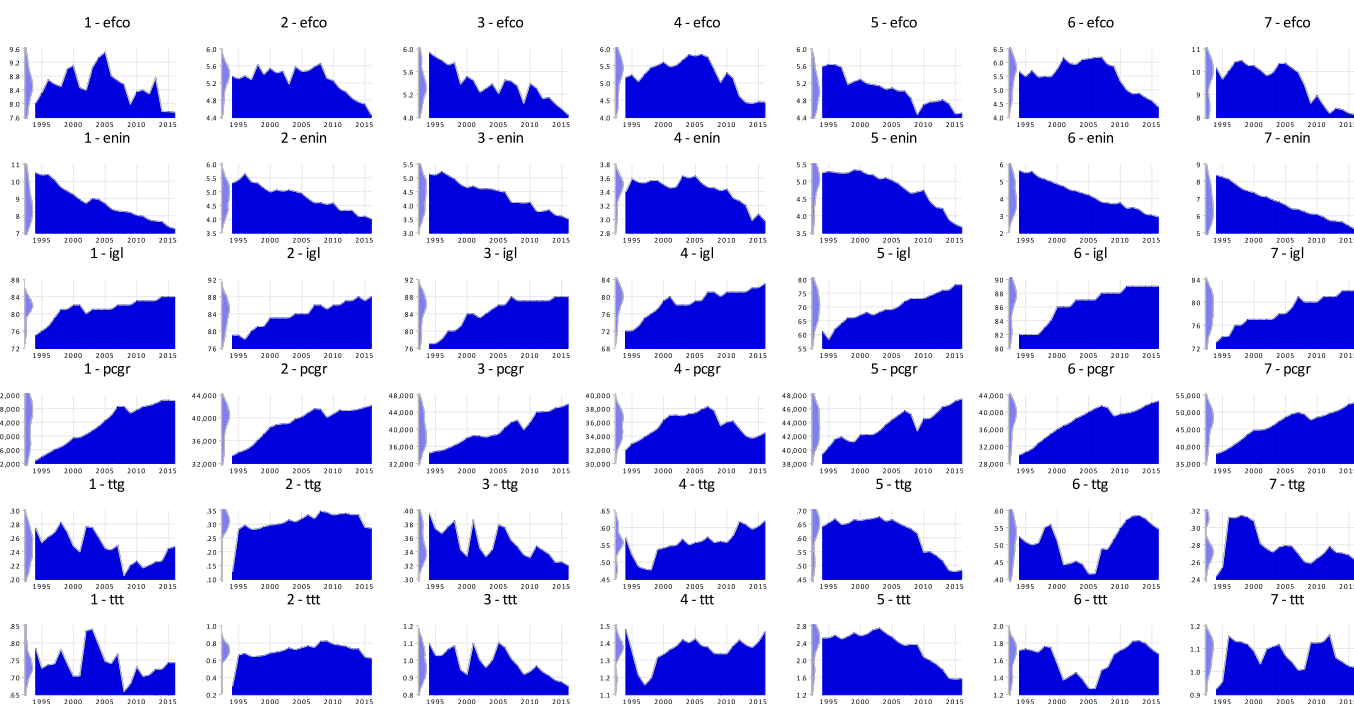
where  $\bar{y}_{t-1} = N^{-1} \sum_{i=1}^N y_{i,t-1}$  and  $\Delta \bar{y}_t = N^{-1} \sum_{i=1}^N \Delta y_{it}$ . The CRIPS test is elaborated as Eq. (8):

$$CRIPS(N, T) = t - \text{bar} = N^{-1} \sum_{i=1}^N t_i(N, T) \tag{8}$$

where  $t_i(N, T)$  is the CRADF statistic for G7 countries by the t-ratio of the

**Table 2**  
Descriptive statistics of study variables.

Variable/country	Stat.	Canada	France	Germany	Italy	Japan	United Kingdom	United States	Total
EFCO	Mean	8.52	5.26	5.37	5.23	5.03	5.52	9.50	6.35
	St. dev.	0.48	0.32	0.29	0.48	0.36	0.55	0.87	1.79
	Max	9.50	5.65	5.93	5.83	5.63	6.19	10.48	10.48
	Min	7.74	4.45	4.84	4.39	4.46	4.37	8.10	4.37
PCGR	Mean	43,333.67	39,065.92	39,854.73	35,476.28	43,609.90	37,807.20	46,399.65	40,792.48
	St. dev.	5925.06	2784.46	3620.47	1791.63	2243.74	3852.92	4392.08	5100.03
	Max	50,427.90	42,140.00	45,844.60	38,272.20	47,403.00	42,523.70	52,746.50	52,746.50
	Min	32,841.00	33,338.30	34,358.60	31,942.40	39,373.20	29,919.90	37,813.80	29,919.90
ENIN	Mean	8.72	4.79	4.38	3.41	4.80	4.22	6.70	5.29
	St. dev.	0.98	0.47	0.54	0.19	0.53	0.85	0.94	1.82
	Max	10.49	5.64	5.22	3.63	5.33	5.60	8.35	10.49
	Min	7.25	4.00	3.50	2.97	3.66	2.92	5.21	2.92
TTG	Mean	0.25	0.30	0.35	0.56	0.61	0.51	0.28	0.41
	St. dev.	0.02	0.04	0.02	0.04	0.07	0.05	0.02	0.14
	Max	0.28	0.35	0.40	0.62	0.68	0.59	0.31	0.68
	Min	0.21	0.13	0.32	0.48	0.48	0.41	0.24	0.13
TTT	Mean	0.74	0.70	0.98	1.36	2.30	1.61	1.07	1.25
	St. dev.	0.04	0.10	0.08	0.08	0.39	0.18	0.06	0.55
	Max	0.84	0.82	1.10	1.48	2.74	1.82	1.16	2.74
	Min	0.66	0.30	0.85	1.15	1.55	1.27	0.92	0.30
IGL	Mean	81.17	83.83	84.30	78.65	69.70	86.39	78.39	80.35
	St. dev.	2.42	3.01	3.70	3.19	5.46	2.59	2.73	6.16
	Max	84.00	88.00	88.00	83.00	78.00	89.00	82.00	89.00
	Min	75.00	78.00	77.00	72.00	58.00	82.00	73.00	58.00



**Fig. 2.** Research data trends for G7 countries.

Source: Authors' estimations

Note: 1 = Canada, 2 = France, 3 = Germany, 4 = Italy, 5 = Japan, 6 = United Kingdom, 7 = United States.

**Table 3**  
Pairwise correlation.

Variables	EFCO	PCGR	ENIN	TTG	TTT	IGL
EFCO	1					
PCGR	0.408***	1				
ENIN	0.814***	0.218***	1			
TTG	-0.624***	-0.318***	-0.600***	1		
TTT	-0.374***	-0.032	-0.343**	0.885***	1	
IGL	-0.092	0.032	-0.200***	-0.401***	-0.585***	1

Notes: \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5, and 10%, respectively.

Means by DATEID

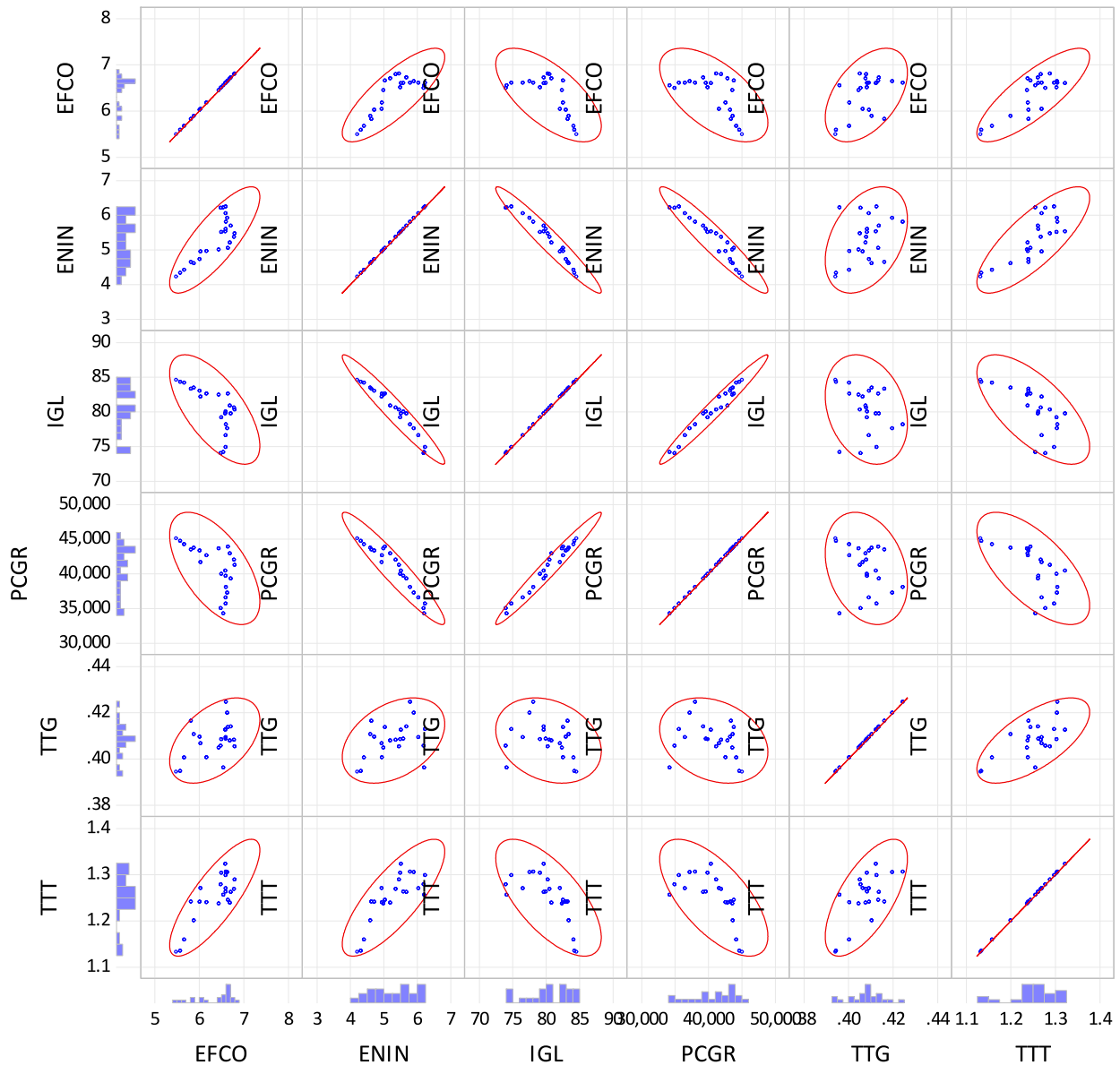


Fig. 3. Scatter matrix plot of research variables. Source: Authors' estimations

coefficient  $y_{i, t-1}$  in Eq. (7).

The absence of slope homogeneity in the sampled countries is the prerequisite criterion for applying the cointegration technique of the second-generation type. This must be satisfied before the test can be applied. As a result of this, we used the homogeneous slopes testing that Pesaran and Yamagata (2008) modified from Swamy (1970) approach. There are two different kinds of parametric statistical formulations, which are as follows:

$$\widetilde{\Delta}ta = \sqrt{N}(N^{-1}\widetilde{SW} - q/2q) \sim \chi^2_q \tag{9}$$

$$\widetilde{\Delta}ta_{adj} = \sqrt{N}(N^{-1}\widetilde{SW} - q/v(T, q)) \sim N(0, 1) \tag{10}$$

where  $N$  represents countries,  $SW$  stands for Swamy's statistical measure,  $q$  represents the regressors, and  $v(T, q)$  represents the residual term (standardized version). Eqs. (9) and (10) are employed for large and small data samples, respectively. However, for robust results, we applied

both of them to test the null hypothesis of homogeneous slopes of countries.

As a further note, the long-term stability among the inspected indicators has been assessed by conducting the cointegration analysis proposed by Westerlund (2007). Incorporating the issue of CRSD, this technique designs the null hypothesis of no cointegration against the alternative one stating that the panel is cointegrated as a whole. This technique proposes the panel statistics captured by  $P_t$  and  $P_a$ , while the groups statistics are denoted by  $G_t$  and  $G_a$ . Additionally, Kao (1999) cointegration test is used as an alternative statistic to check the robustness of our baseline Westerlund cointegration results.

The next step of our analysis is to evaluate the long- and short-run elasticities between EFCO and its determinants, namely ETT, globalization, energy intensity, GDPCR, and squared GDPCR. These associations are estimated by applying the fully modified ordinary least squares (FMOLS) proposed by Pedroni (2000) and pooled mean group autoregressive distributed-lag (PM-ARDL) proposed by Pesaran et al. (1999)

estimation procedures. The panel FMLS can be specified as Eq. (11):

$$\hat{\beta}_{GFM} = \left[ \sum_{i=1}^N \sum_{t=1}^T (x_{it} - \bar{x}_i)(x_{it} - \bar{x}_i)' \right]^{-1} \left[ \sum_{i=1}^N \left( \sum_{t=1}^T (x_{it} - \bar{x}_i) \hat{y}_{it}^+ - T \hat{\Delta}_{\epsilon U}^+ \right) \right] \tag{11}$$

where  $\bar{x}_i$  refers to the averages that are specific for every G7 country,  $N$  captures the cross-sectional dimension;  $T$  stands for the time variable;  $\hat{y}_{it}^+$  refers to the  $y$  series;  $\hat{\Delta}_{\epsilon U}^+$  represents the adjustment term of the residuals. The empirical model for the PM-ARDL technique can be written as Eq. (12):

$$LEFCO_{it} = \sum_{j=1}^p \theta_{ij} LEFCO_{it-j} + \sum_{j=0}^q \rho_{ij} x_{it-j} + \mu_i + u_{it} \tag{12}$$

Here,  $x_{it}$  capture regressors,  $\rho_{ij}$  is the vector of regression parameters,  $\theta_{ij}$  represents the parameter with lags of the regressand,  $\mu_i$  is the country-specific disturbance component, and  $u_{it}$  stands for the general disturbance term. Short-run estimation results are obtained from Eq. (12):

$$\Delta LEFCO_{it} = \alpha_0 + \sum_{i=1}^p \theta_i \Delta LEFCO_{t-i} + \sum_{j=1}^q \delta_j \Delta LPCGR_{t-j} + \sum_{m=1}^q \beta_m \Delta LPCGR2_{t-m} + \sum_{r=1}^q \varphi_r \Delta LENIN_{t-r} + \sum_{s=1}^q \sigma_s \Delta LEOP_{t-s} + \sum_{v=1}^q \sigma_v \Delta LIGL_{t-v} + \tau ECT_{t-1} + \epsilon_{it} \tag{13}$$

with  $p$  representing the lag of regressand and  $q$  as the independent variables' lag.  $ECT$  indicates the error-correction term.

After estimating the long- and short-run estimates, we used the causal analysis devised by Dumitrescu and Hurlin (2012) to determine the directional flow of EFCO in relation to its determinants. The homogeneous non-causality null hypothesis is tested against the alternative one of potential causal associations between the variables of interest.

#### 4. Empirical findings

The first step of our analysis is to test the CRSD by utilizing multiple strategies involving Breusch-Pagan's LM, Pesaran's scale LM, and Pesaran's CD. The empirical findings are presented in Table 4. According to the test results, the null hypothesis of the absence of CRSD is rejected for all three tests. Based on the empirical outcomes, we are able to conclude the existence of CRSD in the inspected variables individually as well as in the overall models. Thus, the estimates from the different tests revealed a strong dependence across the G7 members. The statistical commands of the econometric strategies used in this study are provided in the supplementary materials.

To handle CRSD among sampled countries, in the second stage of our analysis, we utilized the CRIPS unit root test. As seen in Table 5, the null hypothesis of a unit root is accepted in the model with and without trend at levels for certain variables. Particularly, we notice that i) GDPCR and

Squared GDPCR are not stationary at a level while these variables are stationary at the first difference; (ii) the EFCO is stationary at the level and at the first difference; (iii) energy intensity displays the non-stationarity feature in the level form but turns out unit root free after first differencing for countries under consideration; (iv) environmentally related tax revenue from transport (% GDP) and environmentally related tax revenue from transport (% total tax revenue) are stationary at the level and at the first difference; (v) globalization index is also stationary at both level and the first difference. These findings imply that the variables are exhibiting a mix of  $I(1)$  and  $I(0)$  processes. As a further step, as seen in Table 5, the slope homogeneity test findings ruled out the null hypothesis: the homogeneous slopes, confirming the validity of the heterogeneous slopes of the sampled countries.

The next crucial step is to analyze the existence of a long-run relationship among the variables of interest by employing Westerlund (2007) cointegration procedures. Its findings, without trend and constant in the analysis, are provided in Table 6. As identified, the null hypothesis of no cointegration is rejected by the group as well as the panel test statistics in Model (1) at a 5% significance level and Model (2)

at a 1% significance level. Additionally, the robustness check results based on Kao cointegration confirm the existence of cointegration in both models.

Given the existence of the cointegration relationship among the sampled variables, the next step consists of estimating the long- and short-run parameters. We first estimated long-run parameters by using the FMLS estimator. In addition, we employed the PM-ARDL estimator to predict the long- and short-term parameters. The consecutive results are highlighted in Table 7. Moreover, the baseline long-term results of the two models are also presented in Fig. 4.

We estimated two types of models based on two different proxies of ETT: Model 1 included the environmentally related tax revenue from transport (% GDP) [i.e., TTG], while Model 2 incorporated the environmentally related tax revenue from transport (% total tax revenue) [i.e., TTT]. PM-ARDL was used as an alternative estimator to check the robustness of our baseline results. Concerning the impact of ETT, a statistically significant and negative coefficient is reported by FMLS and PM-ARDL in the long run, while a positive and marginally significant effect is noted in the short run for Model 1. However, it presented a neutral role in Model 2. While exploring the long-term perspectives, the results exhibited very few differences when different proxies for ETT were used. An upsurge in the environmentally related tax revenue from transport (% GDP) by 1% is predicted to diminish the EFCO by 0.164% (FMLS) and 0.319% (PM-ARDL) in the long run, on average, ceteris paribus. In Model 2, a 1% increase in the environmentally related tax

**Table 4**  
Results of CRSD tests.

Test/Variable/Model	Test statistics and significance levels								
	LEFCO	LPCGR	LPCGR2	LENIN	LTTG	LTTT	LIGL	Overall Model 1	Overall Model 2
Breusch-Pagan LM	234.16*** (0.000)	338.40*** (0.000)	337.97*** (0.000)	406.85*** (0.000)	90.20*** (0.000)	52.50*** (0.000)	432.52*** (0.000)	87.60*** (0.000)	89.13*** (0.000)
Pesaran scaled LM	31.81*** (0.000)	47.90*** (0.000)	47.83*** (0.000)	58.46*** (0.000)	9.60*** (0.000)	3.78*** (0.000)	62.42*** (0.000)	9.20*** (0.000)	9.43*** (0.000)
Pesaran's CD	14.83*** (0.000)	17.56*** (0.000)	17.54*** (0.000)	20.08*** (0.000)	-2.16** (0.031)	-1.67* (0.094)	20.79*** (0.000)	4.32*** (0.000)	3.62*** (0.000)

Notes: \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5 and 10%, respectively. L stands for the natural logarithm. Braces () contain the probability scores.

**Table 5**  
CRIPS unit root and slope homogeneity test results.

Test/Variable	LEFCO	LPCGR	LPCGR <sup>2</sup>	LENIN	LTTG	LTTT	LIGL
CRIPS (constant)	-2.58***	-1.09	-1.09	-2.06	-2.32*	-2.46**	-2.92***
CRIPS (constant & trend)	-2.76*	-1.48	-1.47	-2.33	-2.92**	-2.84**	-3.42***
Test/Variable	$\Delta$ LEFCO	$\Delta$ LPCGR	$\Delta$ LPCGR <sup>2</sup>	$\Delta$ LENIN	$\Delta$ LTTG	$\Delta$ LTTT	$\Delta$ LIGL
CRIPS (constant)	-4.64***	-2.73***	-2.73***	-5.07***	-4.56***	-4.40***	-5.32***
CRIPS (constant & trend)	-4.54***	-2.74*	-2.74*	-5.24***	-4.65***	-4.58***	-5.35***
Slope homogeneity	Type of test	Statistic	Prob-value	Slope homogeneity	Type of test	Statistic	Prob-value
Model 1	$\Delta$ Delta	4.88	0.000***	Model 2	$\Delta$ Delta	4.63	0.000***
	$\Delta$ Delta <sub>adj</sub>	5.85	0.000***		$\Delta$ Delta <sub>adj</sub>	5.54	0.000***

Notes: \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5 and 10%, respectively.  $\Delta$  stands for the first difference. CRIPS refers to a cross-sectionally augmented unit root test.

**Table 6**  
Westerlund (2007) and Kao (1999) panel cointegration test results.

Test/Model	Statistic	Model 1	Model 2
		Value	Value
Westerlund (2007)	Gt	-3.319*** (0.002)	-3.672*** (0.000)
	Ga	-6.964 (0.950)	-6.992 (0.949)
	Pt	-7.638** (0.015)	-8.269*** (0.004)
	Pa	-6.820 (0.657)	-7.035 (0.630)
Kao (1999)	t-stat	-3.251*** (0.001)	-3.397*** (0.000)

Notes: \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5 and 10%, respectively. Braces () contain the probability scores.

revenue from transport (% total tax revenue) reduces the EFCO by 0.162% (FMLS) and 0.386% (PM-ARDL) in the long term, on average. Short-run impacts are, however, found to be statistically insignificant. In addition, the coefficient of globalization is significant and negative in the long run by both estimators. Notably, a 1% increase in globalization reduces the EFCO by 0.443% (FMLS) and 0.763% (PM-ARDL) in the long run, on average, ceteris paribus.

Concerning the energy intensity effect on EFCO, we found a positive and statistically significant influence in the long run by both estimators. From the long-term parametric results, ceteris paribus, a 1% uphill movement in energy intensity brings about a 0.686% (FMLS) and 0.433% (PM-ARDL) increase in EFCO, respectively, as per Model 1. The parameter estimates of PCGR reported positive and significant estimates, while its squared term yielded negative and statistically significant estimated results, in the long run, inferring the presence of an inverse U-type linkage, thereby confirming the EKC notion in the G7 members. The PM-ARDL estimator depicts the convergence speed of 42.5% in Model 1 and 49.2% in Model 2.

In the final step of our analysis, we employed Dumitrescu and Hurlin (2012) causality test to detect causality in annual panel data for G7 countries. Table 8 presents the estimation outputs for both model specifications. We found bidirectional causal links of ETT, energy intensity, GDPCR, and GDPCR square in relation to EFCO. However, a unidirectional causal link is found running from globalization to EFCO.

### 5. Discussion

Our findings infer the negative elasticity parameters attached to the twin proxies of ETT. This finding evidently shows that as environmentally related tax revenue from the transport sector increases, the EFCO is likely to go downhill, improving the ecological quality via mitigating the pollutant emissions. Aligned with our findings, Hussain et al. (2022) observed a transport emissions mitigation in response to implementing environmental taxation in 35 OECD members. Likewise, Esen et al. (2021) revealed that environmental tax reduced the environmental

burden of 15 EU economies. This evidence also supported the result of Chen et al. (2022), as they uncovered the environmental quality improvement effects of environmental taxes in Chinese regions, but with certain heterogeneities across those regions. Also, our finding was parallel with that of Alola et al. (2023), as they exhibited the ecological co-benefits of environmental taxation in the context of France, Spain, Italy, and Germany. Linked to our findings, Wu et al. (2020b) observed that environmental taxes helped Chinese provincial units mitigate their carbon emissions. However, Depren et al. (2023) manifested the mixed nature of the effects of environmental taxation on environmental pollution measured by carbon emissions only.

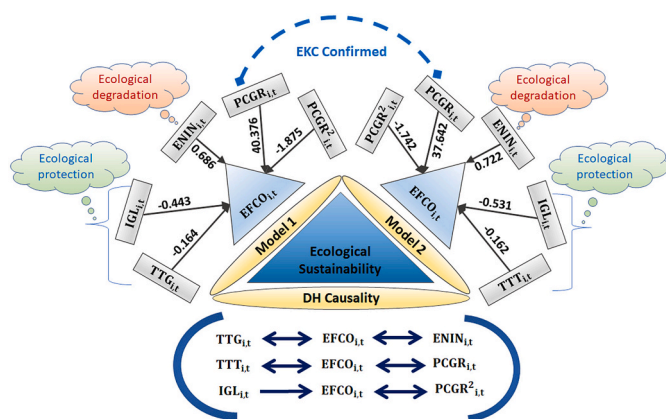
Regarding the relationship between globalization and EFCO, we found a negative and statistically significant long-term impact according to both FMLS and PM-ARDL estimators, affirming that globalization is predicted to stimulate the ecological quality of G7 countries. It has been found that the positive impact is due to the transfer of green know-how and environmentally friendly technological innovations to countries with low environmental standards (Le and Ozturk, 2020). The innocuous environmental impact of globalization was also reported by Xiaoman et al. (2021) for the Middle East and North Africa (MENA) countries, indicating that globalization rectifies environmental problems through the technique effect of trading activities. Consistent with our findings, Yang et al. (2021) observed the ecologically favorable effects of political and financial globalization in the context of the OECD region. Ahmad et al. (2021b) also uncovered the ecologically friendly effects of financial globalization in the G7 members' context. On the flip side, Jabeen et al. (2023) found that the opening of economies deteriorates the ecological quality by boosting consumption- and production-embedded pollutant emissions. Likewise, from the perspective of Brazil, Russia, India, China, and South Africa, Pata (2021) also confirmed the ecological degradation effects of globalization. By the same token, Langnel and Amegavi (2020) came up with the adverse globalization influence in the Ghanaian context. In addition, the findings of Ortiz et al. (2022) presented an analogy with our results in that they spotted the ecologically favorable effects of globalization in the context of 101 world economies. On the contrary, Deng et al. (2022) put forward an environmental destruction effect of social globalization.

Besides, our results reveal a direct connection between energy intensity and EFCO, indicating that an increase in the units of energy used to produce one unit of GDP leads to an increase in EFCO, reducing the ecological quality of G7 countries. This finding is analogous to that of El Anshasy and Katsaiti (2014), as they found a direct link between energy intensity and environmental emissions in 131 global economies. Likewise, Pan et al. (2022) found that energy intensity reduction targets mitigated environmental pollution, particularly in less-developed Chinese cities. Finally, our results strongly approved the validity of the EKC phenomenon for G7 countries as the coefficients with GDPCR and Squared GDPCR are reported as significantly positive and negative, respectively. Both of the estimators approve of an inverse U-type link between GDPCR and EFCO. It implies that environmental degradation is likely to increase in the early stages of growth, but environmental protection restores environmental quality at high-income levels. This

**Table 7**  
Long- and short-run parameter estimation results.

Variable	Long Run Equation (Model 1)		Long Run Equation (Model 2)	
	Coefficient (FMLS)	Coefficient (PM-ARDL (1,2,2,2,2,2))	Coefficient (FMLS)	Coefficient (PM-ARDL (1, 2, 2, 2, 2, 2))
LPCGR	40.376*** (0.000)	64.897*** (0.000)	37.642*** (0.000)	44.720*** (0.000)
LPCGR <sup>2</sup>	-1.875*** (0.000)	-3.025*** (0.000)	-1.742*** (0.000)	-2.073*** (0.000)
LENIN	0.686*** (0.000)	0.433*** (0.000)	0.722*** (0.000)	0.820*** (0.000)
LTTG	-0.164*** (0.004)	-0.319*** (0.000)		
LTTT			-0.162*** (0.000)	-0.386*** (0.000)
LLIGL	-0.443*** (0.008)	-0.763*** (0.000)	-0.531*** (0.001)	-0.701*** (0.000)
COINTEQ01		Short Run Equation -0.425** (0.012)		Short Run Equation -0.492*** (0.000)
D(LPCGR)		63.985* (0.096)		48.525 (0.165)
D(LPCGR(-1))		-81.496* (0.075)		-91.127** (0.042)
D(LPCGR <sup>2</sup> )		-2.966 (0.100)		-2.255 (0.169)
D(LPCGR <sup>2</sup> (-1))		3.858* (0.073)		4.302** (0.042)
D(LENIN)		0.247 (0.155)		-0.073 (0.606)
D(LENIN(-1))		0.127 (0.162)		0.011 (0.915)
D(LTTG)		0.086* (0.093)		
D(LTTG(-1))		0.071 (0.410)		
D(LTTT)				0.099 (0.119)
D(LTTT(-1))				0.088 (0.295)
D(LLIGL)		0.118 (0.753)		-0.081 (0.809)
D(LLIGL(-1))		0.445 (0.179)		0.215 (0.517)
C		-146.260** (0.012)		-116.961*** (0.000)
Observations	154	147	154	147
R-squared	0.979		0.980	
Sum squared resid	0.213	0.040	0.199	0.041
Log likelihood		415.770		422.534

Notes: \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5 and 10%, respectively. Braces () contain the probability scores.



**Fig. 4.** Long-term estimated parameters and causality results for both models. Source: Authors' drawing presenting findings based on FMLS and DH causality

finding supports the conclusions made by mainstream studies (Churchill et al., 2020; Dinda, 2004; Grossman and Krueger, 1991). These results are also aligned with some most recent research works (Ahmad and Wu, 2022b; Satrovic et al., 2022; Sinha et al., 2020). Contrary to the long-run results, short-run estimates did not support the existence of the EKC hypothesis. If we put all this together, it can be concluded that ETT and globalization can empower G7 countries to curb ecological challenges, while intensive energy use may impede it. Eventually, economic growth in G7 countries would assist in realizing the ecological sustainability objectives from the long-term perspective.

### 6. Conclusions

This section concludes our empirical study. It provides concluding remarks and relevant policies. It also singles out the limitations of this study from both empirical and theoretical frontiers and provides directions for the follow-up scholar interested in researching this topic further.

**Table 8**  
Dumitrescu and Hurlin (2012) causality test results.

Panel	LPCGR→LEFCO	LEFCO→LPCGR	LENIN→LEFCO	LEFCO→LENIN	LTTG→LEFCO	LEFCO→LTTG
Z-bar	9.857***	4.047*	7.495***	5.602***	3.555	4.856**
p-value	0.000	0.077	0.000	0.000	0.203	0.010
Panel	LTTT→LEFCO	LEFCO→LTTT	LIGL→LEFCO	LEFCO→LIGL	LPCGR <sup>2</sup> →LEFCO	LEFCO→LPCGR <sup>2</sup>
Z-bar	3.968*	4.132*	9.020***	2.203	9.877***	4.038*
p-value	0.092	0.064	0.000	0.934	0.000	0.079

Notes: Z-bar indicates statistics. \*\*\*, \*\*, \* demonstrate statistical significance at 1, 5, and 10%, respectively.

### 6.1. Conclusion

We employed advanced panel data econometric strategies to investigate whether environmental taxation in transport (ETT) and globalization achieve the ecological sustainability target of Sustainable Development. Our analyses yielded the following main conclusions: *Firstly*, a long-run equilibrium relationship is revealed among EFCO, ETT, globalization, energy intensity, and GDPCR, implying that any short-run arbitrary shock to the under-analysis variables will dissipate in the long run, achieving a stable equilibrium path. *Secondly*, while both indicators of ETT are found to deteriorate ecological sustainability in the short run, they promote the same in the long run. It suggests that ETT does not alter the behaviors of economic agents in the short term as individuals adjust their behaviors and respond to incentives gradually. *Thirdly*, though globalization imparts a neutral role in the short term, it proliferates sustainable ecological systems in the long-term context. It means that globalization opens the avenues of technology transfer and technique effects of international trade in the long term perspective, while their ecologically favorable outcomes seem invisible in the short run. *Fourthly*, energy intensity improves ecological sustainability in the long run, whereas its influence remains neutral in the short run. *Fifthly*, all model specifications discovered the EKC hypothesis valid in the long run. *Finally*, a unidirectional causality is displayed, running from globalization to EFCO, while ETT, energy intensity, and GDPCR established a bidirectional causal link with EFCO.

### 6.2. Policies

Our empirical findings inferred that demand-management policies such as ETT are implemented to achieve long-term ecological sustainability objectives; in the short term, these policies play a neutral role in inducing change to ecological quality. Considering the ETT toolbox of policy instruments, fiscal tools may encourage automobile inventory replacement and steer users to choosing energy-efficient cars, reducing ecological degradation impact. Among G7 countries, we suggest licensing/buying taxation, gasoline taxation, and circulation can be considered essential tools in the ETT toolbox. The licensing fee, an initial expense, would influence a customer's choice to purchase a green vehicle. In this context, demand for electric automobiles can be enhanced, provided a mitigated licensing taxation for such vehicles. Moreover, the circulation taxation, which is annually charged based on the chamber size, carbon discharge capacity, and fuel systems, would be less influential than licensing taxation because buyers may generally attach more importance to the upfront cost of vehicles compared to the yearly circulation tax costs. Besides, gasoline taxation would induce users to adjust their driving habits, reduce transportation fuel use, and purchase more fuel-efficient automobiles. Additionally, higher ETT may motivate the users to transition from personal vehicles to public transportation, lowering the carbon emissions tendencies. Implementing such policy tools may lead to an ecologically sustainable green transport system critical to sustainable development. Finally, globalization has been identified to contribute to sustainable ecosystems, perhaps through the technology exchanges among G7 members and trade in environmental goods and services such as renewable energy technologies, waste-to-clean power production techniques, and green management

practices.

### 6.3. Limitations and future research directions

Though we offered significant academic contributions in this study, several limitations need the attention of future researchers researching the same domain. *First*, we only account for environmental taxation in the transportation sector, which limits the generalizability of the results beyond this sector. Future researchers should focus on environmental taxation in other sectors of the economy to have a better cross-sectoral comparative analysis for in-depth insights into the rich outcomes. *Second*, we considered the aggregate measure of EFCO to measure overall ecological sustainability. Future scholars may consider the building blocks of EFCOs, such as carbon footprint, forestry, grazing, etc., for heterogeneous outcomes across various proxies of ecological systems. *Third*, we used the mean effects estimations, incapable of capturing the distributional heterogeneities across various levels of ecological quality. Therefore, the follow-up studies shall consider the application of panel quantile regression to incorporate such heterogeneous features across a diverse range of quantiles of ecological sustainability for better empirical implications. *Last*, we only considered a single fiscal instrument, namely environmental taxation in the transportation sector, that alone might not effectively achieve the desired results of ecological sustainability in a practical framework. Herein, future studies may include other aspects, such as technological innovation combined with environmental taxation, to observe how innovative process strengthens the ecologically friendly impacts of such taxation phenomenon.

### Declaration of Competing Interest

None.

### Data availability

Data will be made available on request.

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### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecoinf.2023.102009>.

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