Geoscience Frontiers 14 (2023) 101564

Contents lists available at ScienceDirect

Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

Research Paper

Does patents on environmental technologies matter for the ecological footprint in the USA? Evidence from the novel Fourier ARDL approach

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ARTICLE INFO

Article history:
Received 22 October 2022
Revised 16 January 2023
Accepted 31 January 2023
Available online 4 February 2023
Handling Editor: Ugur Pata

Keywords:
Patents on environmental technologies
Eco-innovation
Ecological footprint
USA
Fourier ARDL
Fourier Toda Yamamoto causality

ABSTRACT

The outcome of patents on environmental (POET) technologies on the EF in the USA has not been comprehensively explored. Therefore, to close this breach in the literature, the present study discovers how patents on ecological technologies affect ecological footprint (EF) in the USA while regulatory for GDP and EC using the Fourier-based approaches. The conclusions of the present study reveal that POET are an important predictor of EF in the USA and cause a reduction in ecological deprivation in the long run; as expected, economic growth negatively affects environmental sustainability. The outcomes suggest that it is possible to resolve conflicts between the economy and the environment by using technological innovation. The USA government must reconsider its policy focus, particularly on coal energy sourcing and industrial energy, while continuing with heavy investments in its ambitious renewable energy technology development plan. Moreover, the government should continue to promote investments in environmental technologies.

1. Introduction

As human society grows, greenhouse gas emissions are increasing, thus affecting food, lives, and other areas, which hinders socio-economic activities and the quality of life for citizens. Several studies have indicated that high CO_2 emissions significantly contribute to this problem (Hassan et al., 2019; Sofuoğlu and Ay, 2020; Caglar, 2022). Natural resources are being exploited endlessly, and inequalities between people are increasing due to the deregulation of the environment and endless exploitation of natural resources (Nguyen-Van-Quoc et al., 2022). The COP26 conference held in Glasgow highlighted the importance of setting ambitious targets for reducing discharges by 2030 to attain net zero emissions by 2050.

The proxies for environmental issues have been the focus of extensive discussions in the literature. As a result, many studies commonly use CO_2 emissions to gauge ecological damage (Kartal et al. 2023a; Ullah et al. 2023) as CO_2 account for approximately 70 % of all GHGs and are thought to be one of the leading causes of universal warming (Afshan and Yaqoob, 2022; Irfan et al. 2023). Nevertheless, it can be a poor indicator (Asuzu et al., 2022). Since it aims to address the primary industrial and other human operations that lead to rising ecological deterioration, the present paper considers (EF) to be a more comprehensive assessment of the ecological issue (Ramzan et al. 2022). Most prior literature has only used a single ecological factor, such as CO_2, as a proxy for ecological deterioration. Nevertheless, it is usually observed that the ecological atmosphere is impacted by human activities which dampens the water and land quality; consequently, it is necessary to use a thorough indicator that comprehensively reflects the factors of ecological deterioration. Therefore, the present investigation used EF as a proxy for environmental degradation. Although many indicators are utilized to examine environmental pollution, CO_2 emissions is the most

Abbreviations: ADF, Augmented Dickey-Fuller; ADL, Autoregressive Distributive Lag; AIC, Akaike Information Criteria; AMG, Augmented Mean Group; ARDL, Distributed Lag; BEM, Big Emerging Market; CO_2 emissions, Carbon Dioxide Emissions; DOLS, Dynamic Ordinary Least Squares; DSUR, Dynamic Seemingly Unrelated Regression; EC, Energy Consumption; EF, Ecological Footprint; EG, Economic Growth; EU, European Union; FMOLS, Fully Modified Ordinary Least Squares; GDP, Gross Domestic Product; GHG, Greenhouse Gas Emissions; GMM, Generalized Method of Moments; OECD, The Organization For Economic Cooperation And Development; POET, Patents on Environmental Technologies; QARDL, Quantile Autoregressive-Distributed Lag; SDGs, Sustainable Development Goals; UN, United Nations; USA, The United States of America.

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https://doi.org/10.1016/j.gsf.2023.101564
1674-9871/

frequently used as a proxy for ecological dilapidation (Apergis et al., 2020; Pata and Aydin, 2020), as it essentially represents air pollution. However, ecological footprint takes production and consumption processes into account and calculates different dimensions of environmental dilapidation (Dogan et al., 2020). EF calculations provide a better idea of ecological deprivation as they benefit from a broader methodology (Pata, 2021a; Galli et al., 2012; Pata and Isik, 2021; Alola & Adebayo, 2022). Therefore, it has recently been used in many explore examining environmental degradation (Usman et al., 2020; Nathaniel et al., 2021; Liu et al., 2022; Alper et al., 2022; Ahmed et al., 2022). Wackernagel and Rees (1998) used the term EF to describe the amount of space needed for a sustainable population.

Several initiatives and variables have been established to generate growth that is harmless to the ecosystem in order to achieve ecological sustainability (Zhang et al., 2023; Ağa et al. 2023). Technological advancement stands out for at least three reasons. First, its essential for overcoming growth constraints. Examples include the technological advancements proposed by Neoclassical and New Growth Theorists and the technological intervention described in the Malthusian Theory of Population Growth. The significant problems for the ecosystem caused by growth are extrapolated from the interfering roles of technology in addressing concerns surrounding growth theories. Second, technological progress will improve adaptation and moderation plans for ecological pollution. Thus, technology is the most significant solution for fighting the increasing adverse impacts of ecological decline (Adebayo, 2022). Thirdly, the interaction of technology affects the efficiency of other variables, including green energy, service-driven industries, and ecological policy, among others.

The factors mentioned above are the important causes of technological advancement. Rapid expansion has been witnessed in the United States in recent decades due to substantial technological innovations (Alola et al., 2019; Caglar et al., 2022; Kartal et al. 2023b). Massive investments in research and technology have enabled the US economy to grow, demonstrating the government's commitment to using technology to promote a sustainable path. The United States now ranks highly among nations in terms of technological advancements; in particular, the growing trend in artificial intelligence highlights the country's devotion to technological development (Abbasi et al., 2022; Wang et al. 2023). On the flipside, the USA still ranks highly among countries that emit harmful environmental pollutants (Tsai et al., 2016). Moreover, the volume of US carbon emissions has consistently increased over the years. This paradox calls into question the extent to which technological innovation in the USA is capable of controlling environmental degradation. The USA's existing and future technological prospects and strengthening its ambition to create a sustainable environment through its net zero emissions objectives of 2050 are dependent on the provision of workable answers to this conundrum. The United States' growing trend in CO_2 emissions is inextricably linked to the country's economic growth. There appears to be a positive correlation between the ecological deteriorate and real ouput, which substantially adds to the rapid acceleration of the economic deterioration within the country. Given the USA's leadership in worldwide economic growth and its dependence on fossil fuels (Kirikkaleli and Adebayo, 2021), the fact that carbon emissions continue to grow is unsurprising. Investigating the role of economic development in the United States carbon neutrality model is therefore crucial to make positive policy changes that can preserve environmental quality.

Fig. 1 shows CO_2 emissions per capita and patents on environmental technologies in the USA. Accordingly, while the share of environmental patents in GDP increased in the period 2000–2012 period, it started to decrease after 2012. In addition, CO_2 emissions per capita increased gradually until the 2008 global financial crisis, which triggered a downward trend in the following period.

The present paper examines how technological advancements in the environment mitigate the USA's ecological footprint. To the writers' acquaintance, there are no comprehensive studies in the literature on the effect of POET on the environment in the context of the USA. Therefore, our study examines the impact of patents on environmental technologies on pollution reduction. Environmental innovations are necessary to reduce emissions. Implementing innovation in many areas, such as pollution regulator, requires the selection of the right channel. Innovations in both processes and products go hand in hand. Changing a product requires the production process to be updated and the channel by which the deviations will be employed to be upgraded. The model also considers other reasons that affect ecological footprint, such as GDP and energy use.

The novelty of the current study is explained below, based on the stated aims. First, pragmatic research analyses these correlations using nonlinear techniques, despite the abundance of empirical investigations assessing the contribution of innovations to drive towards ecological sustainability. Secondly, to further strengthen the policy insights that would result from the subsequent studies, the major determinants of ecological footprint are considered in the present study. Thirdly, the paper utilizes advanced econometric approaches, including the Fourier ARDL developed by Yilanci et al. (2020). This method identifies structural changes using Fourier functions. Thus, no additional structural change test or modification of the estimated model for the structural change are required.

The study is structured as: A summary of earlier studies is presented in Section 2. The methods and findings are obtainable in Sections 3 and 4, respectively. The conclusion and policy directions are shown in Section 5.

2. Literature review

2.1. Ecological footprint and economic growth

Large number of studies explored the nexus among EC and EF. For example, Uddin et al. (2016) scrutinized the interconnection between EF and GDP in 22 countries using data from 1961 to 2011. The authors used the vector error correction method to explore this association, revealing that real growth positively influences EF. Using data from 1985 to 2017, Ahmed et al. (2021) used DOLS,FMOLS to assess the association between the ecological footprint of G7 nations. The results revealed that economic expansion impacts EF positively. Moreover, Jahanger et al. (2022) assessed the environment-growth nexus using data from 1990 to 2016. They used the LRC method to explore the association between EF and economic expansion. The results discovered a positive linking between EF and economic growth. Ahmed et al. (2020) scrutinized the link between EF and economic expansion in the situation of Pakistan using data between 1971 and 2016. The outcomes from their study showed that EF and economic expansion are positively connected.

Using data from 1990 to 2016, Jahanger et al. (2022) used SGPUR - long-run cointegration tests- to assess the nexus among EF and GDP in the case of 73 developing nations. The results from their study showed a positive nexus between EF and GDP. Likewise, Wang et al. (2022) scrutinized the linking between EF and economic progress in 166 provinces using data from 1990 to 2015. The authors used a second-generation econometric methodological framework to explore this association and the results from this analysis revealed that economic expansion influences EF

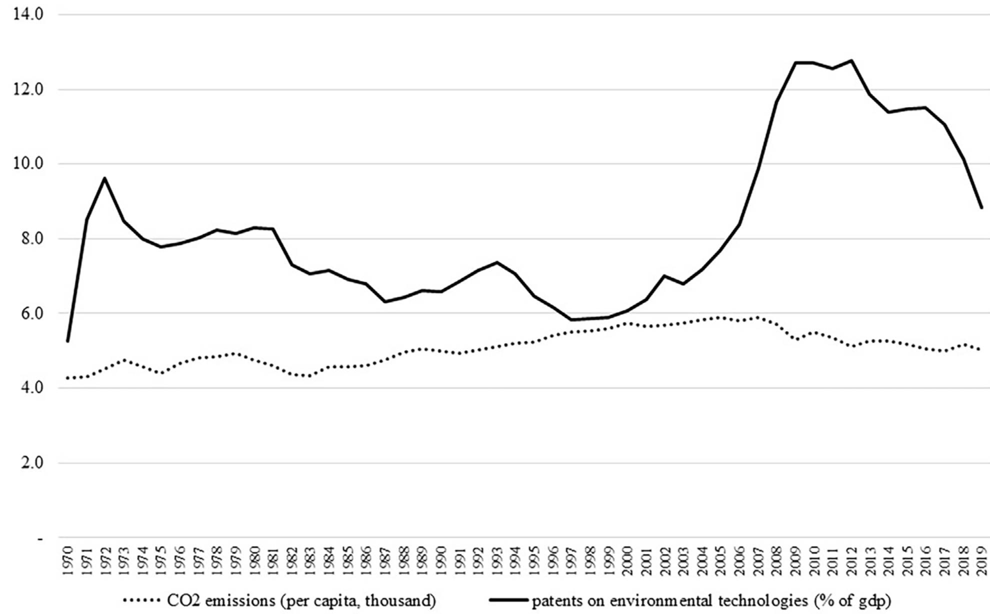

Fig. 1. CO_2 emissions and environmental patents.

positively. Çakmak et al. (2022) inspected the nexus between EF and EG in the top oil-producing nations using data from 1999 to 2017. The investigators used the Dumitrescu-Hurlin and GMM tests to explore the association, and the findings exposed that ecological footprint has no impact on economic expansion. Moreover, Destek and Sarkodie (2019) inspected the nexus between EF and EG in 11 nations using data from 1977 to 2013. The authors used AMG and HPC methods to investigate the association, with the findings revealing a positive connection. Dada et al. (2022) explored the interconnection between EF and EG in Nigeria using data from 1970 to 2017 by employing the ARDL approach. The results obtained revealed that EG contributes positively to EF. Similarly, Ikram et al. (2021) explored the interconnection between EF and EG in Japan using data from 1965 to 2017. The QARDL method was used to inspect the association, and the analysis findings revealed that EG positively influences EF.

2.2. Ecological footprint and energy consumption

As well known, energy is vital for economic activities but its unsustainable use can harm the environment (Kartal & Ullah, 2023). Destek and Sinha (2020) observed the linkage between EF and EC in the case of cooperation and development countries using data from 1980 to 2014. The authors used second-generation panel data to investigate this association, and this analysis showed that an upsurge in energy usage causes a reduction in EF. Likewise, Shahzad et al. (2021) observed the association between EF and EC in the case of the USA using data from 1965 to 2017. The authors used QARDL to explore the association. The outcomes of the investigation indicated that EC has a substantial effect on EF. Using data from the period between 1995 and 2016, Kongbuamai et al. (2021) aimed to investigate the nexus between EF and energy consumption for the BRICS nations. Similarly, their findings exposed that energy consumption has a positive effect on EF. Chen et al. (2019) inspected the link between EF and EC in CEE nations using data from 1991 to 2014. The DSUR approach was used to investigate the association and the outcomes showed a positive EF-EC association.

Salari et al. (2021) inspected the interconnection between EF and EC in emerging nations utilising data from 2002 to 2016. The research disclosed that EC has a negative influence on EF. Liu et al. (2022) explored the link between EF and energy consumption in Pakistan using data from between 1980 and 2017. The findings revealed that EC impacts EF positively. Moreover, Alper et al. (2022) analysed the connection between EF and EC in the case of 7 nations using data from 1970 to 2017. The findings obtained via the ARDL method indicated that EC has an adverse effect on EF.

2.3. Ecological footprint and technological innovation

Destek and Manga (2021) scrutinized the connection between EF and technological innovation (TI) in the case of the BEM nations utilising data from 1995 to 2016. The author used second-generation panel data to inspect the association. The findings showed that technological innovation has no influence on EF. Using data from the period between 1992 and 2018, Chunling et al. (2021) used ARDL to examine the connection between EF and technological innovation in the case of Pakistan. The results revealed that technological innovation increases EF. Using data between 1995 and 2015, Chu et al. (2022) used the advanced panel quantile method to examine the connection between EF and technological innovation in the 27 OECD nations. The results revealed that technological innovation has an impact on EF. Using data from the period between 1985 and 2016, Rout et al. (2022) used the ADL method to scrutinise the connection between EF and technological innovation in the Southeast Asian nations. The findings showed that technological innovation reduces the ecological footprint.

Hassan et al. (2022) analysed the linking between ecological footprint and technological innovation in the case of South African nations using data between 1981 and 2017. The authors used FMOLS and DOLS to explore the nexus. The findings revealed that TI decreases EF. Using data between 1990 and 2017, Kongbuamai et al. (2021) used the STIRPAT framework scheme to inspect the link between EF and TI in the WAME countries. The outcomes showed that technological innovation decreases EF. Using data between 1995 and 2019, Guan et al. (2022) used the ARDL technique to inspect the nexus between EF and technological innovation in the G-10 nations. The outcomes revealed that technological innovation reduces EF.

Though studies have surfaced regarding the nexus bewteen technological innovation and the environment in developed and developing countries but there is no comprehensive study conducted regarding the effect of POET on the EF for the case of the USA. This is the main aim of the present study. The another novelty of the paper is to use the Fourier ARDL which identifies structural changes using Fourier functions. Therefore, no additional structural change test or modification of the estimated model for the structural change are required.

3. Data and methodology

This paper aims to capture the effect of POET on the EF in the USA from 1970 to 2018 by applying the Fourier ARDL approach while controlling GDP and EC. Eq. (1) represents the model for the empirical analysis.

$$LEF_t = \beta_1 LPOET_t + \beta_2 LGDP_t + \beta_3 LEC_t + \varepsilon_t \tag{1}$$

where *LEF*, *LPOET LGDP* and *LEC* stand for ecological footprint, patents on environmental technologies, *GDP* and *EC*, respectively. Table 1 and Table 2 show the description of the indicators and descriptive statistics of the time series, respectively. Standard cointegration tests cannot be applied where the variables are integrated to varying degrees. To overcome this problem, the (ARDL) cointegration test was suggested by Pesaran et al. (2001). The ARDL approach enables independent indicators to be integrated at different degrees if the dependent variable is I(1). Eq. (2) shows the ARDL model for this study.

The cointegration connection between the variables is examined by contrasting the test statistics with the lower and higher bounds designated as I(0) and I(1). The fundamental hypothesis that there is no cointegration is rejected if the test statistic is higher than the crucial upper bound values. Eq. (2) displays the ARDL model for the study.

$$\begin{aligned}\Delta LEF\text{t} = {} & \beta 0 + \beta 1LEF\text{t-1} + \beta 2LPOET\text{t-1} + \beta 3LGDP\text{t-1} \\ & + \beta 4LEC\text{t-1} + \textstyle\sum_{i=1}^{\rho-1} \varphi \text{i}\prime \Delta LEF\text{t-i} \\ & + \textstyle\sum_{i=1}^{\rho-1} \gamma \text{i}\prime \Delta LPOET\text{t-i} + \textstyle\sum_{i=1}^{\rho-1} \delta \text{i}\prime \Delta LGDP\text{t-i} \\ & + \textstyle\sum_{i=1}^{\rho-1} \varnothing \text{i}\prime \Delta LEC\text{t-i} + et\end{aligned} \tag{2}$$

"Δ represents the first difference operator, represent the lag length and et show the disturbance term with zero mean and finite variance. The optimal lag length is chosen using the Akaike Information Criteria (*AIC*)". Pesaran et al. (2001) determined the cointegration relationship by using the *F* test (F_A) and *t*-test (*t*), as shown below.

$$H0A : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0 \tag{3}$$

$$H0B : \beta_1 = 0 \tag{4}$$

Eqs. (3) and (4) were modified by McNon et al. (2018) to create a new F-test (F_B) that examines the null hypothesis, as displayed in Eq. (5).

$$H0C : \beta_2 = \beta_3 = \beta_4 = 0 \tag{5}$$

For the cointegration relationship, Eqs (4), (5) and (6) must be rejected. However, this approach gives more robust results than the standard ARDL approach. McNon et al. (2018) neglected the integration degree of the variables. However, compared to the standard ARDL, this approach provides more robust empirical results. Furthermore, this method identifies structural changes using Fourier functions. Thus, no additional structural change test or modification for the estimated model for the structural change are required. The Fourier function created by Yılancı et al. (2020) considers structural changes in the model, as seen in Eq. (6).

$$d(t) = \textstyle\sum_{k=1}^{n} ak \sin\left(\frac{2\pi kt}{T}\right) + \textstyle\sum_{k=1}^{n} bk \cos\left(\frac{2\pi kt}{T}\right) \tag{6}$$

"where *'n'* indicates the number of frequencies, π = 3.14, *'k'* is the number of special frequencies selected, *'t'* is the trend, and *'T'* is the sample size" (Serener et al., 2022). A single frequency value suggested by Ludlow and Enders (2000) is used in Eq. (6).

$$\text{d}(t) = \gamma 1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma 2 \cos\left(\frac{2\pi kt}{T}\right) \tag{7}$$

The FARDL model for this study is shown in Eq. (8).

$$\begin{aligned}\Delta LEF\text{t} = {} & \beta 0 + \gamma 1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma 2 \cos\left(\frac{2\pi kt}{T}\right) + \beta 1LEF\text{t-1} \\ & + \beta 2LLPOET\text{t-1} + \beta 3LGDP\text{t-1} \\ & + \beta 4LEC\text{t-1} + \textstyle\sum_{i-1}^{\rho-1} \varphi \text{i}\prime \Delta LEF\text{t-i} \\ & + \textstyle\sum_{i-1}^{\rho-1} \delta \text{i}\prime \Delta LPOET\text{t-i} + \textstyle\sum_{i-1}^{\rho-1} \varnothing \text{i}\prime \Delta LGDP\text{t-i} \\ & + \textstyle\sum_{i-1}^{\rho-1} \vartheta \text{i}\prime \Delta LEC\text{t-i} + et\end{aligned} \tag{8}$$

The frequency value at the minimum sum of squared is employed by Yilanci et al. (2020) as Christopoulos and Leon-Ledesma (2011) and Omay (2015) suggested. Using bootstrap simulation, they choose the *CV* for the F_A, F_B, and *t*-tests.

4. Empirical results

In the study, we first apply the FADF unit root test. However, the Fourier trigonometric terms are not significant since LPOET and LEC statistics are smaller than the CV identified by Enders and Lee (2012). In this case, Enders and Lee (2012) recommended the application of the ADF test. Table 3 shows the unit root test results. According to the ADF test results, the series are I(1). For the FARDL bounds test, it is sufficient for the dependent variable to be stationary at the first difference. Therefore, the unit root test results allow testing cointegration between the indicators. Table 4 shows the FARDL cointegration results.

According to the FARDL cointegration analysis results, it is seen that the F_A, t and F_B test stat are larger than the Bootstrap CV. This finding proves that there is a long-term cointegration relationship between the variables. Table 5 shows the FARDL framework.

According to the findings, the coefficient of LPOET is negative, while LGDP is positive, and LEC is insignificant. Therefore, while economic growth increases the ecological footprint, patents on environmental technologies have a negative impact on it. The outcomes show that it is possible to resolve conflicts between the

Table 1
Data Description.

Data	Unit	Code	Period	Source
Ecological footprint	Total gha (global hectar)	LEF	1970–2018	Global Footprint Network
GDP	Constant 2015 international $	LGDP	1970–2018	World Bank
Primary energy consumption	Exajoules	LEC	1970–2018	BP Statistical World Review of Energy
Patents on environmental technologies	% in total	LPOET	1970–2018	OECD

Table 2
Descriptive Statistics.

	LEF	LPOET	LGDP	LEC
Mean	32.68801	2.085042	30.01248	4.422132
Median	32.30188	2.046381	30.02795	4.457516
Maximum	34.53612	2.547881	30.62302	4.574371
Minimum	29.94164	1.662030	29.27714	4.179743
Std. Dev.	1.258455	0.242587	0.411970	0.123687
Skewness	−0.012600	0.542739	−0.198149	−0.372215
Kurtosis	2.966165	2.225108	1.698934	1.631002
Jarque-Bera	0.003708	3.705666	3.853801	5.059022
Probability	0.998148	0.156792	0.145599	0.079698
Sum	1634.401	104.2521	1500.624	221.1066
Sum Sq. Dev.	77.60172	2.883573	8.316236	0.749624
Observations	49	49	49	49

Table 3
Fourier ADF (FADF) and ADF Unit Root Test Results.

Variables	k	FADF test statistics	F test	ADF (level)	ADF (Δ, first difference)
LEF	10	−5.87*	12.95*	−0.63	−7.26*
LPOET	3	−2.97	3.68	−0.70	−7.23*
LGDP	6	−2.77	4.50	4.11	−2.55*
LEC	9	−2.74	12.34*	2.08	−5.32*

The FADF critical values are 10.35, 7.58 and 6.35 for 1%, 5% and 10%, respectively.* shows 1% significance level.

Table 4
FARDL Test Results.

		Bootstrap critical values			t	Bootstrap critical values			F_B	Bootstrap critical values		
Optimal frequency	F_A	10 %	%5	%1		10 %	%5	%1		10 %	%5	%1
1	13.41*	6.85	7.84	10.29	−6.41*	−4.43	−4.81	−5.52	8.97*	4.96	5.94	8.61

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

Table 5
Long-run estimation results based on the FARDL model (LEF is the dependent variable).

LPOET	LGDP	LEC
−4.19*	2.06**	−4.47
(0.00)	(0.02)	(0.40)

Note: Numbers in parentheses show the p-values. * and ** show the significance level at the 1% and 5%.

Table 6
Diagnostic Result for the Fourier Model.

Test	F-statistic	Prob.
Breusch-Godfrey Serial Correlation LM Test	0.49	0.61
Heteroskedasticity Test: Breusch-Pagan-Godfrey	1.06	0.41
Ramsey Reset	0.39	0.69

economy and the environment by using environmental innovation. In the USA, measures that prevent emissions, decarbonize transportation, support electric cars, and employ various types of broad renewable energy technology should be implemented. By accelerating patents on environmental technologies, the USA can contribute to its green strategy by addressing a long-standing radical question on industrial transformation. Furthermore, patents on innovations are ideal for combatting CO_2 emissions, thus contributing to the UN's Sustainable Development Goals (SDGs). It is possible to further check the causal interrelationship between the series. Table 7 indicates the Fourier TY causality test outcomes.

A CUSUM test and a CUSUM of squares test graph are presented in Figs. 2 and 3 respectively. These plots show that all coefficients in the error-correction model are relatively stable as can be seen in Figs. 2 and 3. Moreover, the stability of the model is also checked via the Heteroskedasticity, LM, and Ramsey Reset tests, and the conclusions of the tests in Table 6 prove the stability of the model.

Table 7
Fourier Toda-Yamamoto Causality Test Result.

	t-stat	p-value
LPOET → LEF	8.79	0.07***
LGDP → LEF	10.46	0.03**
LEC → LEF	12.05	0.02**

Note: *,**,*** show the significance at the 1 %, 5 % and 10 % significance level. → denotes the direction of the causality.

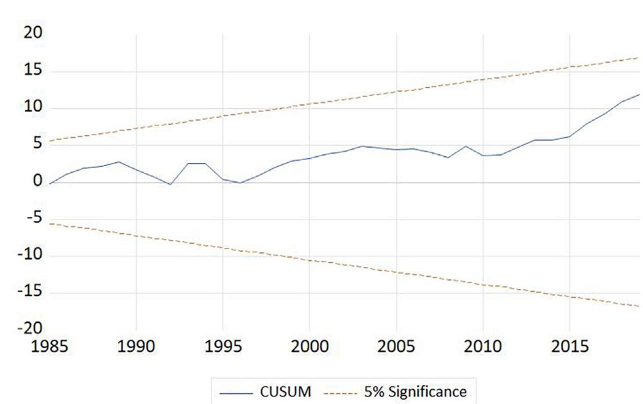

Fig. 2. CUSUM.

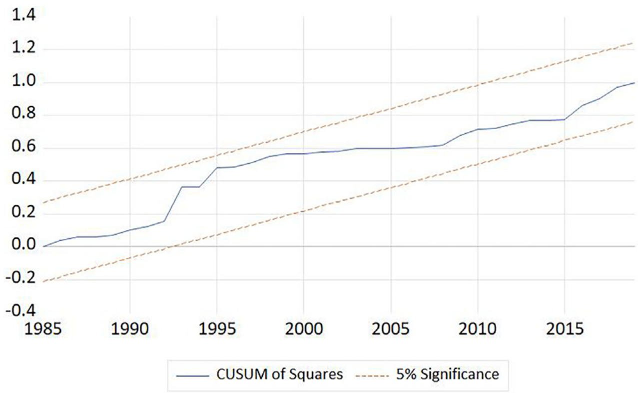

Fig. 3. CUSUM of squares.

According to the discoveries of the Fourier TY causality test, changes in patents on environmental technologies cause changes in EF in the USA, implying that environmental innovations are an important predictor for environmental sustainability. The present study also reveals that GDP and EC cause EF. The outcomes of the Fourier TY causality test support the findings of Charfeddine and Mrabet (2017), Destek and Sarkodie (2019), and Ahmed, Zafar, and Mansoor (2020).

5. Conclusion

No comprehensive study has examined how POET affect ecological footprint in the USA. The present study explores how POET affect ecological dilapidation in the United States in order to fill the literature gap while controlling for EC and GDP. The current research used the novel Fourier ARDL and Fourier Toda Yamamoto test approach. The main advantage of using the Fourier-based ARDL approach is that it identifies structural changes using Fourier functions. In addition, no structural breaks, structural changes or modification of the estimated model for the structural change are required for Fourier-based models. The present study outcomes reveal that POET are an important predictor of ecological footprint in the USA and cause a reduction in environmental degradation in the long run. By patenting environmental technologies, the USA can contribute to its green strategy by addressing a long-standing radical question on industrial transformation. The present study also found that as expected, economic growth and energy consumption negatively affect the environmental sustainability in the USA. Utilizing more renewable energy will increase environmental sustainability, reinforce the fight against climate change, and advance sustainable growth objectives (Dogan et al., 2022). Furthermore, patents on innovations are ideal for combatting CO_2 emissions, thus contributing to the UN's SDGs.

Environmental patents can be a valuable tool for gauging ecological innovation, including emissions control and green energy technologies. Additionally, the US government should continue to promote the implementation of electric cars since it is widely acknowledged that transportation is one of the biggest contributors to CO_2 emissions. Reducing the ecological footprint through environmental patents can be a strategic tool for the US to achieve the SDGs. By reducing its ecological footprint, the USA can increase environmental sustainability and encourage the development of low-carbon and climate-resilient production and consumption structures. In this way, four SDGs can be achieved: i) producing low-carbon and modern energy solutions (SDG 7: Affordable and clean energy). ii) Reducing ecological footprint and CO_2 emissions through innovation and R&D in the industrial sector (SDG 9: industry, infrastructure and innovation, SDG 13: Climate action). iii) sustainable production and consumption structures (SDG 12: Responsible production and consumption).

This study proposes a specific future research. Recently, a new hypothesis has been developed in the field of environmental economics: the load capacity curve (LCF). This hypothesis was first introduced by Pata (2021b) and tested for G-7 countries by Dogan and Pata (2022). LCF is calculated as biocapacity/EF. In this context, studies that will examine the impact of environmental patents on ecological quality in the context of LCF will contribute to the literature.

CRediT authorship contribution statement

Dervis Kirikkaleli: Conceptualization, Software, Supervision, Project administration, Writing – review & editing. **Emrah Sofuoğlu:** Methodology, Data curation, Formal analysis, Writing – original draft. **Opeoluwaseun Ojekemi:** Formal analysis, Writing – review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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