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ORIGINAL PAPER

The role of energy intensity, green energy transition, and environmental policy stringency on environmental sustainability in G7 countries

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Abstract

The increase in energy intensity and energy depletion may lead to faster depletion of natural resources and increased environmental impacts. The green energy transition can improve environmental quality by reducing the pressure on natural resources and the carbon footprint. At this point, public environmental regulations are significant for environmental sustainability. On the one hand, the environmental policy stringency imposes high environmental taxes on polluting activities and, on the other hand, provides R&D support to clean technologies. This study examines the impact of energy intensity, energy depletion, green energy transition, and environmental policy stringency on load capacity factor in G7 countries from 1990–2020 using common correlated effects mean group and augmented mean group panel long run estimators. The study's robust results show that i) energy intensity has a negative impact on environmental sustainability in Germany, Italy, and the USA, ii) energy depletion has a negative impact on environmental sustainability in Canada and France, and iii) green energy transition has a positive impact on environmental sustainability in Japan. G7 countries must reverse the adverse effects of energy intensity and energy depletion by accelerating the transition to green energy. These countries with significant fiscal capacity should use environmental policy instruments that include environmental taxes.

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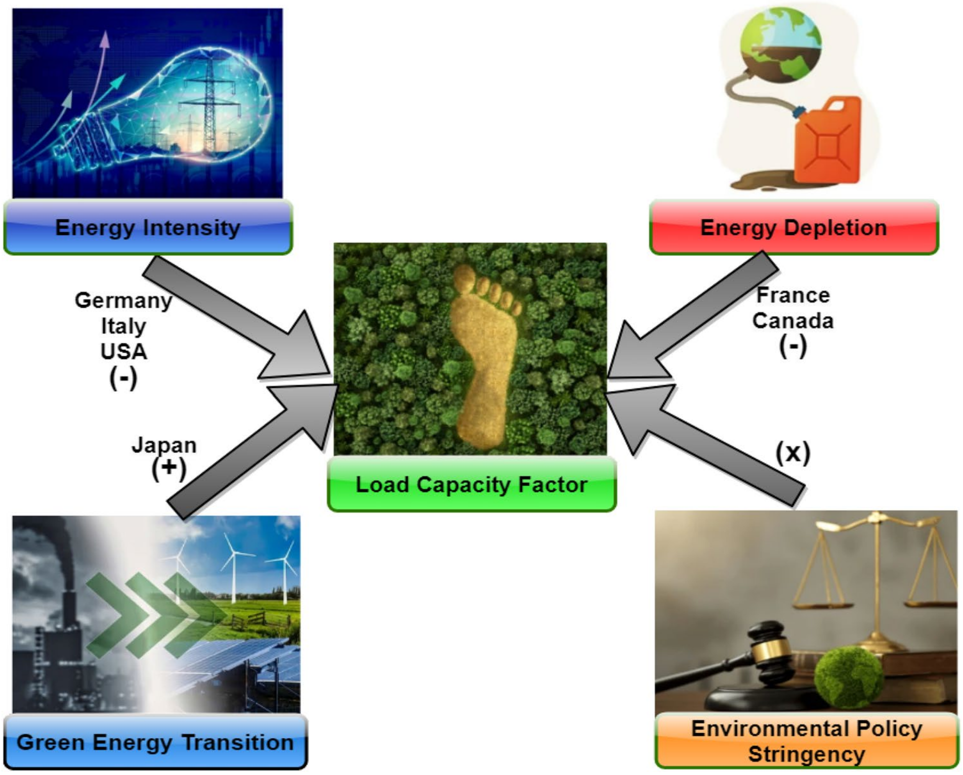
Graphical abstract



Keywords Energy intensity · Natural resource depletion · Renewable energy · Environmental policy stringency · Load capacity factor

Introduction

Nowadays, environmental problems have become an increasing source of concern. Climate change, energy depletion, and overuse of natural resources threaten ecosystems and human health worldwide. The fact that countries maintain their growth targets puts pressure on natural resources and, therefore, on the ecology. In this context, environmental sustainability aims to achieve a long run balance by focusing on goals such as protecting natural resources, energy efficiency, and minimizing environmental impacts (Apergis et al. 2023).

Energy intensity refers to the amount of energy used for each unit of goods or services produced in an economy. This concept is critical in determining the relationship between a country's economic activities and energy consumption (Bosseboeuf et al. 1997). While, increasing energy intensity means that an economy grows using more energy, this can lead to faster depletion of natural resources and increased environmental impacts. Increases in energy intensity are often directly related to increases in energy demand. This means intensive use of fossil fuels, contributing to increasing carbon emissions and exacerbating environmental problems such as climate change (Shakya et al., 2022). In addition, energy intensity may contribute to energy depletion (Khan et al. 2022c). Increases in energy depletion and energy intensity, which interact with each other, are worrying in terms of sustainability, and in this context, the adoption of energy productivity and green energy alternatives is a crucial step to increase environmental sustainability (Namahoro et al. 2021; Lee and Ho 2022). Determining the effects of energy intensity on environmental sustainability will also contribute to efforts to balance growth and ecological protection.

Green energy transition refers to a strategic transition from traditional, carbon-intensive energy sources to clean, sustainable, and low-carbon energy sources (Dong et al. 2022). This transformation can be a solution against factors that threaten environmental sustainability, especially energy depletion and energy intensity. The contributions of the transition of green energy to environmental sustainability gain importance primarily through its potential to reduce energy depletion (Ahmad et al. 2023). Green energy sources, especially solar, wind, hydropower, and biomass,

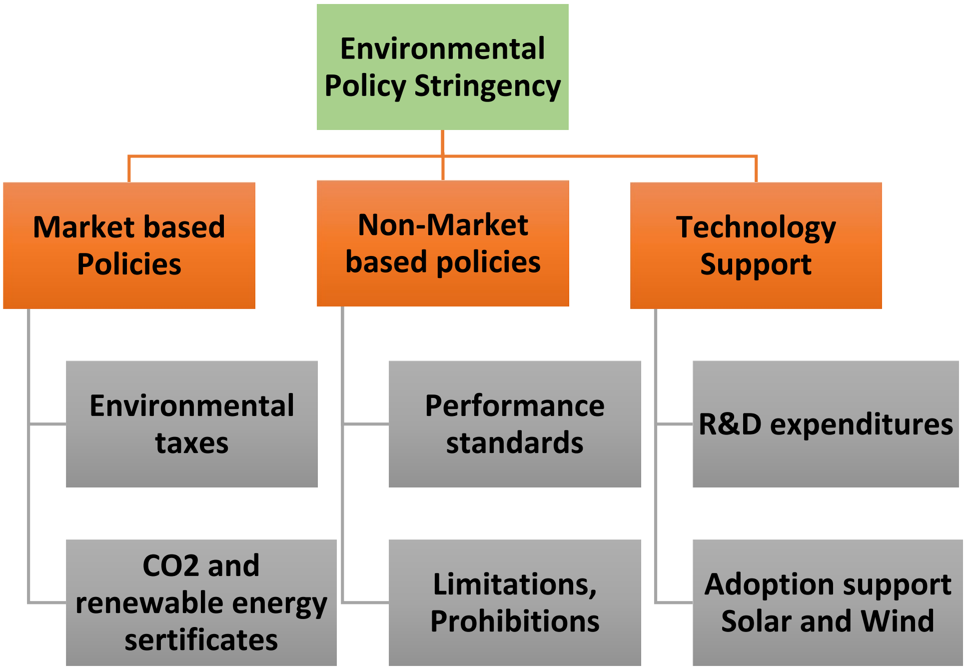


Fig. 1 Components of environmental policy stringency

can use natural resources and sustainably produce energy. This means reducing energy production based on fossil fuels and allowing energy resources to be used for longer periods. In addition, the transition to green energy aims to reduce energy intensity. Renewable energy sources have a lower energy intensity than conventional energy production. This results in fewer natural resources for the same amount of energy production and, therefore, a decrease in energy intensity (Gales et al. 2007; Feng et al. 2023). This is an essential step towards increasing environmental sustainability because lower energy intensity enables more efficient use of natural resources. Another advantage of the transition to green energy is that it will improve sustainability in economic and industrial sectors. The development and proliferation of renewable energy technologies allow businesses to manage energy use more efficiently and in an environmentally friendly way (Bashir et al. 2022; Wang et al. 2022). This can help companies to reduce their costs and minimize environmental impacts.

Environmental policy stringency plays a critical role in achieving environmental sustainability goals. This strategy, on the one hand, internalizes environmental costs by applying high environmental taxes to polluting activities, and on the other hand, encourages innovation with incentives such

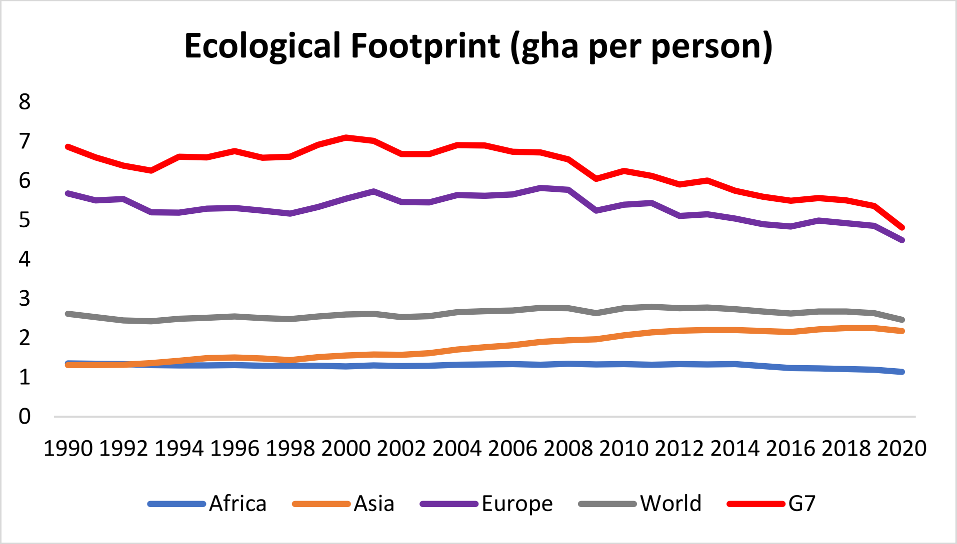


Fig. 2 Ecological footprint. *Source*: Global Footprint Network

as R&D support for the development of clean technologies (Wang et al. 2020; Li et al. 2023). These effects of environmental policy stringency are shown in Fig. 1.

Figure 1 shows that market-based and nonmarket-based policies are environmental regulations used to deter polluting activities. Technology support is the ecological regulation that promotes clean technologies and energy resources.

Environmental taxes increase polluting activities' costs and encourage companies to switch to environmentally friendly practices. This allows companies to manage environmental costs more effectively and transition to sustainable business practices. High environmental taxes also encourage environmental responsibility and provide a mechanism to reduce the environmental impacts of economic activities. R&D support for developing clean technologies is an essential tool that encourages innovation. These supports provide financial resources to companies and research institutions to develop environmentally friendly technologies (Khurshid et al. 2022). In this way, the emergence and dissemination of technologies that increase energy efficiency, reduce carbon footprint, and aim to use natural resources more sustainably are encouraged (Safi et al. 2023). Additionally, using ecological regulations is an aspect of environmental policy stringency (Afshan et al. 2022). Public environmental regulations, such as limiting, quotas, and bans on polluting activities, are practical tools to achieve environmental sustainability goals. These regulations direct industries towards cleaner and greener practices, improving environmental quality standards and optimizing resource use. Consequently, environmental policy stringency offers a comprehensive strategy to reduce the environmental impacts of economic activities (Wolde-Rufael and Mulat-Weldemeskel 2021). This approach, which combines various tools to sustain economic growth and achieve ecological sustainability goals, is a critical framework aiming to achieve a long run balance.

Based on this background, this study examines the effects of energy depletion, energy intensity, green energy transition, and environmental policy stringency on environmental sustainability in G7 countries from 1990–2020. By focusing on G7 nations, which wield significant economic power and influence, this research seeks to shed light on the critical role of energy policies and practices in shaping global sustainability efforts. Furthermore, the study aims to uncover how interactions between these factors influence environmental outcomes, providing valuable insights for policymakers and stakeholders. The study of G7 countries is based on several important reasons. First, G7 countries have high economic power, accounting for a large share of the world economy. These countries' high energy demand and consumption increase their impact on energy intensity, energy depletion, and environmental impacts. Therefore, the energy policies and practices of G7 countries play a decisive role in global energy use and environmental sustainability. Second, G7 countries are leaders in technological innovation and R&D. Environmentally friendly technologies, energy efficiency solutions, and sustainable practices developed in these countries are important factors that promote environmental sustainability globally. Third, G7 countries play a decisive role in global economic relations and diplomacy. These countries' environmental policies can impact other countries through international agreements and environmental regulations. Finally, the ecological footprint is significantly higher in G7 countries. This situation is shown in Fig. 2.

Although environmental quality in G7 countries tended to increase after 2008, the economic development of these countries slowed down the improvement in ecological quality. It is thought that environmental problems in G7 countries will continue unless green growth models are developed.

This study has several novelties, unlike previous literature. Although previous literature has examined the effects of energy intensity (Bekun et al. 2021), energy depletion (Abbasi et al. 2021; Khan and Bazai 2023), green energy

Table 1 Ecological quality and energy intensity

Author	Sample	Method	Finding
El Anshasy and Katsaiti (2014)	From 1972 to 2010 131 countries	p. d. analysis	Energy intensity → environmental sustainability (−)
He and Lin (2019)	From 2003 to 2017 China	PSTR	Energy intensity → environmental sustainability (✓)
Danish et al. (2020)	from 1985 to 2017 USA	p. d. analysis	Energy intensity → environmental sustainability (−)
Koyuncu et al. (2021)	from 1990 to 2015 Turkey	TAR	Energy intensity → environmental sustainability (-)
Bekun et al. (2021)	From 1990 to 2017 27 EU nations	p. d. analysis	Energy intensity → environmental sustainability (−)
Shokoohi et al. (2022)	From 1971 to 2015 three countries	ARDL	Energy intensity → environmental sustainability (-)
Khan et al. (2022a)	From 1990 to 2016 APEC countries	p. d. analysis	Energy intensity → environmental sustainability (−)
Chu and Le (2022)	From 1997 to 2015 G7 countries	p. d. analysis	Energy intensity → environmental sustainability (−)
Shahzad et al. (2023)	from 1970 to 2018 ten countries	QQ	Clean energy intensity → ecological quality (+)
Hasan and Adnan (2023)	From 1980 to 2018 32 countries	p. d. analysis	Energy intensity → environmental sustainability (✓)

+: positive effect, −: negative effect, ✓: relationship

Table 2 Ecological quality and energy depletion

Author	Sample	Method	Finding
Khan et al. (2016)	From 2000 to 2013 nine nations	GMM	Energy depletion → environmental sustainability (✓)
Bhuiyan et al. (2018)	From 1995 to 2016 13 nations	GMM	Energy depletion → environmental sustainability (−)
Hussain et al. (2020)	From 1990 to 2014, 56 nations	CCEMG	Natural resource depletion → environmental sustainability (−)
Abbasi et al. (2021)	From 1980 to 2018, Thailand	ARDL	Energy depletion → environmental sustainability (−)
Zhang et al. (2022)	From 1990 to 2020, 48 nations	CSARDL	Natural resources rents → environmental sustainability (−)
Hossain et al. (2023)	From 1980 to 2019 USA	ARDL	Energy depletion → environmental sustainability (−)
Ullah et al. (2023)	From 1985 to 2018 Pakistan	AARDL	Energy depletion → environmental sustainability (+)
Huo and Peng (2023)	From 1971 to 2019 China	ARDL	Natural resource depletion → environmental sustainability (+)
Khan and Bazai (2023)	From 1990 to 2022 Pakistan	ARDL	Energy depletion → environmental sustainability (−)
Lin and Ullah (2024)	From 1990 to 2020 Pakistan	DARDL	Energy depletion → environmental sustainability (−)

+ : positive effect, − : negative effect, ✓: relationship

Table 3 Ecological quality and environmental policy stringency

Author	Sample	Method	Finding
Cole et al. (2005)	1990–1998 UK	Panel data	Environmental regulations (+)
Povitkina (2018)	1970–2011 144 countries	Panel regression	Environmental policy stringency (+)
Wang et al. (2020)	1990–2015 23 OECD countries	SYS-GMM	Environmental policy stringency (x)
Ahmed (2020)	1999–2015 20 OECD countries	PMG	Environmental policy stringency (✓)
Jain et al. (2021)	1984–2017 Nine Asian countries	Panel data anl	Environmental policy stringency (−)
Kongbuamai et al. (2021)	1995–2016 BRICS countries	D.H. causality	Environmental policy stringency (+)
Lu et al. (2022)	1993–2019 China	NARDL	Environmental policy stringency (+)
Wang et al. (2022)	2000–2018 15 Central and Eastern European nations	Panel data anl	Green tax (+)
Afshan et al. (2023)	2000–2017 China	QARDL	Environmental policy stringency (+)
Khurshid et al. (2023b)	1990–2020 38 OECD nations	PMG-ARDL	Green tax (+)
Balsalobre-Lorente et al. (2023)	1994–2018 APEC countries	Panel FMOLS	Environmental policy stringency (+)
Kazemzadeh et al. (2023a)	1990–2019 G7 nations	MM-QR	Environmental policy stringency → indoor and outdoor deaths (−)
Borowiec and Papież (2024)	1992–2019 38 countries	DCCE-MG	Environmental policy stringency (✓)

+ : positive effect, −:negative effect, ✓:relationship

transition (Murshed 2020; Bouyghrissi et al. 2022), and environmental policy stringency (Yirong 2022; Khurshid et al. 2022, 2023a; Dai and Du 2023) on ecological quality separately, no study has been found that discusses the collective impact of these factors, which drive and interact with each other. Additionally, these studies mainly examined carbon emissions and ecological footprint. Using the load capacity factor, which considers both the supply and demand sides of natural resources, provides a more comprehensive framework for environmental sustainability. Finally, this study obtained robust results using the second-generation CCEMG and AMG long run estimators. At these points, this study is expected to contribute to the literature.

The study includes four main chapters. The first chapter explains the theoretical background of environmental issues. Second chapter presents the literature summary. Third chapter introduces the empirical methodology and reports findings. The last chapter discusses the empirical results and delivers policy recommendations for the policymakers.

Literature review

Energy intensity briefly represents the energy required for one unit of economic growth. Energy intensity is a widely used indicator, especially in studies on the environment and energy. Although reducing energy intensity is very important for green growth, it is not enough for a sustainable environment (DeSimeno and Popoff, 2000). Table 1 presents studies examining the effects of energy intensity on ecology.

Since, the energy sector is a carbon-intensive sector, studies on this subject have mostly examined carbon emissions.

Table 4 Ecological quality and green energy transition

Author	Sample	Method	Finding
Murshed et al. (2021)	From 1990 to 2016 6 nations	p. d. analysis	Green energy transition → environmental sustainability (+)
Sun et al. (2022)	From 1995 to 2018 BRICS nations	MM-QR	Green energy transition → environmental sustainability (✓)
Khan et al. (2022b)	From 1990 to 2015 OECD countries	p. d. analysis	Green energy transition → environmental sustainability (+)
Onwe et al. (2023)	From 1994 to 2020 G7 countries	MMQ	Green energy transition → environmental sustainability (+)
Bashir et al. (2023)	From 1995 to 2019 10 countries	CS-ARDL	Green energy transition → environmental sustainability (+)
Apergis et al. (2023)	From 1980 to 2015 USA	ARDL	Green energy → environmental sustainability (+)
Ahmad et al. (2023)	From 1990 to 2018 G11 countries	CS-ARDL	Green energy transition → environmental sustainability (+)
Kazemzadeh et al. (2023b)	From 1990 to 2017 64 nations	MM-QR	Green energy transition → environmental sustainability (+)
Kazemzadeh et al. (2024)	From 2006 to 2020 75 countries	p. d. analysis	Green energy transition → environmental sustainability (+)
Alam et al. (2024)	From 1996 to 2021 BRICS	Panel d. a	Clean energy transition → environmental sustainability (+)

+ :positive effect, ✓:relationship

It is accepted, including empirical analyses, that energy intensity has an increasing effect on carbon emissions. While, Chu and Le (2022) argue that total energy intensity reduces ecological quality, Shahzah (2023) argues that clean energy intensity increases ecological quality. No study has examined the effects of energy intensity on the load capacity factor, providing a broad perspective on environmental sustainability.

Industrialization and urbanization are the main reasons for natural resource depletion. Concrete evidence shows that natural resources increase pollutant emissions and degrade the ecosystem (Yi et al. 2023). Natural resource depletion is widely used to maintain ecological quality and determine sustainability. Natural resource depletion is an essential reflection of economic performance, and this indicator is recognized in the literature (Khan et al. 2021). The energy sector is responsible for at least 75% of air pollution today. Today, where dependence on polluting resources continues, the depletion of conventional energy resources is significant in terms of both environmental sustainability and energy sustainability. In this context, energy depletion within natural resource depletion has attracted attention in the literature in recent years. The literature on the connection between energy depletion and the environment is shown in Table 2.

While, most studies show that energy depletion negatively affects ecological degradation, Ullah et al. (2023) argue that it has positive effects. Similarly, unlike other studies, Huo and Peng (2023) draw attention to the positive effects of natural resource depletion on the ecology. Studies are primarily focused on a single country, and studies on country groups are a minority. Finally, studies in this area have focused on impacts on pollutant emissions rather than impacts on environmental sustainability.

Today, energy depletion and ecological problems are increasing. Increases in energy demand have directed policymakers to green energies. While, governments use environmental taxes to prevent turning to polluting sources, they also provide R&D support to increase the focus on renewable energies. The ecological policy stringency index is a comprehensive indicator that includes all these public instruments. The literature on the connection between the environmental policy stringency and the ecology is shown in Table 3.

Studies have focused on the effects of green taxes and R&D supports separately on the ecology. Few studies have examined the ecological impacts of environmental policy stringency. Additionally, these studies focus on the effects of public regulations on pollutant emissions and lack a comprehensive indicator representing environmental sustainability. Finally, while most studies argue that government regulations positively affect ecology, Jain et al. (2021) argue that they have negative effects.

Table 5 Detailed explanation of variables. *Source*: Authors

Variables	Specifications	Data origin
Load capacity factor (LCF)	$\frac{\text{Biocapacity}}{\text{EF}}$	Global Footprint Network
Energy intensity (EI)	Per capita, toe	OECD Data
Energy depletion (ED)	Percentage of GNI	World Bank
Environmental policy stringency (EPS)	Index	OECD Data
Green energy transition (GET)	Renewable energy c. (% of energy consumption)	World Bank

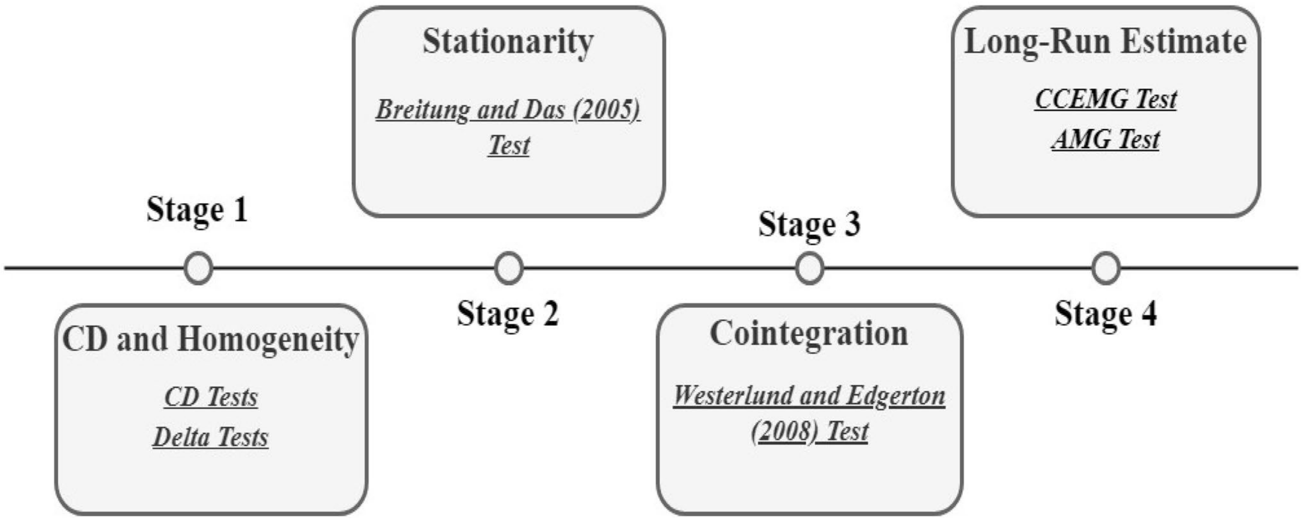


Fig. 3 Empirical approach

Table 6 Empirical analysis (Stage 1)

CSD				Slope homogeneity	
Variables	CD_{LM}	CD_{BP}	CD	Test	Test stat
LCF	36.80^{a}	259.54^{a}	12.33^{a}	$\hat{\Delta}$	5.371^{a}
EI	50.87^{a}	350.71^{a}	17.68^{a}		
ED	21.53^{a}	160.57^{a}	9.27^{a}	$\hat{\Delta}_{Adj}$	5.981^{a}
GET	57.87^{a}	396.10^{a}	18.19^{a}		
EPS	80.73^{a}	544.25^{a}	23.30^{a}		

‘a’, signify that the null hypothesis was rejected at the ‘1%’ significance level

Table 7 Empirical analysis (Stage 2 and 3)

Breitung and Das unit root analysis			Cointegration analysis	
Variables	I(0)	I(1)	Westerlund and Edgerton (2008)	
LCF	−0.169	-2.880^{a}	$LM\tau$	-2.495^{a}
EI	0.494	-1.957^{b}		
ED	−1.180	-2.168^{b}	$LM\varphi$	-4.791^{a}
GET	1.257	-2.059^{b}		
EPS	1.401	-3.893^{a}		

‘a’ and ‘b’ signifies that the null hypothesis was rejected at the ‘1%’ and ‘%5’ significance levels

Many market-based, command and control, and technology-based public policies are implemented to prefer renewable resources to polluting sources. The proliferation of green energy is vital for ecological sustainability. Many researchers have examined the relationship between green energy and ecological quality. Researchers have mainly examined energy consumption. However, energy consumption is expected to increase with population and urbanization. Therefore, the green energy transition, which shows the share of clean energies in energy consumption, has become an indicator that has attracted more attention in recent years. Table 4 presents the literature on the relationship between the transition to green energy and ecological sustainability.

The majority of studies show that clean energy increases ecological quality. Onwe et al. (2023) found that green energy increases ecological quality in G7 countries. Other studies in the table, including these studies, used the carbon emissions or ecological footprint. These indicators, which do not consider the supply side of natural resources, are considered insufficient to represent environmental sustainability.

If the studies are evaluated in general, the effects of energy depletion, energy intensity, clean energy transition, and environmental policy stringency variables on ecology were examined individually. No study has been found that examines these variables, which are interrelated and have the potential to affect ecology together. In addition, the authors paid attention to carbon emissions, which were considered insufficient to represent environmental sustainability, and only provided data on air pollution. While, the results of the studies could be more consistent, the use of inadequate variables to represent environmental sustainability and the failure to examine these variables that interact with each other has necessitated research in this field.

Theoretical framework, data collection, empirical methodology, and findings

This study aims to reveal the impact of EI, ED, EPS, and GET on LCF for G7 countries (see Table 5) from 1990 to 2020. Table 5 offers a detailed exposition of the variables' specifications. The variables of energy intensity, energy depletion, green energy transition, and environmental policy stringency were chosen due to their significant relevance to environmental sustainability within the context of G7 countries. The green energy consumption of G7 countries is quite high. Additionally, these countries have significant financial resources. In this way, they can use environmental policies effectively. Energy intensity and depletion directly impact resource management and environmental impact, while green energy transition and policy stringency are critical strategies for mitigating environmental challenges. These variables were selected to provide a focused analysis of key determinants shaping environmental sustainability in the G7 nations.

This study explored the factors affecting LCF, an indicator of environmental quality, through the model shown in Eq. 1, encompassing the following explanatory variables.

$$LCF_{it} : a_0 + a_1 EI_{it} + a_2 ED_{it} + a_3 EP + a_4 GET + \varepsilon_{it} \tag{1}$$

The empirical approach shown in Fig. 3 was employed in the empirical examination of this model.

Table 8 Empirical analysis (Stage 4)

Robustness analyses: Long run estimates

Countries	Method	EI	ED	GET	EPS
Canada	CCEMG	−0.008	**−0.089**^{a}	−0.010	0.005
	AMG	−0.122^{a}	**−0.090**^{a}	−0.007	−0.021^{b}
France	CCEMG	0.035	**−1.763**^{c}	−0.004	0.010
	AMG	−0.027	**−2.207**^{a}	0.005	0.009^{c}
Germany	CCEMG	**−0.080**^{b}	−0.195	−0.003	0.005
	AMG	**−0.067**^{b}	−0.175	−0.003	0.034^{a}
Italy	CCEMG	**−0.037**^{c}	−0.024	0.002	−0.008
	AMG	**−0.037**^{a}	−0.075	0.004^{a}	−0.008^{c}
Japan	CCEMG	0.009	−0.838	**0.007**^{a}	−0.001
	AMG	−0.006	0.190	**0.004**^{a}	0.003
United Kingdom	CCEMG	−0.033	−0.004	0.003	0.018^{c}
	AMG	−0.028	−0.026^{b}	0.004^{b}	−0.007
United States	CCEMG	**−0.052**^{b}	0.105^{a}	0.005	0.012
	AMG	**−0.127**^{a}	−0.004	−0.001	−0.028^{c}
Panel	CCEMG	−0.024	−0.401	−0.001	0.006^{c}
	AMG	−0.059^{a}	−0.341	0.001	−0.002

The values with the bold represent robust results that are significant for both estimators

'a', 'b', and 'c' signify that the long-term coefficients are statistically significant at '1%', '%5', and '%10' significance levels

The empirical investigation stage of this study was organized into four stages, as shown in Fig. 3. In line with this, the preliminary stage assesses cross-sectional dependence (CSD) and slope homogeneity. In panel data analysis, it is necessary to scrutinize crosssection dependence (CSD) and slope homogeneity to ensure the reliability and accuracy of the analyses carried out in subsequent phases. In this regard, this research explores CSD with Breusch and Pagan's (1980) CD$_{\mathrm{BP},}$ Pesaran's (2004) CD$_{\mathrm{LM}}$, and Pesaran's (2015) CD approaches. While, the CD$_{\mathrm{BP}}$ and CD$_{\mathrm{LM}}$ examinations scrutinize CSD, assuming the absence of CSD, the CD test discloses the strength of CSD under the assumption that CSD is weak. The outcomes of the CSD analyses indicate that, based on the results from the CD$_{\mathrm{BP}}$ and CD$_{\mathrm{LM}}$ tests, a CSD exists for all variables in Eq. 1, and this CSD is vital, as indicated by the CD test (see Table 6). Within the investigation, the homogeneity of the slope in the model shown in Eq. 1 was assessed using the Delta examinations suggested by Pesaran and Yamagata (2008). In Delta tests, homogeneity is detected through $\widehat{\Delta}$ and $\widehat{\Delta}_{Adj}$ test statistics under the hypothesis of homogeneity, as per the outcomes of both delta analysis, heterogeneity is shown in the model. (See Table 6).

During the second stage of the empirical approach, we investigate the stationarity of the variables in the model through the Breitung (2001)-Breitung and Das (2005) unit root method. This method allows the CSD and exhibits good properties in small sample sizes. The null hypothesis of the method posits the existence of a unit root. The results in Stage 2 revealed that despite unit roots at the level for all variables, they exhibited stationarity at the first differences. This outcome leads to the deduction that all variables are integrated of order 1 (I(1)) (see Table 7).

Taking into account the results of the stationarity analysis, the third stage of the research focused on investigating the long run relationship in the model shown in Eq. 1. This inquiry was carried out through the Westerlund and Edgerton (2008) cointegration analysis. The reason for using this analysis is that it takes into account the CSD and possible structural breaks detected in the previous steps. Westerlund and Edgerton's (2008) approach assesses the null hypothesis of the absence of a relationship by using $LM\varphi$ and $LM\tau$ statistics through the cointegration model in Eq. 2, which considers structural breaks in determining a long run relationship.

$$\Delta \widehat{S}_{it} = \text{constant} + \varphi_i \widehat{S}_{it-1} + \sum_{j=1}^{pi} \varphi_{ij} \Delta \widehat{S}_{it-1} + \text{error} \tag{2}$$

$$LM\varphi(i) = T\widehat{\varphi}_i\left(\frac{\widehat{\omega}_i}{\widehat{\sigma}_i}\right),\ LM\tau(i) = \frac{\widehat{\varphi}_i}{Se(\widehat{\varphi}_i)} \tag{3}$$

where '$\widehat{\varphi}_i$' expresses the least squares estimate, while '$\widehat{\sigma}_i$' represents the estimated standard errors.

The findings in Stage 3 indicate that LCF and explanatory variables move together in the model in the long run (see Table 7).

In the fourth stage, robust outcomes were achieved by employing two distinct long run estimators (Pesaran's (2006) common correlated effects mean group (CCEMG) and Eberhardt and Bond's (2009) augmented mean group (AMG)) to elucidate the magnitude of the long run relationship. Taking into account the robust results from both tests, the following conclusions (see Table 8):

According to Table 8, the significant and robust findings are as follows:

- In Canada and France, ED negatively influences LCF.
- In Germany, Italy, and the United States, the impact of EI manifests as a reduction in LCF.
- In Japan, GET positively affects LCF.
- There is no robust finding for the effect of EPS in any country.

Based on theoretical expectations, energy intensity could undermine environmental sustainability since it requires more energy for the output. We found that energy intensity decreases environmental quality in Germany, Italy, and the United States. It also negatively impacts the environment in Canada. However, the findings are not robust. Energy intensity should decrease to achieve a better environment and protect natural resources. Many studies confirm that energy intensity increases environmental pollution (Shahbaz et al. 2015; Esso and Keho 2016; Namahoro et al. 2021). The negative impact of energy depletion could lead to environmental degradation. Energy depletion refers to decreased fossil fuel stocks in a certain period. Energy depletion also poses some risks to ecological sustainability in France and Canada. It is also considered a barrier to economic growth (Lin and Ullah 2024). Therefore, energy depletion has revealed the importance of green transition. However, unfortunately, we found a statistically positive impact of green transition only for Japan. Green transition discussions have just begun to be discussed globally, especially since the Paris Agreement. Therefore, the significant effects of the green transition will be seen in the coming years. According to the findings, no robust finding was captured for environmental stringency However, it is known that increasing environmental policy stringency encourages countries and companies to identify new adaptation and mitigation policies in the fight against climate change. This result also briefs us on the insufficient stringency policies in environmental sustainability.

Conclusion and policy recommendations

Environmental sustainability is a serious issue for current and future generations, and it requires complex environmental and economic policies. Therefore, countries must integrate economy, energy, environmental, and infrastructure policies. An increase in energy intensity and energy depletion could undermine environmental quality through fossil fuels. Green transition is vital to reverse this process since it mitigates environmental degradation by increasing renewable supply and protecting natural resources. Therefore, countries with high carbon footprints should simultaneously apply public environmental regulations requiring strict environmental policy through environmental incentives. This study investigates the effect of energy intensity, energy depletion, green energy transition, and environmental policy stringency on ecological sustainability in G7 countries from 1990 to 2020. The findings reveal that energy intensity exacerbates environmental sustainability in Germany, Italy, and the USA, energy depletion negatively impacts Canada and France, and green energy transition positively impacts Japan. Finally, we failed to capture any robust findings for environmental policy stringency. When comparing empirical findings, we see that while some studies found similar results, some studies reach the opposite. For instance, (Sun et al. 2022; Onwe et al. 2023; Kazemzadeh et al. 2024) found that green transition contributes to environmental sustainability as we capture a positive link in Japan. In parallel to our finding, Wang et al. (2020) found no significant impact of environmental policy stringency on environmental sustainability, however, studies generally found a positive relationship between environmental sustainability and environmental policy stringency (Cole et al. 2005; Ahmed 2020; Afshan et al. 2023; Borowiec and Papież, 2024). Some studies even found a negative association between the variables (Jain et al. 2021). Bhuiyan et al. (2018), Abbasi et al. (2021) and Hossain et al. (2023) revealed that energy depletion affects environmental sustainability as we found for Canada and France. However, Ullah et al. (2023) capture an adverse effect of energy depletion on the environment. Finally, Danish et al. (2020), Koyuncu et al. (2021) and Bekun et al. (2021) confirmed our finding which refers that energy intensity contributes to environmental sustainability.

Energy depletion and energy intensity could be barriers to achieving better environmental quality and a green economy since they could trigger fossil fuel consumption. However, researchers have recently begun to discuss the decoupling between economic growth and environmental degradation (Karakaya et al. 2021; Jiang et al. 2022; Akdoğan et al. 2023). To achieve decoupling environmental pollution from economic growth, it is vital to develop long-term combinations of economy, energy, and environmental policies. Therefore, G-7 countries should develop efficient environmental strategies to reverse the negative impact of energy intensity and energy depletion. In this case, another key strategy is focusing on how to realize the green transition. For instance, in 2019, the European Union created a comprehensive strategy to transition to a green economy in the fight against environmental degradation through the European Green Deal. Some critical targets of the European Green Deal are as follows: i) achieving net zero emissions by 2050, creating a circular economy, decoupling resource use from economic growth, and ensuring that other countries adapt to these processes through cross-border adjustment (European Commission., 2021). Through the border carbon adjustment, the European Green Deal forces not only European countries to transition to green but also other countries with commercial relations with Europe. In this context, market-based approaches are crucial for countries seeking to sustain economic activities with European countries. However, we found that green transition is only significant in Japan. We believe that countries need time to see a strong impact of the green transition on environmental sustainability. Giving importance to environmental tax policies, which are essential in measuring environmental stringency for G7 countries, can be an effective tool because these countries have significant financial capacity to implement ambitious environmental strategies.

The most surprising result from the empirical analysis is that we found no robust findings for any country regarding environmental policy stringency. This result shows no clear impact of environmental policy stringency, even in top-developed countries. G7 countries account for approximately 30% share of global GDP (Statista 2023). Therefore, it is impossible to achieve environmental sustainability without the contribution and effort of the G7 countries. In this context, G7 countries should focus more on environmental policy stringency. However, the critical point here is to achieve balance. Otherwise, investors may shift their investments to countries with lower environmental regulations due to ecological stringency, as underlined in the *Pollution Haven Hypothesis*. This could further exacerbate environmental degradation. In this context, countries should correctly identify activities that cause climate change and environmental problems and conduct environmental pollution analysis to determine the negative environmental externalities. Then, policymakers should adopt long-term and specific economic, energy, and environmental strategies.

Environmental policy stringency not only leads to better environmental quality, but also positively affects other dimensions of sustainable development through production, technology, investment, human capital, innovation and efficiency. Therefore, it is not the right strategy for governments to consider environmental policies as an obstacle to economic growth. Combining economic and environmental policies will support the environment and sustainable development (Ahmad et al. 2024). The countries included in the empirical analysis are all welfare economies. A decoupling between environmental pollution and economic growth is easier to achieve in these countries. Therefore, strict environmental policies will also trigger this decoupling and facilitate the green transition. In addition, encouraging environmental technologies through environmental patents and R&D will also positively affect this divergence. Porter, (1996) argued that environmental regulations are generally used to correct market failure, whereas these regulations will stimulate productivity and R&D activities and positively affect production costs by encouraging technological change.

The load capacity factor is an essential indicator for environmental research as it considers several ecological dimensions. However, the study has some limitations. First, research that identifies the subcomponents of the total load factor and examines the effect of independent variables on different indicators could provide specific findings and policy recommendations. For future research, we recommend researchers examine load capacity factor on a global scale and capture empirical findings according to the countries' income levels.

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Declarations

Conflict of interest The authors declare no competing interests.

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