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RESEARCH ARTICLE

Examining the impact of environmental technologies, environmental taxes, energy consumption, and natural resources on GHG emissions in G-7 economies

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Abstract
The focus areas for COP-27 include fast-tracking our worldwide evolution to decarbonization in the energy industry and clean energy as the stockholder's effort to restrict global warming to 1.5 °C (2.7 °F) above the levels of pre-industrial. After this COP-27 summit, most of the developing countries will provoke challenges in accomplishing their targets of a carbon neutrality and sustainable economy with the minimum possible greenhouse gas (GHG) emissions. In this regard, the G-7 countries, despite prosperous cautiously, have not prospered in certifying ecological welfare in tandem. Nevertheless, these economies cannot endure their green growth attainments without instantaneously safeguarding their ecological features. To do this, green technologies and environmental taxes are vital apparatuses that can assist in accomplishing carbon neutrality objectives. Consequently, the current study investigates the influence of green technologies, environmental taxes, natural resources, renewable, and fossil fuel energy on GHG emissions in G-7 nations from 1994 to 2020. After confirming the cross-sectional dependency issue, this study uses a battery of second-generation panel methods to estimate the empirical findings. The estimated evidences discovered that green technologies, environmental taxes, and renewable protect environmental quality in the long run. However, natural resources and fossil fuel energy increase the GHG emissions levels. Furthermore, this study suggests that G-7 economies should be more focus on green technologies, imposing environmental taxes eco-innovation related developments, and promote renewable energy projects through the sustainable alteration of their consumption and production processes.

Keywords COP-27 conference · GHG emissions · Green technologies · Environmental taxes · Natural resources · Renewable and fossil fuels energy · G-7 countries

Introduction

Green approaches can be a treatment for a polluted atmosphere. Green methods depend on nature-oriented cleaner energy resources, therefore rising obtaining sustainable development goals (SDGs) (Khan et al. 2018; Usman and Balsalobre-Lorente 2022). Owing to continuing issue of ecological dilapidation, environmentalists strain that economies have reconditioned their outdated business processes with green technologies, environmental taxes. and protected the world from the mist of environmental pollution (Sharif et al. 2023). Reasonably, the elements elaborated in the procedures of technology expansion and the mechanisms complicated in green technology have scarcer undesirable influence on the atmosphere. Rendering to the novel study of Liu et al. (2022), features arriving with green technology and environmental taxes alleviate carbon emissions (CO_2) emissions and predominantly decrease environmental that unfavorably influence human life and natural resources. In this regard, research and development (R&D) sections demonstrate that revolution in green technology offers ultra-modern structures that are fewer emission-intensive and avoids consumptions in the raw ingredients form, gases, and water. These

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attachments upsurge the productivity and effectiveness level of individual firms (Balsalobre-Lorente et al. 2023; Huang et al. 2023). Nevertheless, prodigies of green technology and environmental taxes not solitary promise to upper-level practical developments but protection the commercial and domestic level occupational business to sustain their particular technologies. This philosophy has been flawlessly comprised by advanced economies, for instance G-7[1] economies (Hao et al. 2021) that encourage socially reasonable applications, which devour the slightest probable energy and develop the uppermost ecological expertise exporters.

The European Green Deal (EGD) covers whole subdivisions of the existing economies, particularly buildings, energy, transport, industries, and agriculture, for example, steel, ICT, cement, chemicals, and textiles. To customary into legislature the radical determination of being the world's primary environmental neutrality continent by 2050, the directive will contemporary within first hundred days "*European Climate Law*." To influence our ecological and climate determination, the directive will also explore the biodiversity approach for the years 2030, the novel Industrial Strategy and Circular Economy Action Plan (ISCEAP) especially linked with G-7 economies because many of the economies are from European Union (EU), and this proposals for carbon-free Europe. Conference the major purposes of the EGD will necessitate momentous investment. Accomplishing the existing 2030 energy and climate goals is projected to need €260 billion of extra yearly investment, on behalf of about 1.5% of 2018 economic growth. Particularly, in this, investment will essential the deployment of the private and public sectors. The main commission will contemporary in early 2020 a Sustainable Europe Investment Plan (SEIP) to support encounter investment requirements. As a minimum of the 25% of the EU's long-run economical budget should be enthusiastic to the European Investment Bank, European climate action, Europe's climate bank, will deliver additional sustenance. For the private division to subsidise and supporting the green evolution, the central commission will discover a Green Financing plan during the year of 2020 (Saqib and Usman 2023). The universal challenges of ecological deprivation and climate change necessitate a worldwide response. In this circumstance, the EU community will continue to endorse its ecological standards and targets in the United Nation's biodiversity and environmental conventions and support its green international relations. The G-7, bilateral relationships, and universal agreements will be used to encourage others to increase their works. Moreover, the EU will also practise trade policy to confirm sustainability and it will shape corporations with its neighbours in the Africa and Balkans to support them with their individual evolutions (Wang et al. 2023a).

A similar method, for example an environmental tax, is carried frontward with socioeconomic designers on high-consuming power apparatus to boost the accrued prices of production (Safi et al. 2021) but concurrently increase the green technological development (Wang et al. 2023a). Likewise, economic growth reduces due to financial responsibilities on tax increases (Sharif et al. 2023). Although blockades to ecological taxes reduce trading activities and tourism development in the short term, constructive developments are certain in the long term. Numerous studies affirm that countries levy environmental taxes on non-renewable energy with the assistance of a down-top demand for energy model if they are economically stable and proactive to embellishment green economic actions and events (Trencher et al. 2021; Doğan et al. 2022; Saqib and Usman 2023). Therefore, applying these taxes diminish an adverse atmospheric issues externality (Sharif et al. 2023) and encourages the well-organized and effectual green energies production in the course of nature-friendly and carbon-free technologies (Usman and Radulescu 2022).

Particularly to the G-7 countries, Canada is rich in natural resources, including oil, natural gas, minerals, and forests and France has limited natural resources, but it has significant reserves of uranium, which is used to fuel its nuclear power plants. Moreover, Germany has significant reserves of lignite coal, which has been a major source of energy for the country. Besides, Italy has limited natural resources, but it has significant reserves of natural gas, which is used to fuel its electricity generation and similarly; Japan has also limited natural resources and relies heavily on imports for its energy needs, including oil, natural gas, and coal. Moreover, the UK has significant reserves of oil and natural gas in the North Sea, which have been a major source of energy for the country and the US is also rich in natural resources, including oil, natural gas, coal, minerals, and forests. It is one of the world's largest producers of oil and natural gas.

The previous literature in the existing literature reports vague results concerning the role of environmental technologies and environmental taxes (Doğan et al. 2022; Sun et al. 2023; Uddin et al. 2023; Zeraibi et al. 2023). These studies overlook the diminishing character of environmental technologies and environmental taxes in the energy mix transition with the presence of natural resources. Consequently, it is important to examine these aspects and postulate environment based economic and environmental policy proposals to diminish the overall level of environmental pollution without hurting the pace of economic growth trajectory for the G-7 nations. A conclusive policy approach is essential to support the G-7 economies to decrease the level of GHG emissions by implementing carbon taxation. Nevertheless, there are considerable dissimilarities across nations in examining

[1] Germany, Canada, Japan, Italy, France, United Kingdom, and the United States.

strategies on the apparatuses of carbon taxes. Discovering the influence of the environmental tax is an indispensable condition to accomplishing a reliable standard of the influence on GHG emissions. According to the (Doğan et al. 2022) there are extensive differences in carbon pricing and environmental taxes across nations, prominent in the differences in tasks across nations to accomplish the targets of Paris Agreement summit. In this regard, the observed and estimated analysis of this study explores that the implementation of ecological taxes and green environmental technologies can augment climate wellbeing and substitute technical complexity and the utilization of energy from renewable and alternative sources, and its conclusions can argument to appropriate policy inferences for sustainable environmental expansion.

The contribution and novelty of this study to the literature of environmental economics is mainly three-fold. Initially, to the authors imperfect knowledge, none of the single studies examines the role of green technologies and environmental taxes in greenhouse gas (GHG) emissions. This research employed the up-to-date and developed available data (1994–2020) from G-7 nations and examined whether patents on environmental technologies has slightly role in nourishing GHG emissions. Moreover, the G-7 nations requires high level of eco-innovation, innovation, renewable, and fossil fuel energy use fulfil this need without emitting GHG emission and ecological taxes also confine the societies and institutions to produce elevated GHG emissions level. Consequently, a required pragmatic study also synthesizes the role of environment taxes, natural resources, renewable and fossil fuel energy utilization, and expansion of green technologies in amplification GHG emissions and it would be a valuable accumulation to the present literature body. Third, the present research increases the consideration of how environmental green technologies and natural resource diminish GHG emissions and subsequent ecological contamination in G-7 nations. Fourth, this study investigates what the role of renewable energy and environment-related taxes in dipping carbon emissions, offering a basis for G-7 nations to regulate the efficiency of their system of environmental tax and make obligatory modifications. Fifth, in order to address the issue of possible slope heterogeneity and cross-sectional dependency, this research employed the most lasted panel data approach (AMG and CCEMG) to accomplish the above-mentioned objectives. These approaches have the distinguishing of reliable that produced robust estimated evidences. Inclusively, the present study offers an empirical basis for redesigning actual planning for strategies of climate change and global warming, thus allowing the G-7 countries to accomplish their ecological sustainability targets. Following are the basic research questions of this study:

1) Does green technology help in GHG emission reduction in G-7 countries?
2) Do environmental taxes and assistance in GHG emission reduction in G-7 countries?
3) Does renewable energy support in GHG emission reduction in G-7 countries?
4) Do natural resources and fossil fuel energy increase the GHG emission levels in G-7 countries?

Literature review

The rising age of technologies transmutes the economies completely, and modern living standards ways arouse adversities and flexibility. The same materializes when technological expansion increase, ecological decay boost, and natural resources decreases appear apparent. Consequently, Shan et al. (2021) elevated this worldwide issue by stirring an adverse association of green technology with ecological damages. Similarly, Danish and Ulucak (2020) examined a system in the course of that environmental technologies influences the pace of green growth in BRICS economies. The empirical evidences show the carbon intensive resources use include direction over renewable and fossil fuel energy reduction. These findings encourage that green technologies contribute toward the increase of green growth, renewable/cleaner energy grounds a significant growth in green growth and, despite the fact fossil fuel energy, have a harmful influence. Likewise, Kilic and Cankaya (2020) unswerve a comparable influence that G-7 and BRICS bloc are prerequisite to invent innovations and techniques in their alternative and clean energy sector to increase the carbon-free environment. Even though it is remarkable that advanced green technologies definitely combat the adverse consequences of the environment, few studies second this element (Sharif et al. 2023; Ke et al. 2022; Wang et al. 2023a). In addition, Du and Li (2019) performed a research to regulate the singularity in the course of which modernizations in green technology influences the productivity of carbon and disclose an alteration between innovations and development in the pace of green technology. Conversely, Hao et al. (2021) discourse that the low emissions and green revolution owing to carbon emissions in G-7 nations. This emphasizes on the role of green development in ratifying sustainable environments by by means of robust approaches. The outcomes reveal that carbon emissions could be alleviated by symmetric and asymmetric relations of green development. Furthermore, it is acknowledged that cleaner energy, human capital, and environmental tax assist to recover the atmosphere, similar parades signified in the studies by Sharma et al. (2021). Moreover, Doğan et al. (2022) examined the influence of an environmental-related taxes on carbon pollution in the

G-7 countries. Correspondingly, this study elucidates the association between characteristics, for example, economic complexity and natural resources that source environmental pollution. The findings also discovered that environmental tax and their governing function control energy deployment and environmental pollution. Nevertheless, the findings validate how these types of taxes can effectively increase the protection of environment and shown as a carbon-free economy.

In the same way, In the case of Pakistan, Khan et al. (2019) discovered the impact of several economic factors, globalization, and energy use on environmental degradation over the span from 1971–2016. The findings indicated that economic globalization, economic growth, energy use, significantly upsurges the pollution level in Pakistan. Furthermore, Muhammad (2019) showed that real output expansion with enhanced energy consumption in developing countries despite the fact that a decrease in MENA countries carbon emissions rise in all countries. Energy utilization increases in all countries but real income growth ascends in all economies with the exclusion of MENA consequently the increase in overall pollution level. Moreover, Waheed et al. (2019) explored that energy use and real income growth are measured as considerable sources of environmental pollution levels, and also, in emerging countries, high deployment of energy resources consequences in a boost in real GDP growth whereas in developed countries pivots a smaller amount on energy use for sustainable economic growth. In the case of the United States, Pata (2021) showed the influence of energy utilization and economic complexity on ecological footprint and observed an encouraging link with ecological contamination. This study's finding shows that the effect of economic complexity was more important as compared to trade openness with the purpose of the achievement of sustainable growth and can assist in accomplishing the targets of long-term growth.

In China, Sarwar et al. (2019) observed that the industrialization process and deployment of non-renewable energy resources considerably augment the carbon emissions in the long run. Afterward, for a global panel, Ozturk et al. (2016) scrutinized the influence of real income, renewable energy, tourism, urbanization, and trade openness on the ecological footprint from 1988 to 2008 in the EKC hypothesis structure. This study's outcomes revealed that fossil fuel energy use exceeds about to augments the ecological footprint. In recent, Appiah-Otoo (2021) scrutinized the influence of economic policy uncertainty and the deployment of renewable energy in 20 economies. The estimated evidence explored that there is the absence of any causal relationship between renewable energy growth and economic policy uncertainty. In addition, Sadiq et al. (2023) also investigated that nuclear and renewable energy deployment reduces ecological footprints in the top nuclear energy consumer economies. Moreover, Khan et al. (2018) investigated that renewable energy deployment reduces the pollution level in the case of Pakistan. Their findings advised that the policymakers and central authorities should boost the consumption of alternative and cleaner energy to decrease the GHGs emissions in the long run.

Research gap

The present study develops the existing literature on the following fronts: initially, this research includes environmental taxes, green technology, natural resources, and renewable and fossil fuel energy in simultaneous framework for the first time for G-7 economies. This research variable model is motivated and magnets strength from the agenda of SDGs targets that is scarcely for the investigated area of research. Furthermore, the present study advances the existent scope of literature in G-7 economies. In recollection, it is discovered in the current literature that green technologies and environmental taxes swiftly renovate consumer actions toward pollution-intensive goods. Likewise, the invention cost of energy-interrelated commodities increases owing to the pragmatic mitigation of GHG emissions. Hereafter, the noteworthy influence between green technologies, environmental taxes, and GHG emissions authenticates the discoveries of Sharif et al. (2023), but still, nations vacillate to levy taxes on tourism, exports, and carbon-intensive commodities because these technologies transform and taxes expressively lessening the GDP growth. After examining the link between a green technology, environmental taxes, and ecological pollution by examining the last scraps of indication, it is found that lacking transformation or adaptation towards environmental patent technology, and environmental taxes, it is not possible to eliminate the consequences of environmental contamination (Sharif et al. 2023; Ramzan et al. 2023; Usman and Hammar (2021); Yang and Usman (2021); Zhengxia et al. 2023; Wang et al. 2023b). Nevertheless, studies are undecided and not clear about the exterior integrated economies operations that use trading industries and banquet dangerous significances of carbon pollution. Additionally, the gap recognized is that rarely studies enlighten the green and cleaner environmental activities for high-income countries considering their alliances with emerging nations. Henceforth, the GHG circle relics reliable due to low stringent strategies followed worldwide to alleviate environmental pollution. Nevertheless, the requirement for applied solutions and ideologies is important to uplift sustainability through adapting complex and novel methods to green technology. Consequently, practical methods must be anticipated to execute environmental taxes and green technologies transformation without hurting green environmental growth to fulfill this gap.

Theoretical framework

The life elegance of human contest has considerably enhanced by the swift pace of technological innovations, energy transition, and economic growth; nevertheless, on the other side, there are innumerable adverse externalities connected with this development. For example, the current energy consumption and demand is considerably higher than it was few previous decades. Maximum power sources are immobile reliant on the non-renewables, subsequent in undesirable externalities from energy consumption and production. Consequently, global organizations and leading economies are nowadays focused to attain sustainable development without lacerating environmental quality. To this end, numerous tools and strategies are recommended and realized to diminish these harmful externalities, precisely carbon emissions. In this regard, environmental technology and taxes play an important role in plummeting ecological contamination, particularly through the renewable and alternative electricity use. Nevertheless, many aspects like natural resources and a nonexistence of suitable environmental tax policies can make the operation and adoption of such technologies more problematic. In this detection, environmental technology and renewable energy can offer sustainable resolutions to discourse the ecological effluence challenge, but such technologies can be excessively affluent or necessitate substantial mechanical expertise. Therefore, it may take time for such technologies to be espoused and combined into the prevailing systems, and the adoption and implementation cost may be a substantial fence. The countries with more differentiated economic actions are more expected to adapt and adopt these green technological innovations since their economies are improved fortified to fascinate the expenses of investments in ecological technology than those with less multifaceted economies. The degree to which renewable and alternative energy is espoused is inclined by economic factors, for example, the accessibility and cost of renewable sources of energy in addition to policy encouragements like taxes and subsidies credits. Besides, the policies related to environmental tax are perilous to encouraging the implementation of ecologically developed technologies. Environmental taxes can perform as inducements to endorse the espousal of renewable and alternative sources of energy by making ecologically destructive actions, such as non-renewable energy exploitation, less desirable or more expensive. The environmental taxes can also assist to lessen the adverse influences of ecological contamination and inspire an alteration toward more maintainable applies. The environmental tax level is resolute by the administration and is archetypally based on the pollution quantity produced by an economy. The profits engendered from the ecological taxes can be applied to endowment investments in environmental technology or to offer inducements for economies to implement renewable production. Altogether, the incorporation of environmental technology, natural resources, environmental taxes, and energy consumption is a multifaceted procedure that necessitates a multi-faceted tactic. Nevertheless, the efficiency of these apparatuses is predisposed by economic factors like the economic growth trajectory level and the accessibility and cost of alternative and renewable energy sources. Policymakers and environmentalists must prudently balance these indicators in order to redesign operative policies for plummeting environmental degradation.

Data and empirical methodology

Data and descriptive statistics

This research employs secondary panel data set from 1994 to 2020 for G-7 countries, comprising Germany, Canada, Japan, Italy, France, the United States, and the United Kingdom. The selection of the time period depends on the availability of data. This study explores the long-run influences of greenhouse gas emission patents on environmental technologies (used as proxy of green technologies) and environmental taxes on greenhouse gas (GHG) emissions, at the same time as controlling total natural resources, renewable energy use, and fossil fuel energy use as other imperative drivers of GHG emissions, the model specification in Eq. 1 as follows:

$$\mathrm{GHG_{it}} = \mathrm{f}\left(\mathrm{GTECH_{it}}, \mathrm{ETX_{it}}, \mathrm{NRR_{it}}, \mathrm{REC_{it}}, \mathrm{FFEC_{it}}\right) \quad (1)$$

To avoid the issue of autocorrelation, data sharpness, scale equivalence, and heteroscedasticity, all the candidate variables are transformed into the natural logarithmic algorithms (ln). The adapted form of Eq. 1 can be stated in the form of Eq. 2 as follows:

$$\begin{aligned}\ln(\mathrm{GHG_{it}}) = {} & \delta_0+\delta_1\ln(\mathrm{GTECH_{it}})+\delta_2\ln(\mathrm{ETX_{it}}) \\ & + \delta_3\ln(\mathrm{NRR_{it}})+\delta_4\ln(\mathrm{REC_{it}}) + \delta_5\ln(\mathrm{FFEC_{it}}) + \mathcal{E}_{it}\end{aligned} \quad (2)$$

where *i* and *t* shows the country and time, ln(GHG), ln(GTECH), ln(ETX), ln(NRR), ln(REC), and ln(FFEC) denote the logarithm of greenhouse gas emissions, patents on environmental technologies, environmental taxes, total natural resources, renewable energy use, and fossil fuel energy use. Further, δ_0 denotes the intercept, and $\delta_1 \rightarrow \delta_5$ presents the slope parameters of candidate series. The term $\mathcal{E}_{it}$ explores the stochastic error term. Table 1 shows the description of variables, measurement unit, and data sources.

The results of descriptive information are presented in Table 2. These findings show that, on average, the G-7 economies illustrate 2.5123 tonnes per capita as GHG

Table 1 Variables, measurement unit, and data sources (1994–2020)

Acronyms	Description	Unit of measurement	Data sources
GHG	Greenhous gas emissions	Tonnes per capita	OECD (2022)
GTECH	Patents on environmental technologies	Total percentage	OECD (2022)
ETX	Environmental taxes	% of GDP	WDI (2022)
NRR	Total natural resources	% of GDP	WDI (2022)
REC	Renewable energy use	% of total final energy use	WDI (2022)
FFEC	Fossil fuel energy use	% of total	WDI (2022)

Table 2 Descriptive statistics

	LGHG	LGTECH	LETX	LFFE	LNRR	LREC
Mean	2.512397	2.263346	0.586301	4.343983	− 1.636634	2.014569
Median	2.392152	2.298577	0.770108	4.400302	− 1.964973	2.152924
Maximum	3.256904	2.763800	1.280934	4.581961	1.610937	3.121924
Minimum	1.780193	1.627278	− 0.415515	3.755940	− 4.539445	− 0.162519
Std. Dev	0.416773	0.289491	0.438288	0.191375	1.639853	0.812583
Skewness	0.465158	− 0.399068	− 0.508560	− 1.612554	0.143422	− 0.744198
Kurtosis	1.957534	2.097426	2.201975	4.611166	1.876750	3.244331
Jarque–Bera	15.37376	11.43182	13.16209	102.3527	10.58377	17.91579
Probability	0.000459	0.003293	0.001386	0.000000	0.005032	0.000129
Sum	474.8430	427.7725	110.8109	821.0128	− 309.3238	380.7536
Sum Sq. Dev	32.65548	15.75536	36.11408	6.885395	505.5543	124.1347
Observations	189	189	189	189	189	189

emissions over the approximately previous three decades. However, the highest GHG is reported as 3.2569 tonnes per capita while lowest is 1.7801. Also, the average value of LGTECH, LETX, LFFE, LNRR, and LREC pragmatic during the study period was 2.2633, 0.5863, 4.3439, – 1.6366, and 2.0145 with a minimum value of 1.6272, – 0.4155, 3.7559, – 4.5394, and – 0.162519 and maximum values of 2.7638, 1.2809, 4.5819, 1.6109, and 3.1219, respectively.

The bivariate analysis of correlation of the series is explored in Table 3. The outcomes report that there is a high and adverse correlation exists between LGTECH and LETX with LGHG emissions. Conversely, it is found a positive and significant correlation exists between LFFE, LNRR, and LREC with LGHG emissions. Furthermore, Fig. 1 presents the trend analysis of selected variables mean in G-7 countries (1994–2020).

Empirical methodology

Cross-sectional dependence tests

In the analysis of panel data, cross-sectional dependency (CD) refers to the situation where there is a correlation or interdependence between the observations of different units (such as individuals, firms, or countries etc.,) at a particular point in time. To address this issue, this study will use second-generation spatial econometric techniques developed by Pesaran (2004; 2006), and Breusch and Pagan (1980) that explicitly account for the correlation between observations. These models allow for the estimation of the effects of time-varying and time-invariant factors on the dependent variable, while controlling for the potential CD issue. The mathematical expression of Pesaran CD test can be reported as follows:

$$\mathrm{CD} = \sqrt{\frac{2(T)}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\beta}_{ik}\right) \sim N(0,1)\ \mathrm{i,k} \tag{3}$$

$$\mathrm{CD} = (1,2,3,4,5\ldots\ldots 62\ldots\ldots N)$$

$$M = \sqrt{\frac{2(T)}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\beta}_{ij}\right)\left[\frac{(T-J)\hat{\beta}_{ij}^{2}-(T-J)\hat{\beta}_{ik}^{2}}{Var(T-K)\hat{\beta}_{ik}^{2}}\right] \tag{4}$$

The term $\hat{\beta}_{ik}^{2}$ denotes the bivariate pairwise cross-correlation of sample estimates which is estimated through the OLS regression method.

Table 3 Pairwise correlation matrix

Series	LGHGS	LGTECH	LETX	LFFE	LNRR	LREC
LGHGS	1.000000					
	—-					
	—-					
LGTECH	−0.188769	1.000000				
	[−2.62864]	—-				
	(0.0093)	—-				
LETX	−0.797679	−0.170753	1.000000			
	[−18.0872]	[−2.36981]	—-			
	(0.0000)	(0.0188)	—-			
LFFE	0.319039	−0.192202	−0.156576	1.000000		
	[4.60335]	[−2.67825]	[−2.16788]	—-		
	(0.0000)	(0.0081)	(0.0314)	—-		
LNRR	0.687073	−0.048993	−0.434912	0.194956	1.000000	
	[12.9311]	[−0.67076]	[−6.60468]	[2.71814]	—-	
	(0.0000)	(0.5032)	(0.0000)	(0.0072)	—-	
LREC	0.078483	0.520371	−0.208093	−0.429912	0.187334	1.000000
	[1.07655]	[8.33309]	[−2.90931]	[−6.51141]	[2.60791]	—-
	(0.2831)	(0.0000)	(0.0041)	(0.0000)	(0.0098)	—-

[] and () designates the *t*-stats and *P*-values, respectively

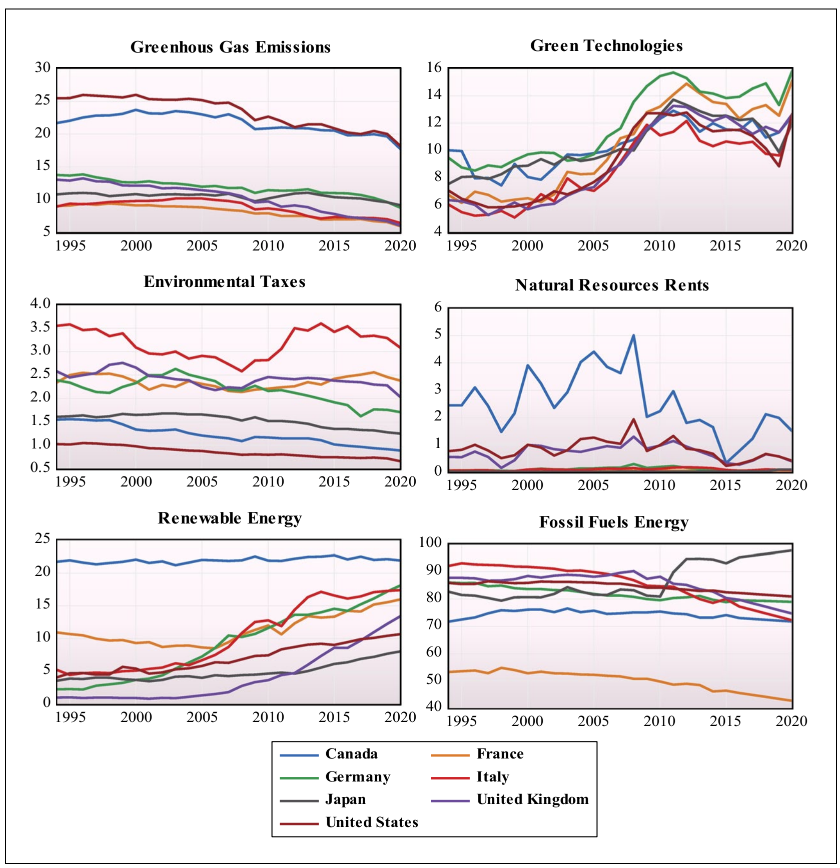

Fig. 1 Trend analysis of selected variables mean in G-7 countries (1994–2020)

Panel unit root tests

After confirming the CD, it is vital to implement panel second-generation stationarity tests. These tests are statistical tests that are used to determine whether a panel dataset exhibits unit root behavior or not. A unit root is a statistical property of a time series where the series has a root that is equal to one, representing that the variables are not following the stationary process and has a stochastic trend (Usman and Makhdum 2021). The cross-sectional Im, Pesaran, and Shin (CIPS), and the cross-sectional augmented Dickey–Fuller (CADF) are the second-generation unit root tests, which has ability to tackle the issue of CD and slope heterogeneity. In this regard, Pesaran (2007) proposed CIPS and CADF methods to tackle the CD across panels. The CADF statistic can be computed as follows:

$$S_{it} = £_i + \beta_i s_{i,t-1} + \xi_i \bar{s}_{t-1} + \eta_i \Delta \bar{s}_t + \varepsilon_{it} \quad (5)$$

Here, Δ presents the first difference operator and ε_{it} and S_{it} denote the error term and selected variables applied in this research. However, incorporating the one lag (previous values) in the above equation, the findings can be presented in the below equation as follows:

$$\Delta S_{it} = £_i + \beta_i z_{i,t-1} + \Omega_i \bar{s}_{t-1} + \sum_{j=0}^{p} \pi_{ij} \Delta \bar{s}_{t-j} + \sum_{j=1}^{p} \mathrm{w}_{ij} \Delta s_{i,t-j} + \mathcal{E}_{it} \quad (6)$$

where $£_i$ explores the constant, $\bar{s}_{t-j}$ and $\Delta s_{i,t-j}$ presents the average and the operators of first difference at the lagged level of each G-7 nations. CIPS test can be reported as follows:

$$\mathrm{CIPS} = N^{-1} \sum_{i=1}^{N} \beta_i(N, T) \quad (7)$$

where the term $\beta_i(N, T)$ term illustrates the coefficient of previous estimate (CADF) test that can be substituted with the contemporary term, and this can be presented as follows:

$$\mathrm{CIPS} = N^{-1} \sum_{i=1}^{N} \mathrm{CADF}_i \quad (8)$$

Westerlund cointegration test

The Westerlund cointegration approach is a statistical test used to determine whether a set of variables are cointegrated in a panel data context. Cointegration is a statistical property of a set of time series data, which indicates that the variables are related in a way that allows for the estimation of a long-run equilibrium association between them. The Westerlund (2007) approach is a second-generation stationary approach that accounts for CD in panel datasets. It is based on the estimation of a common factor model, which allows for a common stochastic trend among the variables (Wang et al. 2023b). The mathematical form of the Westerlund test can be written as follows:

$$\mathrm{G}_\tau = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \frac{\delta_i}{\mathrm{SE}(\hat{\delta}_i)} \text{ and } \mathrm{G}_a = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \frac{\mathrm{T}\delta_i}{\delta\prime_i(1)} \quad (9)$$

$$\mathrm{P}_\tau = \frac{\hat{\delta}_i}{\mathrm{SE}(\hat{\delta}_i)} \text{ and } \mathrm{P}_a = \mathrm{T}\hat{\delta} \quad (10)$$

AMG and CCEMG estimators

For addressing the issue of CD in the estimation of long-run elasticity, this study uses augmented mean group (AMG) and common corelated effect mean group (CCEMG) estimators. The AMG estimator is an extension of the mean group estimator, which assumes that the coefficients of the independent variables are different across individuals or groups within the panel. The AMG estimator, on the other hand, allows for some degree of heterogeneity across groups while imposing a structure on the coefficients. The AMG estimator is useful when there is some degree of heterogeneity among individuals or groups, but the researcher still wants to impose some structure on the coefficients. For example, if a researcher believes that some variables affect all individuals in the panel, while others affect only a subset of individuals, the AMG estimator can be used to estimate the relationship between the variables and the dependent variable while considering this CD and heterogeneity. The heterogeneous panel AMG estimator developed by Eberhardt and Teal (2010) and Eberhardt and Bond (2009) were utilized in this research as following the appearance below:

AMG (first stage):

$$\Delta S_{\mathrm{it}} = \pi_{\mathrm{i}} + \Omega_{\mathrm{i}} \Delta X_{\mathrm{it}} + £_{\mathrm{i}} \mathrm{H}_{\mathrm{t}} + \sum_{\mathrm{t}=2}^{\mathrm{T}} €_{\mathrm{i}} \Delta \mathrm{W}_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \quad (11)$$

AMG (second stage):

$$\hat{\Omega}_{AMG} = \mathrm{N}^{-1} \sum_{i=1}^{N} \hat{\Omega}_{\mathrm{i}} \quad (12)$$

where π_i shows the intercept, X_{it} and S_{it} illustrate selected variables, H_t denotes the in observed common dynamic with individual heterogeneous segments, $\hat{\beta}_{AMG}$ explores the mean-group (MG) of AMG estimators, and finally, ε_{it} shows the random error term. This estimator is calculated by first estimating the coefficients of each individual or group in the panel separately using ordinary least squares (OLS) regression. Then, the individual estimates are combined using a weighted average, where the weights are calculated based on

Table 4 Cross-sectional dependence tests results

Variables	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CSD	
	Stat	Prob	Stat	Prob	Stat	Prob	Stat	Prob
LGHG	439.4671	0.0000	64.5708	0.0000	64.4362	0.0000	20.8204	0.0000
LGTECH	497.7888	0.0000	73.5701	0.0000	73.4355	0.0000	22.2975	0.0020
LETX	190.2017	0.0000	26.1080	0.0000	25.9737	0.0000	8.8255	0.0000
LNRR	172.1818	0.0000	23.3278	0.0000	23.1932	0.0000	7.65507	0.0000
LREC	390.9288	0.0000	57.0812	0.0000	56.9466	0.0000	19.5093	0.0000
LFFEC	377.9464	0.0000	55.0781	0.0000	54.9434	0.0000	7.5417	0.0000

the variance of each individual estimate. The weights ensure that individuals with more precise estimates contribute more to the overall estimate.

Similarly, considering CD and slope heterogeneity issues, Pesaran (2006) proposed the CCEMG test that generates robust and reliable results. The CCEMG test allows the slope heterogeneous parameter crossways of each G-7 countries by origination the mean elasticity of each economy. The evaluation procedure of the CCEMG test can be explored as follows:

$$X_{it} = \theta_{1i} + \pi_i Y_{it} + \lambda_i \xi_{it} + \mu_{it} \tag{13}$$

The augmented explanation with mean of all entities (i) of all variables (dependent and independent) can be reported as follows:

$$X_{it} = \theta_{1i} + \pi_i Y_{it} + \Psi_i \overline{y}_{it} + \delta_i \overline{z}_{it} + +\eta_i \xi_{it} + \varepsilon_{it} \tag{14}$$

Table 5 Unit–root test results (trend and intercept)

Variables	Stats	CADF		CIPS	
		Level	First difference	Level	First difference
LGHG	t-bar	−2.730	−3.606*	−2.345	−4.670*
	P-value	0.116	0.000		
LGTECH	t-bar	−3.505*	−4.430*	−3.179*	−5.423*
	P-value	0.000	0.000		
LETX	t-bar	−2.213	−3.885*	−1.964	−4.411*
	P-value	0.606	0.000		
LNRR	t-bar	−1.943	−3.840*	−2.670	−5.925*
	P-value	0.852	0.000		
LREC	t-bar	−2.369	−4.703*	−2.231	−5.635*
	P-value	0.433	0.000		
LFFEC	t-bar	−1.932	−4.652*	−1.933	−6.304*
	P-value	0.859	0.000		

*significance level at 1%

Results and discussion

In the present research, the authors applied the four dissimilar CD tests, for instance Pesaran scaled LM, Pesaran CD, Breusch–Pagan LM, and bias-corrected scaled LM, to investigate the CD issue properties of the candidate variables. In this regard, Table 4 explores the findings of CD tests, which suggest that all statistic is rejected the null hypothesis of no CD at 1% level of significance. This confirms that there is significant CD issue exists in the data set.

In the very next step, this study applied the second-generation unit tests. Table 5 shows the outcomes of second-generation unit root tests (i.e., CIPS and CADF). The variables LGTECH are stationary at level I (0) in both tests, while all other indicators such as LGHG, LETX, LNRR, LREC, and LFFEC are not following the stationary process at level I (0). However, all the variables are following the stationarity property after taking their first integration order I (1).

Based on the findings of the long-run cointegration test as explored in Table 6, there seems to be a significant link between the variable of interests that lasts for a long term.

Table 6 Westerlund cointegration test results

Statistics	Values	Z-values	P-values	Robust P-values
$G\tau$	−3.4762	4.385	0.009	0.006
$G\alpha$	−6.6709	1.4172	0.7283	0.029
$P\tau$	−12.6435	4.1573	0.002	0.001
$P\alpha$	−13.9352	1.3067	0.045	0.007

The group and panel statistics that Westerlund put together show that this is accurate. The findings show that there is a long-term cointegration exists within the variables.

The long-run estimated coefficients from the analysis of MG, AMG, and CCEMG estimators are reported in Table 7. In this context, the findings explore that the coefficient of green technology (GTECH) is significantly negative. This depicts that that GTECH adversely influences the GHG emissions, a 1% positive change in GTECH will reduce the GHG emissions by 0.2654%, 0.2311%, and 0.2506% according to MG, AMG, and CCEMG regression in the long run in G-7 nations. There are many

Table 7 MG, AMG, and CCEMG long-run analysis findings

Variables	MG				AMG				CCEMG			
	Coeff	Std. Err	*z*-stats	Prob	Coeff	Std. Err	*z*-stats	Prob	Coeff	Std. Err	*z*-stats	Prob
LGTECH	−0.2654*	0.1098	−2.41	0.007	−0.2311*	0.0855	−2.72	0.000	−0.2506*	0.0465	−5.38	0.000
LETX	−0.6822*	0.2657	−2.56	0.000	−0.6788*	0.0994	−6.82	0.000	−0.5124**	0.3002	−1.70	0.032
LNRR	0.1981	0.9854	0.201	0.673	0.1684*	0.0595	2.83	0.004	0.1987*	0.0844	2.35	0.007
LREC	−0.6947*	0.2549	−2.72	0.000	−0.6516*	0.2969	−2.19	0.003	−0.6194**	0.3289	−1.88	0.035
LFFEC	1.7043*	0.3371	5.06	0.000	0.7675*	0.21119	3.63	0.000	0.7497***	0.4548	1.64	0.075
Constant	−4.9194*	1.4465	−3.41	0.001	−0.7419	1.0844	−0.68	0.975	−1.3256	1.5013	−0.88	0.377
RMSE	0.0265				0.0175				0.0207			
Wald Chi^2 (5)	38.75*				535.79*				90.16*			
Prob > Chi^2	0.000				0.000				0.0000			

*Significance level at 1%

**Significance level at 5%

***Significance level at 10%

Source: authors' estimation

reasons that why G-7 countries might choose to protect the environment through GTECH. These countries recognize the need to reduce GHGs emissions in order to combat the harmful effects of climate change, such as rising sea levels, increased frequency of extreme weather events, and loss of biodiversity. Moreover, GTECH sources can help G-7 countries to reduce their reliance on imported fossil fuels, which can enhance their energy security. Reducing pollution and improving air and water quality can have significant health benefits for the population, including reducing the incidence of respiratory diseases and improving overall quality of life (Usman and Radulescu 2022; Usman et al. 2022; Kamal et al. 2021). Furthermore, G-7 countries reveal their commitment to environmental protection and sustainable development by leading the way in the development and adoption of green technologies. Overall, these are the major reasons behind the negative role of GTECH for G-7 countries in the long run.

In context to the role of environmental taxes (ETX), the coefficient of ETX is also negative and significant in G-7 region. Particularly, a 1% augmentation in ETX will diminish the level of GHG emissions by 0.6822%, 0.6788%, and 0.5124% according to MG, AMG, and CCEMG regression in the long run in G-7 nations. The ETX are a policy tool used by G-7 countries to incentivize environmentally friendly behavior and discourage activities that harm the environment. The possible reason behind the environmental taxes that can be imposed on activities that generate pollution, such as emissions from factories or vehicles. By increasing the cost of these activities, ETX encourage individuals and companies to reduce their pollution levels. Moreover, taxes on environmental resources, such as oil or coal, can encourage conservation and the use of alternative, and renewable resources. This can help to reduce the depletion of natural resources and promote sustainable development. Another possible reason behind the negative effect of environmental taxes on GHG emissions is that it can provide an incentive for companies to invest in research and development of cleaner technologies, such as renewable energy sources or more efficient manufacturing processes. Moreover, ETX can generate revenue for governments, which can be used to fund environmental protection programs or other public goods. By increasing the cost of environmentally harmful activities and products, environmental taxes can encourage individuals to make more eco-friendly choices. For example, a tax on plastic bags can encourage people to bring their own reusable bags when shopping.

In context to the role of natural resources (NRR), the coefficient of NRR is positive and significant in the G-7 region. Particularly, a 1% augmentation in NRR will boost the level of GHG emissions by 0.1981%, 0.1684%, and 0.1987% according to MG, AMG, and CCEMG regression in the long run in G-7 nations. In this regard, it is observed that natural resource degradation is a significant environmental challenge in G-7 countries, as the exploitation of natural resources can have negative impacts on the environment. The positive coefficient of natural resources is that the clearing of forests for timber, agriculture, or other uses can lead to habitat loss, soil erosion, and biodiversity loss. Deforestation also contributes to climate change by releasing CO_2 into the atmosphere. Moreover, mining for minerals and other resources can lead to soil and water pollution, habitat destruction, and the release of toxic chemicals into the environment. Another reason is that the extraction of oil and gas can lead to habitat destruction, air and water pollution, and the release of greenhouse gases into the atmosphere, contributing to climate change (Usman and Makhdum 2021). Moreover, the exploitation of natural resources in

G-7 countries can have significant negative impacts on the environment (increase GHG emissions), including loss of biodiversity, soil and water pollution, habitat destruction, and climate change. The conceivable reason is that it is important for G-7 countries to adopt sustainable practices that balance the need for resource use with the need to protect the environment and promote sustainable environment. This can include measures such as sustainable forestry practices, responsible mining, renewable energy development, and sustainable water management.

In context to the role of renewable energy (REC), REC and fossil fuels energy sources have significant impacts on the environment of G-7 countries. Specifically, the coefficient of REC is also negative and significant in G-7 region. Particularly, a 1% augmentation in REC will diminish the level of environmental pollution by 0.6947%, 0.6516%, and 0.6194% according to MG, AMG, and CCEMG regression in the long run in G-7 nations. These findings in line with the conclusion of (Usman and Makhdum 2021; Usman et al. 2021; Pata 2021; Ibrahim et al. 2022; Usman et al. 2023; Jahanger et al. 2023). In recent years, these countries have been making efforts to reduce their dependence on nonrenewable energy sources and shift towards renewable energy sources to address the challenges of climate change and energy security. Renewable energy sources generate fewer greenhouse gas emissions than nonrenewable sources. Renewable energy sources like wind, solar, and hydropower can help mitigate climate change by reducing the carbon emissions (Saqib et al. 2022; Ayad et al. 2023). Renewable energy sources enhance energy security, reduce dependence on imported fossil fuels, and minimize the risks of supply disruptions, thereby improving energy security for G-7 countries. Renewable energy sources have a low impact on the environment since they do not produce waste products or emit harmful pollutants (Jahanger and Usman 2023).

Moreover, in context to the role of fossil fuel energy (FFEC), the coefficient of FFEC is positive and significant in G-7 region. Particularly, a 1% augmentation in FFEC will boost the level of GHG emissions by 1.7043%, 0.7675%, and 0.7497% following to the estimation of MG, AMG, and CCEMG analysis in the long run in G-7 nations. These findings corroborated with the conclusion of (Jahanger et al. 2023). The use of FFEC sources has significant environmental impacts, including air and water pollution, habitat destruction, and climate change (Makhdum et al. 2022; Jahanger et al. 2023; Saqib et al. 2023). The dependence on nonrenewable energy sources from politically unstable regions poses risks for energy security. Though FFEC sources are readily available and have been used as a primary energy source, this energy sources provide a reliable source of energy for transportation, industry, and homes for decades. The price volatility of nonrenewable energy sources affects the economic and national security of these countries. In conclusion, these countries are making efforts to reduce their dependence on nonrenewable energy sources and shift towards REC sources. The transition to REC has significant economic, environmental, and security impacts. These impacts should be considered while developing energy policies and strategies for the G-7 countries. In conclusion, both types of energies have significant environmental impacts in these economies. The environmental impacts of both types of energy sources should be considered while developing energy policies and strategies for the transition to sustainable energy systems (Fig. 2).

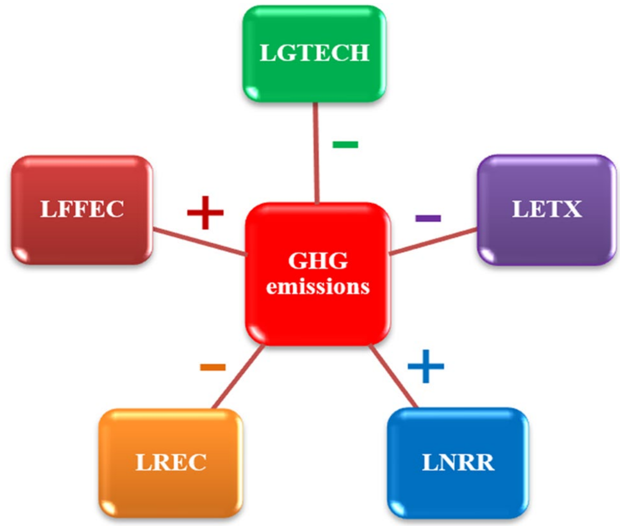

Fig. 2 Graphical presentation of long-run findings

Conclusion and policy implications

This study investigates the influences of green technologies, environmental taxes, natural resources, renewable energy, and fossil fuels energy use on GHG emissions of the G-7 economies between 1994 and 2020. After confirming the issue of cross-sectional dependency, this study applied the second-generation procedure for econometric estimation. The estimated evidences from the analysis of regression revealed that green technologies, environmental taxes, and renewable energy diminishes the GHG emissions in the region, while natural resources and fossil fuel energy deteriorates the eminence of environment in the long run.

Based on such estimated evidences, well-nigh sustainable strategies are proposed to improve the green environmental scheme in G-7 economies. Principally, the green technology variable portrays the undesirable influence on GHG emissions. Therefore, investors and policymakers enhance their processes by communicating green strategical tactics universally through the means of exports and imports, foreign investments, and authorizing from high-income to low-income countries. By executing this, rough market constancy diminishes, and sustainability upsurges largely. Likewise, in the course of growth-oriented financial policies, per capita income boosts. Based on this, G-7 economies pledge instructive programs and capability/skill knowledge programs to produce eco-friendly technological innovations that will advantage in extenuating GHG emissions. By doing so, they can help mitigate the impacts of climate change, enhance their energy security, create new economic opportunities, improve public health, and demonstrate their commitment to sustainable development. Correspondingly, researchers strain the consequence of ecological taxes in invigorating the unadorned significances of ecological contamination. Estimated findings reveal that central authorities must levy high taxes on carbon-containing goods and abandon private administrations for startup productions that exploit fossil fuel/non-renewable energies. Additionally, with the support of tax assortments, carbon-free consciousness agendas, contributions, and knowledge must be uniform.

Likewise, the energy and industrial sector of G-7 economies is a prodigious contributor to GHG emissions. Therefore, a prearranged tax outline will execute to diminish the extraction of fossil fuels/nonrenewable energy and encourage low-emission equipment. By doing so, G-7 bloc can accomplish the arranged goal with developed economies to upsurge the market share of biofuels. In general, environmental taxes can help to protect the environment in G-7 countries by incentivizing sustainable behavior, promoting innovation, and generating revenue for environmental protection programs. However, it is important to design these taxes carefully to avoid unintended consequences, such as disproportionately impacting low-income individuals or businesses, or incentivizing environmentally harmful activities in other countries with weaker environmental regulations.

Lastly, there are some caveats of this investigation that should be addressed in upcoming studies. This research only investigated the G-7 economies. Consequently, comparison between developed and emerging economies were left out. Upcoming studies aimed at a larger sample of developed and developing countries might enhance to a more inclusive information of the current nexus. Data limitation/unavailability is another limitation of this study. Additionally, this research only investigated the linear role of green technologies, and environmental taxes but not included the social macroeconomic indicators such as (rule of law, corruption, regulatory authority, etc.). Future studies should investigate this nexus within the STIRPAT framework in G-7 economies.

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