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Assessing the impact of output growth, renewable energy consumption and financial development on environmental quality: empirical evidence from India

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Abstract

Purpose – This study aims to assess the nexus among output growth, renewable energy consumption, financial development and environmental quality (EQ) in the presence of non-renewable energy consumption for India using annual time series data for the period 1980–2021.

Design/methodology/approach – To conduct an econometric analysis, this study uses the augmented autoregressive distributed lag (AARDL) model, which offers the benefit of simultaneously estimating both long-run and short-run estimators. Furthermore, this study uses the Toda-Yamamoto (1995) test and the Breitung and Candelon (2006) test to explore causal relationships in both time and frequency domains (FDs), aiming to understand the dynamic associations between variables.

Findings – Using the AARDL model, the authors found that initially, with an increase in output growth, EQ deteriorates, but once output growth reaches a threshold level, EQ improves. Likewise, this study found that financial development enhances EQ. Furthermore, the authors found a unidirectional causality from the load capacity factor (LCF) to output growth, renewable energy consumption and non-renewable energy consumption in the case of time domain analysis, and no feedback causality was documented. In the FD causality approach, this study reveals a causality nexus from LCF to output growth, financial development and renewable energy consumption at low, middle and high frequencies.

Practical implications – The findings highlight the need for targeted policies to balance economic growth and environmental sustainability in India. Policymakers should promote green technologies and enhance renewable energy use to mitigate the initial negative impact of output growth on EQ. The positive role of financial development suggests that encouraging green financing and sustainable investments can further improve environmental outcomes. The Indian economy needs to prioritise sustainable growth in its financial sector by aligning it with ongoing transformative processes for sustainable development. To achieve the sustainable development goals pertaining to EQ, the Indian economy must diminish its reliance on fossil fuels. In addition, the government of India must provide financial assistance to environmental organisations to foster the LCF.

Originality/value – To the best of the authors' knowledge, this is the first study to investigate the dynamic nexus among financial development, output growth, renewable energy consumption and EQ proxied by LCF within the Indian context in the presence of non-renewable energy consumption. Likewise, this study uses the LCF to assess environmental sustainability in India, offering a comprehensive evaluation by integrating both supply and demand dimensions. From a policy perspective, this study highlights the significance of fostering sustainable economic growth, implementing environmentally conscious banking policies, and adopting

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diversified and ecologically friendly strategies. These policy directions are essential for conserving ecological resources and fostering a more sustainable and resilient development trajectory for India.

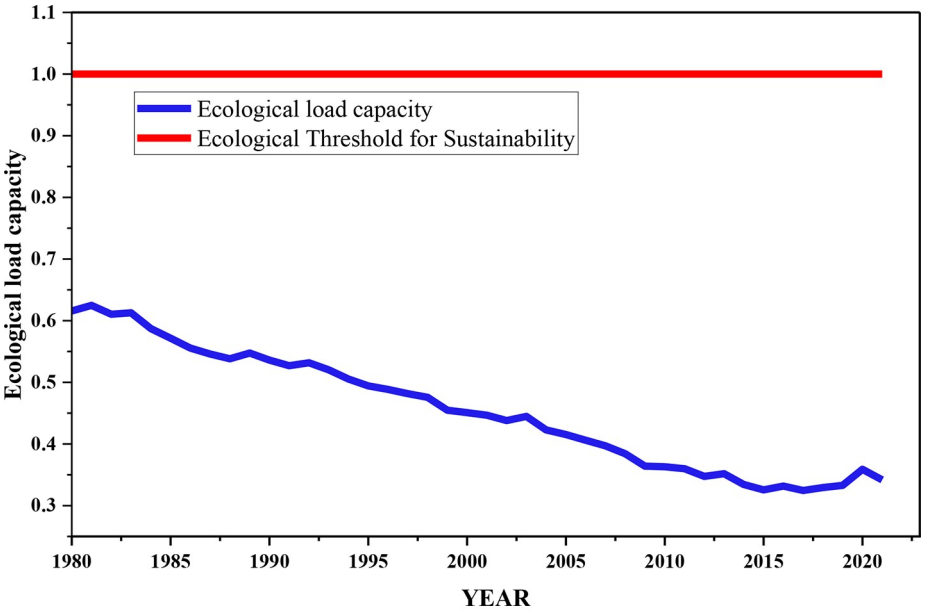
Keywords Environmental sustainability, Renewable energy, Load capacity factor, Augmented ARDL, Financial development

Paper type Research paper

1. Introduction

Global warming and Climate change are recognised as twin evils emerging as paramount threats to human existence and survival in contemporary times (Ali *et al.*, 2022; Cheng *et al.*, 2023; Lee *et al.*, 2023; Eregha *et al.*, 2022). This concern has motivated policymakers in both developed and developing nations to seek environmental friendly energy sources capable of meeting their energy requirements while mitigating CO_2 emissions. In the Indian context, there has been a notable increase of more than 70% in emissions, accompanied by a discernible rise in the average temperature by 1.5°C since 1960. Projections indicate an anticipated further increase of 1.5°C by the year 2040 (IPCC, 2022). These disconcerting statistical trends underscore the compelling necessity for India to proactively address and curtail its emissions, as well as mitigate the repercussions of climate change. The absence of timely and decisive action poses the risk of exacerbating the adverse impacts of climate change, thereby perpetuating disruptions in global ecosystems and economies. Urgent and comprehensive measures are imperative to address and mitigate these consequential challenges (Wang *et al.*, 2023a, 2023b, 2023c; Jie *et al.*, 2023). In recent years, the concept of sustainable development has gained increasing attention from scholars, policymakers and environmental economists (Wu *et al.*, 2023; Ozturk and Ullah, 2022). In a nation such as India, where the majority of the population is employed in the primary sector and a significant portion of the population grapples with challenging economic circumstances, achieving a harmonious equilibrium between environmental preservation and economic development is imperative.

Researchers and policymakers have traditionally focused on analysing CO_2 emissions as a dependent variable when studying environmental sustainability in India (Bandyopadhyay and Rej, 2021; Itoo and Ali, 2023; Uche *et al.*, 2023). However, this approach only considers air pollution and neglects water and soil pollution. To address this limitation, the ecological footprint (EF) variable has been introduced as an additional indicator of environmental degradation (Pata *et al.*, 2022; Hussain *et al.*, 2023; Wang *et al.*, 2023a, 2023b, 2023c). Nevertheless, both CO_2 and EF variables fail to simultaneously account for both the demand and supply sides of environmental considerations. To overcome this issue, Siche *et al.* (2010) introduced the concept of the load capacity factor (LCF) as a proxy for environmental quality (EQ). The LCF is quantified as biocapacity $\times$ EF^{-1}. When the LCF value falls below "1", it signifies that the consumption habits of a community are detrimental to the environment. A value of "1" in the LCF study represents the sustainability limit. Conversely, an LCF value exceeding "1" indicates that the current environmental conditions and natural resources are substantial enough to fulfil human needs (Pata and Tanriover, 2023). By integrating both the EF and biocapacity, the LCF provides a more precise environmental assessment by evaluating both human demand for natural resources and nature's capacity to meet that demand. Notably, the LCF aligns well with sustainable development goals (SDGs) 12, 13, 14 and 15, addressing sustainable and responsible human consumption as well as the restoration of water and land. In this regard, the LCF proves to be an essential tool for environmental scrutiny. Figure 1 supports the argument that environmental degradation has become unsustainable, consistently falling below the critical sustainability threshold of 1 over the years. Specifically, India's LCF, which stood at 0.6156 in 1980, has declined to 0.3416 in 2022, marking a notable 50% decrease. This reduction suggests that the available supply of natural



Source: Authors' own creation

Figure 1. Ecological situation in India from 1980 to 2020

resources is insufficient to support India's prevailing production and consumption patterns. Clearly, the LCF, as a more insightful indicator of EQ, can provide valuable insights for shaping pertinent environmental policies. This identified gap in existing environmental studies serves as the impetus for undertaking this empirical study.

The transition to renewable energy is one of the most effective strategies for reducing CO_2 emissions and combating climate change (Mehmood, 2022). In India, the shift from fossil fuel-based energy production to renewable sources such as solar, wind, hydro and biomass is gaining momentum, driven by both government policy and market forces. India has set a goal to increase its renewable energy capacity to 275 GW by 2027. Despite significant progress in renewable energy, India still relied on fossil fuels for 89.5% of its total energy consumption in 2021. In response to such concerns, many countries, including India, have committed to international agreements like the Paris Agreement and the Kyoto Protocol to reduce greenhouse gas emissions and combat climate change. After exploring the contributions of renewable energy and output growth to EQ, it is important to acknowledge the significant impact of financial development, a factor that is often overlooked in such discussions. Financial development, characterised by the efficiency and accessibility of financial markets, affects EQ through various channels (Mesagan and Olunkwa, 2022). One the one hand, it can facilitate investments in cleaner technologies and renewable energy by providing essential funding and reducing capital costs, leading to lower carbon emissions. However, it can also stimulate economic activity and energy consumption, potentially increasing emissions if fossil fuels are the primary energy source (Shehzad *et al*., 2023.) In developing countries like India, where access to finance is often limited, enhancing financial development is key to unlocking investments in green technologies.

Against this backdrop, the present study assesses the impact of output growth, renewable energy consumption and financial development on EQ within the framework of the load capacity curve (LCC) hypothesis. The motivation for this study stems from the pressing need to balance economic growth with environmental sustainability in developing economies like India. With rapid industrialisation and urbanisation contributing to environmental degradation, it becomes crucial to explore pathways for green growth. The study focuses on three key factors: output growth, renewable energy consumption and financial development, which are pivotal in determining environmental outcomes. While output growth drives development, it often comes at the cost of environmental health, whereas renewable energy offers a sustainable alternative to fossil fuel reliance. In addition, financial development plays a crucial role in mobilising resources for green technologies and renewable energy initiatives. By investigating the interactions among these factors, the study aims to provide valuable insights into how India and other emerging economies can achieve sustainable development while addressing environmental challenges.

This research makes substantial contributions to the existing body of literature in several significant ways. Firstly, to the best of the authors' knowledge, the current study is the first study that investigates the dynamic nexus among financial development, output growth, renewable energy consumption and EQ proxied by LCF within the Indian context in presence of non-renewable energy consumption. Unlike CO_2 emissions and EF variables, which typically focus on either the demand or supply side, the LCF incorporates both demand and supply aspects of environmental sustainability. By incorporating both sides, the LCF can reveal whether current practices are truly sustainable in the long term. It helps to identify potential areas of imbalance where either excessive demand or insufficient supply could lead to environmental degradation. This metric is crucial for policymakers and environmental economists, as it provides a vibrant picture of sustainability and can guide more effective and balanced strategies for managing natural resources and reducing environmental impact. Hence, considering both supply and demand aspects, it mitigates the risk of conflicting policy directions and ensures a more cohesive and effective approach towards attaining environmental sustainability. Secondly, no empirical studies have investigated the relationship between financial development and EQ within the framework of the LCC hypothesis in the context of India. This lacuna in the literature underscores the necessity of investigating the intricate relationship between financial development and environmental outcomes in India. Rather than using a single proxy for financial development, our study uses multiple dimensions of financial development. Contrary to prior research, our study uses a comprehensive financial development index that integrates indicators assessing the depth, access and efficiency of a country's financial institutions and markets. Thirdly, in contrast to the prevalent use of linear models in prior studies analysing the relationship between output growth and the LCF, this research adopts a non-linear model to capture the nuanced shape of the curve. Fourthly, this investigation uses both time-domain and frequency-domain causality tests to thoroughly examine both linear and non-linear causal relationship between per capita income, financial development, per capita fossil fuel consumption, renewable energy and the environmental LCF in the Indian context. By integrating these approaches, the study aims to provide a comprehensive understanding of how these variables interact over time and across different frequencies. This dual-method analysis offers a robust framework for identifying potential causal links and their dynamic behaviour, thereby contributing valuable insights into sustainable development strategies and policy-making in India. Finally, to the best of the available literature evidence, this study is the first to test the validity of the LCC using both necessary and sufficient conditions. In summary, this study endeavours to offer valuable insights into the intricate dynamics between economic factors and the environmental LCF through the application of advanced

econometric techniques. By using the load capacity metric, a non-linear model, and the time domain and frequency domain (FD) causality tests, the research enriches our understanding of the complex interplay between economic factors and ecological sustainability in the Indian context.

2. Literature review

This section provides an empirical review of the dynamic linkage between output growth, financial development, renewable energy consumption and EQ.

2.1 Output growth and environmental quality nexus

Many developing nations struggle to implement effective policies and initiatives for environmental sustainability. This challenge is often attributed to their prioritisation of sustained economic growth over environmental concerns. In energy-growth nexus, researchers use a range of environmental variables in empirical studies to examine the nexus between output-growth and environmental sustainability. This diversity in variables stems from difficulties in quantifying EQ accurately. In contemporary environmental economics research, carbon dioxide (CO_2) emissions have been widely used as a key indicator of environmental degradation. For instance, Aye and Edoja (2017), using a dynamic panel threshold framework for 31 developing countries, revealed that economic growth reduces CO_2 emission below the threshold growth regimes but increases it in above threshold regimes, with the marginal effect being more significant in the high-growth regimes. Likewise, Al-Mulali *et al.* (2015) found that the Environmental Kuznets curve (EKC) hypothesis did not hold for Vietnam during the period 1981–2011, as the relationship between GDP and pollution was consistently positive in both the short and long run. However, Muhammad (2019) found that economic growth leads to higher CO_2 emissions in developed and MENA countries. Furthermore, Liu (2020) identified an inverted *U*-shaped relationship between economic growth and CO_2 emissions. Similar conclusions have been drawn by other studies, such as Bandyopadhyay and Rej (2021) for India, Murshed and Dao (2022) for South Asian economies, Mehmood (2022) for four major SAARC economies, Kostakis *et al.* (2023) for MENA economies, and Mitić *et al.* (2023) for eight South-Eastern European countries. In a similar fashion, EF gained prominence as an additional indicator for assessing environmental degradation (see Bozkaya and Duran, 2022; Zhou *et al.*, 2022; Javeed *et al.*, 2023; Boukhelkhal, 2022; Usman *et al.*, 2023; Sampene *et al.*, 2023; Neifar *et al.*, 2023).

More recently, LCF has emerged as a tool for environmental assessments, although its application is still somewhat limited. Recent empirical studies have indicated that using CO_2 emissions or EF as proxies for environmental sustainability may not be adequate, as these indicators consider only the demand or supply side of EQ. Therefore, the research community has adopted a new dimension, the LCF, as an indicator of environmental sustainability. The LCF accounts for both demand and supply aspects of environmental sustainability, offering a more comprehensive assessment. Pata and Isik (2021) explored the relationship between economic growth and the LCF in China from 1981 to 2017 using the autoregressive distributed lag (ARDL) model. Their empirical findings revealed a negative association between output growth and the LCF. However, Pata and Tanriover (2023), using a balanced panel data set from the top ten tourism destinations, refuted the validity of both the EKC and the LCF hypotheses. Similarly, Sun *et al.* (2023), using a panel data set of 17 Asia-Pacific Economic Cooperation (APEC) countries from 1990 to 2019, revealed a negative association between economic growth and the LCF, implying that economic growth reduces EQ. In addition, Huilan *et al.* (2024) for Mexico, Pata and Samour (2022) for France, Deng *et al.* (2023) for the ten largest global emitters, and Erdogan (2023) for resource-rich sub-Saharan African countries reported

similar findings. On the basis of this premise, it is apparent that the LCF offers a more integrated and comprehensive assessment than merely evaluating carbon emissions and EF.

2.2 Financial development and environmental quality nexus

Research scholars and policymakers use a wide range of variables as determinants of EQ. Some research studies use financial development as a metric to evaluate environmental conditions. Financial development plays a pivotal role in shaping environmental outcomes by influencing investments in green technologies and cleaner production processes. Access to credit and capital markets can enable firms to adopt environmentally friendly practices and promote innovation in renewable energy sectors. Empirical studies exploring the relationship between financial development and the environment have yielded conflicting results. Some studies have reported a positive influence of financial development on EQ (see Khan and Ozturk, 2021; Mesagan and Olunkwa, 2022; Wu *et al.*, 2023; Fu *et al.*, 2023; Khanday *et al.*, 2023). However, certain studies have reported a negative association between financial development and EQ (see, e.g. Petrović and Lobanov, 2022; Wang *et al.*, 2023a, 2023b, 2023c; Shehzad *et al.*, 2023; Dada *et al.*, 2023; Fakher and Ahmed, 2023). This complexity underscores the need for further investigation and nuanced analysis to better understand the intricate interplay between financial development and its environmental implications.

2.3 Renewable energy consumption and environmental quality nexus

Renewable energy consumption is widely regarded as a key factor in mitigating environmental degradation by reducing dependence on fossil fuels and lowering carbon emissions. Empirical studies consistently highlight the positive impact of renewable energy on EQ across various economies. In terms of renewable energy consumption, Mehmood (2022) for panel data of South Asian countries., Hakkak *et al.* (2023) for Russia, Yang *et al.* (2023) for BRICS economies, Shang *et al.* (2022) for ASEAN Countries, Sun *et al.* (2023) for 17 APEC countries and Aydin *et al.* (2023) for G7 countries have found a significant impact of renewable energy consumption on ecological conditions, using CO_2, EF and LCF as metrics for EQ. However, Al-Mulali *et al.* (2015) for Vietnam, Dong *et al.* (2020) for a global panel of 120 countries, Pata and Caglar (2021) for China, Nathaniel *et al.* (2021) for MENA countries and Pata and Kartal (2023) for south Korea posits that renewable resources fail to mitigate environmental degradation due to their ineffective utilisation. Despite the overall positive outlook, the transition to renewable energy in India faces challenges such as high initial investment costs, regulatory barriers and infrastructural limitations. These obstacles must be addressed to fully realise the environmental benefits of renewable energy consumption.

Although there is a wealth of empirical research on the relationship between output growth and environmental sustainability, there are still significant gaps that need to be addressed. Previous studies examining the impact of output growth on the LCF are not only limited, particularly concerning the Indian economy, but their findings are also inconclusive. Apart from the recent development of the LCC by Pata and Kartal (2023), most studies investigating the LCF have relied on linear model specifications. Therefore, the literature offers limited empirical evidence on the nature of the relationship between output growth and the LCF. Therefore, further empirical research is essential to enhance our understanding and facilitate the formulation of more definitive conclusions. Similarly, we did not find any empirical studies examining the relationship between financial development, output growth, renewable energy consumption and EQ within the LCC hypothesis in India. Furthermore, traditional econometric techniques used in previous studies exhibit several limitations, including issues with heterogeneity, endogeneity bias and serial correlation. Considering these research gaps, our study will address them by using advanced econometric techniques to more effectively analyse the relationships between output

growth, renewable energy consumption, financial development and EQ within the framework of the LCC hypothesis in India.

3. Data

The primary objective of the current study is to assess the impact of output growth, renewable energy consumption and financial development on EQ within the framework of the LCC hypothesis, focusing on the Indian economy for the period from 1980 to 2021. Details pertaining to chosen variables, symbols, data description and the data source can be found in Table 1.

4. Empirical model

As previously elucidated, the present study investigates the impact of output growth, renewable energy consumption and financial development on EQ within the framework of the LCC hypothesis. Hence, in alignment with the theoretical framework and research objectives, we formulated the model specification, incorporating both linear and quadratic terms for GDP per capita. Following the methodologies established by Pata and Tanriover (2023) and Deng *et al.* (2023), we have developed the following empirical model:

$$LCF = F\left(PGDP, PGDP^2, FNDX, FF, REN\right) \quad (1)$$

To address the issues of heteroskedasticity and autocorrelation, we transformed all the variables into their natural logarithms. The logarithmic expression for this function is as follows:

$$LLCF = \gamma_0 + \gamma_1 LPGDP + \gamma_2 (LPGDP)^2 + \gamma_3 LFNDX + \gamma_4 LFF + \gamma_5 LREN + \mu_t \quad (2)$$

4.1 Necessary condition for the existence of load capacity curve

On the basis of equation (2), there are five possible mathematical relationships between LCF and per capita GDP (its linear and quadratic). The direction of elasticities indicates whether

Table 1. Definition, sources and measurements of the variables

Variable	Symbol	Description	Unit	Data source
Load capacity factor	LLCF	$\left(\frac{\text{Ecologicalfootprint}}{\text{biocapacity}}\right)$ (gha per person)	Natural logarithm of LCF	Global Footprint Network
Percapita GD	LPGDP	GDP per capita (constant 2015 US$)	Natural logarithm of PGDP	World Development Indicators (WDI)
Financial development index	LFNDX	"Financial development index based on the depth, access, and efficiency of the financial institutions and markets of a country."	Natural logarithm of FNDX	International Monetary Fund (IMF)
Renewable energy consumption	LREN	Renewables (% equivalent primary energy) (KWH)	Natural logarithm of REN	Our World in Data Database
Fossil fuel per capita	LFF	Average energy consumption per person from coal, oil, and gas	Natural logarithm of FF	Our World in Data Database

Source: Authors' own calculations

the existing LCC is *U*, inverted *U*, monotonic increasing, or decreasing (i.e. does not exist). These conditions serve as necessary conditions for a valid LCC to exist:

(1) if $\gamma_1 > 0$, $\gamma_2 = 0$ LCC is monotonically increasing;

(2) if $\gamma_1 < 0$, $\gamma_2 = 0$ LCC is monotonically decreasing;

(3) if $\gamma_1 < 0$, $\gamma_2 > 0$ LCC is inverted *U*-shaped;

(4) if $\gamma_1 > 0$, $\gamma_2 < 0$ LCC is *U*-shaped; and

(5) if $\gamma_1 = \gamma_2 = 0$ no relationship exists.

4.2 Sufficient condition for the existence of load capacity curve

Conclusions drawn without adequately testing the "sufficient conditions" may yield deceptive findings. When we refer to sufficient conditions, we are specifically investigating whether the "Turning Points or Tipping Points" in per capita GDP, where the LCC alters the direction of the association, are real and distinct or imaginary. To address this, we adhere to a set of fundamental steps for determining the sufficient conditions and estimating the turning point.

Step 1. Other variable being constant, we take the partial derivative of equation (2) with respect to per capita GDP as follows:

$$\frac{d(LLCF)}{d(PGDP)} = \frac{d}{PGDP}\left\{\gamma_0 + \gamma_1 LPGDP + \gamma_2 (LPGDP)^2 + \gamma_3 LFNDX + \gamma_4 LFF + \gamma_5 LREN + \mu_t\right\} \tag{3}$$

Step 2. To identify critical values, we set the partial derivative:

$$\frac{d(LLCF)}{d(PGDP)} = 0$$

$$\Rightarrow \gamma_1 \times \frac{1}{PGDP} + 2\gamma_2 LPGDP \times \frac{1}{PGDP} = 0$$

$$\Rightarrow \gamma_1 + 2\gamma_2 LPGDP = 0 \tag{4}$$

Step 3: Equation (4) is linear in LPGDP. We can find its roots using the substitution method as:

$$\gamma_1 + 2\gamma_2 LPGDP = 0$$

$$\Rightarrow 2\gamma_2 LPGDP = -\gamma_1$$

$$\Rightarrow LPGDP = \frac{-\gamma_1}{2\gamma_2} \tag{5}$$

Here $\frac{-\gamma_1}{2\gamma_2}$ denotes the sufficient condition for existence of a valid LCC.

Step 4: Assuming the existence of sufficient conditions, we proceed to estimate the turning point of per capita GDP within the context of a Quadratic polynomial by using the antilogarithm, as follows:

$$\text{PGDP} = \text{Antilog}\left(\frac{-\gamma_1}{2\gamma_2}\right) \tag{6}$$

5. Econometric estimation

5.1 Unit root testing

The accuracy of statistical inferences in time series models depends on the stationarity of the data, as time series data can be affected by shocks that cause persistent fluctuations and potentially biased estimates. To assess the stationarity of our data, we applied the "Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests".

5.2 Augmented autoregressive distributed lag method

The ARDL method developed by Pesaran and Shin (1998) and Pesaran *et al.* (2001) serves as a workhorse for gauging and assessing long-term relationships in the presence of both I(0) and I(1) variables (Ali *et al.*, 2022). Its unique equation structure enhances usability, making interpretations straightforward. Unlike traditional error correction approaches, the ARDL method avoids endogeneity issues (Apergis *et al.*, 2023). The cointegration analysis involves a bounds test, which establishes critical values for assessing the cointegration link. In the traditional ARDL approach, the cointegration analysis relies on *t*-tests and *F*-tests. However, researchers often overlook the application of the *t*-test to dependent variables and the requirement that the dependent variable must be I(1) is sometimes neglected due to weaknesses in unit root tests. One limitation of the ARDL method is its inability to derive cointegration if the calculated *F*-statistic lies between the lower and upper critical values. McNown *et al.* (2018) addressed these issues by introducing bootstrap simulations to the ARDL method. They introduced a new cointegration test statistic, *F*-indep and emphasised that the *t*-test, *F*-overall and *F*-indep statistics should simultaneously exhibit statistical significance to confirm cointegration.

The Augmented ARDL (AARDL) approach addresses the challenge of determining whether the dependent variable should be I(0) or I(1). When the dependent variable is I(0), inferring a long-run relationship with the regressor(s) becomes intricate, even if the *F*-statistic exceeds the upper critical bound in the bounds-testing procedure. This challenge arises from the fact that the I(0) nature of the dependent variable renders the series stationary. Consequently, the dominance of the I(0) variable in joint relationship testing may lead to erroneous inferences regarding the significance of other variables in contributing to the long-run relationship. The AARDL approach, applied using equation (7), aims to alleviate these issues.

We formulate the ARDL model in the following manner:

$$\Delta\text{LLCF}_t = \alpha_0 + \sum_{a=1}^{p}\theta_1\Delta\text{LLCF}_{t-a} + \sum_{b=0}^{q}\theta_2\Delta\text{LPGDP}_{t-b} + \sum_{b=0}^{q}\theta_3\Delta\text{PLGDP}^2_{t-b} + \sum_{b=0}^{q}\theta_4\Delta\text{LFNDX}_{t-b}$$

$$+ \sum_{b=0}^{q}\theta_5\Delta\text{LFF}_{t-b} + \sum_{b=0}^{q}\theta_6\Delta\text{LREN}_{t-b} + \left(\tau_1\text{LLCF}_{t-1} + \tau_2\text{PGDP}_{t-1} + \tau_3\text{PLGDP}^2_{t-1}\right.$$

$$+ \tau_4 LFNDX_{t-1} + \tau_5 LFF_{t-1} + \tau_6 LREN_{t-1}) + u_t \quad (7)$$

First, the null hypothesis for the overall *F*-test on all variables is:

$$F_{ALL} \rightarrow H_0 : \tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = \tau_6 = 0 \quad (8)$$

Second, the null hypothesis for the *t*-test on only the dependent variable is:

$$T_{DEP} \rightarrow H_0 : \tau_1 = 0 \quad (9)$$

Third, the *F*-test on independent variables is:

$$F_{INDP} \rightarrow H_0 : \tau_2 = \tau_3 = \tau_4 = \tau_5 = \tau_6 = 0 \quad (10)$$

5.2.1 Taxonomies of augmented bounds test

- If null hypotheses (8) and (9) are accepted, but null hypothesis (10) is rejected, it signifies a scenario of a degenerate lagged independent variable. This situation signifies the absence of cointegration.
- If null hypotheses (8) and (10) are accepted, but null hypothesis (9) is rejected, it indicates a scenario identified as a degenerate lagged dependent variable. This condition also signifies the lack of cointegration.
- The rejection of null hypotheses (8), (9) and (10) indicates the presence of cointegration.

The outlined approach provides a clear roadmap, emphasising the need to adopt the augmented ARDL testing procedure for cointegration. This procedure mitigates concerns about whether the dependent variable is I(0) or I(1), as long as the rejection of all three null hypotheses is achieved.

The established roadmap entails the necessity of using the augmented ARDL testing procedure for cointegration. This approach eliminates concerns about the order of integration [I(0) or I(1)] of the dependent variable, provided that the rejection of all three null hypotheses is achieved. The error correction model aims to capture and articulate the short-term dynamics presented below:

$$\Delta LLCF_t = \vartheta_0 + \sum_{a=1}^{p} \theta_1 \Delta LLCF_{t-a} + \sum_{b=0}^{q} \theta_2 \Delta LPGDP_{t-b} + \sum_{b=0}^{q} \theta_3 \Delta PLGDP^2_{t-b} + \sum_{b=0}^{q} \theta_4 \Delta LFNDX_{t-b}$$

$$+ \sum_{b=0}^{q} \theta_5 \Delta LFF_{t-b} + \sum_{b=0}^{q} \theta_6 \Delta LREN_{t-b} + \Omega ECT_{t-1} + u_t \quad (11)$$

In this context, Ω denotes the error correction coefficient, which signifies the pace of adjustment towards reaching long-term equilibrium. The estimated value of Ω falls within the range of [−1, 0]. A positive estimate suggests a deviation from the equilibrium path, while a negative estimate indicates convergence. A value of $\Omega = -1$ signifies complete convergence (100%), and a value of $\Omega = 0$ implies no adjustment.

5.3 Toda–Yamamoto causality test

To investigate the causal relationships among variables in the time domain, the study use the widely recognised Toda and Yamamoto (1995) test, hereafter referred to as the Toda–Yamamoto

(TY) test. The TY method stands out as a widely used variant of Granger causality (GC) tests, which assess the causal relationship between two correlated time series using vector autoregressive (VAR) models. Unlike traditional GC tests that consider stationarity and cointegration relationships, the TY approach evaluates hypotheses independently of these factors. The TY causality method exhibits greater statistical power compared to the GC test, enabling it to detect causal relationships between time series with greater precision.

The TY test is denoted as follows:

$$Yt = \alpha_0 + \sum_{i=1}^{k} \beta_{1,i} Y_{t-1} + \sum_{i=k+1}^{k+dmax} \beta_{1,i} Y_{t-1} + \sum_{i=1}^{k} \gamma_{1,i} X_{t-1} + \sum_{i=k+1}^{k+dmax} \gamma_{1,i} X_{t-1} + \zeta_t \quad (12)$$

$$Xt = \alpha_1 + \sum_{i=1}^{k} \delta_{1,i} X_{t-1} + \sum_{i=k+1}^{k+dmax} \delta_{1,i} X_{t-1} + \sum_{i=1}^{k} \varphi_{1,i} Y_{t-1} + \sum_{i=k+1}^{k+dmax} \varphi_{1,i} Y_{t-1} + \eta_t \quad (13)$$

In equations (12) and (13), d_{max} signifies the highest order of integration among the series, k denotes the optimal lag length, ζ_t and η_t represent the disturbance terms characterised by white noise.

5.4 Frequency domain causality test

The principal difference between the time-domain and frequency-domain approaches lies in their respective functionalities. The time-domain method informs us about the specific timing of a variation within a time series, whereas the frequency-domain procedure computes the amplitude or magnitude of that fluctuation. To scrutinise causality across short, medium and long-time frames, we use FD analysis. From an econometric perspective, FD involves investigating mathematical functions or signals across different frequencies rather than over time. In this context, a specific stationary process is broken down into a weighted combination of sinusoidal components, each associated with a particular frequency (X). While the fundamental concept of causality remains consistent for both time and FDs, the method of examination differs. The evolution of a signal over time is depicted in a time-domain chart. In contrast, the intensity of a signal within each frequency range across a spectrum is represented in an FD graph. In simple terms, time reflects the occurrence of a change, and frequency gauges the magnitude of that variation. Despite various approaches documented in the literature for GC analysis in FD, we opted for the recently established framework by Breitung and Candelon (2006), hereafter referred to as BC. This method offers the flexibility of being suitable for either a set of stationary variables, integrated but not cointegrated (using data in first differences), or both integrated and cointegrated (using data in levels). Furthermore, FD analysis addresses the issue of seasonal variations, particularly in situations where the data set for analysis is limited. The methodology also accommodates non-linearities and causality cycles, allowing for causality analysis at both low and high frequencies.

The relationship between variables P and Q, as conducted by Breitung and Candelon (2006), can be examined using a VAR-based framework.

Consider a two-dimensional time series vector, denoted as $Z_t = (P_t, Q_t)$ derived at each time point $t = 1\ldots, T$, possessing a finite-order VAR representation as follows:

$$\theta(L)Z_t = \mu_t \quad (14)$$

where $\theta(L) = 1 - \theta_1 L - \theta_2 L^2 - \ldots - \theta_P L^P$ is a characteristic lag polynomial of order 2×2 with $L^k Z_t = Z_t - k$, μ_t is considered to be spherical errors. Let G and G' be the lower and upper triangular matrices with Cholesky decomposition $G'G = \Sigma^{-1}$ such that $E\left(\epsilon_t \epsilon_t'\right) = I$ and $\epsilon_t = G\mu_t$. By using this Cholesky decomposition, the MA representation of the framework is provided as follows:

$$Z_t = \Phi(L)\mu_t = \begin{bmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \end{bmatrix} \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix} \tag{15}$$

$$= \Psi(L)\mu_t = \begin{bmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{bmatrix} \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \end{bmatrix} \tag{16}$$

where $\Phi(L) = \theta(L)^{-1}$ and $\Psi(L) = \Phi(L)G^{-1}$. By using the Fourier transformation of the system, the expression of the spectral density for P_t is presented as below.

$$f_P(\omega) = \frac{1}{2\pi}\left\{\left|\Psi_{11}(e^{-i\omega})\right|^2 + \left|\Psi_{12}(e^{-i\omega})\right|^2\right\} \tag{17}$$

In accordance with equation (15) and equation (16), the volatility in the regressand can be elucidated as the summation of two uncorrelated moving averages processes. These processes possess the capability to influence the regressors. The ability of the independent variable to predict outcomes at each frequency (m) can be assessed by comparing its predictive contribution in the spectrum with the intrinsic component of the frequency. Therefore, it can be observed that the independent variable does not contribute to the volatility of the dependent variable at frequency m when the predictive factor related to the dependent variable's volatility spectrum at that frequency is zero. The measure of causality proposed by Geweke (1982) and Hosoya (1991) is explicitly defined as:

$$M_{P\to Q}(\omega) = log\left[\frac{2\pi f_P(\omega)}{\left|\Psi_{11}(e^{-i\omega})\right|^2}\right] \tag{18}$$

$$= log\left[1 + \frac{\left|\Psi_{12}(e^{-i\omega})\right|^2}{\left|\Psi_{11}(e^{-i\omega})\right|^2}\right] \tag{19}$$

If $|\Psi_{12}(e^{-i\omega})| = 0$, it indicates the absence of causality from variable Q to variable P at frequency ω. Testing the following null hypothesis:

$$H_0 : M_{P\to Q}(\omega) = 0 \tag{20}$$

may prove challenging in practice due to the intricate non-linear nature of the asymptotic distribution associated with the Wald statistic and its dependence on VAR parameters. Breitung and Candelon (2006) presented a simple method for testing H_0.
They demonstrate that when $\left|\Psi_{12}(e^{-i\omega})\right|$ equal to 0, the corresponding spectral GC measure [equation (20)] $M_{P\to Q}(\omega) = 0$ also 0. This implies that it is possible to assert that Q does not Granger cause P at frequency ω, given that the following condition is met:

$$|\Theta_{12}(e^{-i\omega})| = \left| \sum_{k=1}^{p} \varphi_{12,k} \cos(k\omega) - \sum_{k=1}^{p} \varphi_{12,k} \sin(k\omega) i \right| = 0 \quad (21)$$

where $\varphi_{12,k}$ is the (1, 2)-element of $\boldsymbol{\theta}_k$. In this scenario, the necessary and sufficient conditions for $|\Theta_{12}(e^{-i\omega})| = 0$ are as follows:

$$\sum_{k=1}^{p} \varphi_{12,k} \cos(k\omega) = 0 \quad (22)$$

$$\sum_{k=1}^{p} \varphi_{12,k} \sin(k\omega) i = 0 \quad (23)$$

Breitung and Candelon (2006) reformulated these constraints by expressing the equation for P_t in the VAR(p) system in following manner:

$$P_t = \delta_1 P_{t-1} + \ldots + \delta_p P_{t-p} + \tau_1 Q_{t-1} + \ldots + \delta_1 Q_{t-p} + \varepsilon_t \quad (24)$$

The null hypothesis used in Geweke (1982), $H_0 : M_{P \to Q}(\omega) = 0$ has been reformulated by BC into, $H_0 : M_{P \to Q}(\omega)\Omega = 0$. Where Ω denotes a vector of coefficients of Q:

$$R(\omega) = \begin{bmatrix} \cos(\omega) & \cos(2\omega) & \ldots & \cos(p\omega) \\ \sin(\omega) & \sin(\omega) & \ldots & \sin(p\omega) \end{bmatrix} \quad (25)$$

The F-statistics associated with equation (24) follow $F(2, T - 2p)$ for $\omega \epsilon (0, \pi)$. Here, the restriction number is denoted by 2, and "T" represents the total number of observations used in the estimation of the VAR model with order p.

6. Results and discussion

Table 2 offers a comprehensive overview of the series of investigations by presenting descriptive statistics. The data set reveals that LLCF and LPGDP have distributions close to normal in terms of skewness, but they differ in kurtosis. $LPGDP^2$ shows a slight negative skew and moderate kurtosis, while LFNDX is significantly left-skewed and has the highest

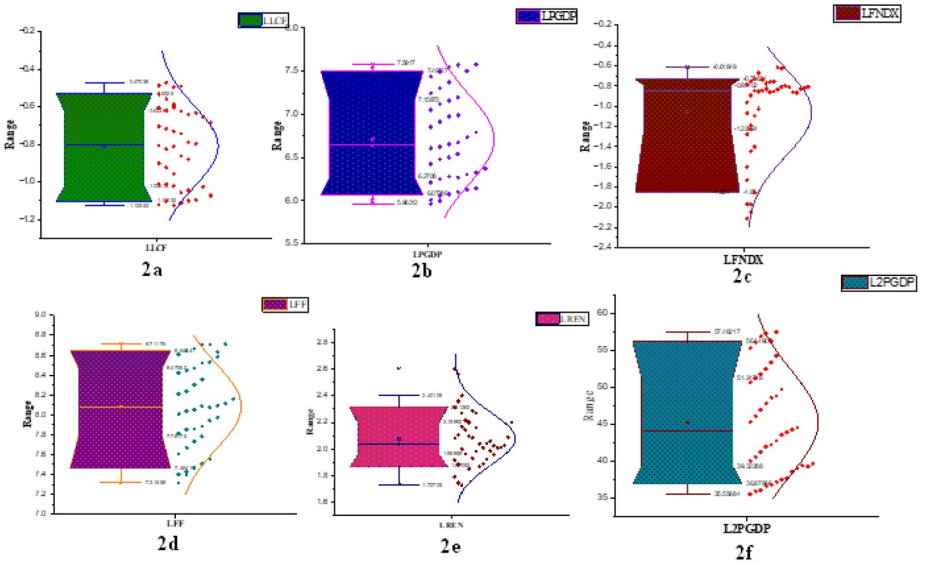
Table 2. Descriptive statistics

Variables →	LLCF	LPGDP	$LPGDP^2$	LFNDX	LFF	LREN
Mean	−0.810	6.711	3.397	−1.062	8.083	2.077
Median	−0.801	6.641	3.440	−0.583	8.089	2.040
Minimum	−1.125	5.963	2.813	−2.110	7.315	1.727
Maximum	−0.470	7.581	3.795	−0.618	8.717	2.599
SD	0.212	0.515	0.225	0.425	0.425	0.195
Skewness	−0.034	0.249	−0.681	−1.293	−0.124	0.668
Kurtosis	1.657	1.757	2.916	3.355	1.875	3.422
Jarque-Bera	3.164	3.136	9.317	11.924	2.323	3.44
Prob	0.205	0.195	0.009	0.002	0.312	0.178

Source: Authors' own calculations

kurtosis, indicating many extreme values. LFF has near-zero skewness and low kurtosis, suggesting a distribution close to normal with few outliers. LREN is positively skewed with moderate kurtosis. Regarding the mean values, LFF has the highest average at 8.083, indicating the highest typical level among the variables. In contrast, LFNDX has the lowest mean at −1.062, suggesting it typically has negative values in the data set. Figure 2(a)–(f) presents graphical illustration of descriptive statistics.

Table 3 gives a synoptic overview of the results derived from the "Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests". As indicated in Table 3 except LREN and LFNDX all other variables exhibit non-stationarity at the level. Furthermore, upon applying the first difference, it is observed that all variables display a time-invariant mean and



Source: Authors' own creation

Figure 2. (a–f) Box plot with normal distribution curve of the study variables

Table 3. Outcomes of unit root test

	ADF test		PP test	
Variables	Level *t*-statistic	1st difference *t*-statistic	Level Adj. *t*-stat	1st difference Adj. *t*-stat
LLCF	−0.9297	−7.1448***	−0.9510	−7.1153***
LPGDP	1.0350	−5.9746***	1.2012	−5.5606***
$LPGDP^2$	1.4974	−5.7691***	1.7093	−5.7658***
LREN	−2.7590***	–	−2.7590***	–
LFNDX	−3.6524***	–	−3.6848***	–
LFF	−1.6095	−6.6444***	−1.6796	−6.6411***

Notes: ***, ** and *represent statistical significance at 1, 5 and 10% levels, respectively
Source: Authors' own calculations

Table 4. The augmented ARDL bounds test: cointegration results

Test statistic	Level of significance (%)	UCB	LCB	Reference	Remark
$\mathbf{F_{All}}$ = 8.465***	*1*	4.68	3.41	Narayan (2005)	Cointegrated
	5	3.79	2.62		
	10	3.35	2.26		
$\mathbf{T_{DEP}}$ = −4.589**	*1*	−4.79	−3.43	Pesaran *et al.* (2001)	Cointegrated
	5	–4.19	–2.86		
	10	–3.86	–2.57		
$\mathbf{F_{IND}}$ = 5.9863***	*1*	5.02	3.05	Sam *et al.* (2019)	Cointegrated
	5	3.90	2.24		
	10	3.39	1.86		

Notes: *, ** and *** represent statistical significance at 10, 5 and 1% levels, respectively
Source: Authors' own calculations

variance, indicating stationarity. In summary, the variables demonstrate a mixed order of integration.

After assessing the stationarity of the variables, the next step is to examine the cointegration relationship among the variables. To address the issue of degenerate cases in the traditional ARDL model, the current study has used the Augmented ARDL. As illustrated in Table 4, cointegration is evident in our model, as all three test statistics (F_{All}, T_{DEP} and F_{IND}) exceed their respective upper critical values.

Following the establishment of cointegration and the verification of the augmented ARDL model's compliance with various assumptions, the study proceeds to simultaneously estimate the long- and short-term coefficients in the final stage. As indicated in Table 5, the coefficient for GDP is negative, while that for LPGDP^2 is positive; both coefficients exhibit

Table 5. Long and short-run coefficients

	Dependent variable: LLCF			
Variables	Coefficient	Std. error	*t*-statistic	Prob.
Panel A: long-run estimates				
LPGDP	−3.40566***	0.480609	−7.086143	0.0000
LPGDP^2	0.24103***	0.037267	6.467867	0.0000
LREN	0.03854	0.042160	0.914206	0.3681
LFNDX	0.24124***	0.035814	6.736154	0.0000
LFF	0.50774***	0.093993	−5.401945	0.0000
Inflection point (PGDP)* 1530.47$				
Panel B: short-run estimates				
C	11.14182***	2.241872	4.969873	0.0000
LCF(−1)	−0.72242***	0.157411	−4.589444	0.0001
LPGDP(−1)	−2.46035***	0.531347	−4.630407	0.0001
LGDP^2(−1)	0.17413***	0.037546	4.637819	0.0001
LREN	0.02278	0.035008	0.95363	0.4329
LFNDX(−1)	0.17428***	0.044732	3896141	0.0005
LFF	−0.36680***	0.114047	−3.216298	0.0032
CointEq(−1)	−0.722429***	0.093618	−7.716789	0.0000

Notes: *, ** and ***represent statistical significance at 10, 5 and 1% levels, respectively
Source: Authors' own calculations

statistical significance at the 1% level. This observation substantiates the validity of the LCC hypothesis. The affirmation of the LCC hypothesis suggests that as India's per capita income exceeds a certain threshold, the level of LCF rises, leading to an improvement in EQ. As societies experience rising incomes, there is a growing demand for cleaner marine and aquatic environments, improved air quality and more green spaces. Consequently, a rise in income has the potential to decrease EF in the future and enhance biocapacity through investments in the environment. The perspective that output growth will evolve into an environmentally sustainable factor for India aligns with the findings of several studies, including Sinha and Shahbaz (2018), Usman *et al.* (2019), Bandyopadhyay and Rej (2021) and Sahoo *et al.* (2021).

Regarding the influence of LFNDX on LCF, our study reveals a positive and statistically significant association in both the short run and the long run, respectively. In this regard, financial development contributes to the improvement of EQ. The positive impact of financial development on EQ in India can be attributed to increased investments in green technologies, improved access to green financing and greater corporate compliance with environmental standards. Financial development also supports economic diversification, reducing reliance on polluting industries, while aligning with regulatory frameworks to promote sustainable development. The obtained result aligns with the conclusions drawn by Fakher and Ahmed, 2023 and Charfeddine (2017), all of whom have found evidence that financial development contributes to the enhancement of EQ. This underscores the notion that financial development can be regarded as a tool to maintain environmental cleanliness through the implementation of financial regulations.

The insignificant effect of renewable energy utilisation on environmental sustainability reinforces the notion that India continues to heavily rely on fossil fuels. The outcomes of our investigation indicate that renewable energy in India does not yield significant environmental benefits. The insignificant impact of renewable energy consumption on EQ in India can be attributed to several factors. Firstly, the dominance of fossil fuels in India's energy mix limits the contribution of renewables, as they account for only a small share of total energy consumption. In addition, inefficiencies in renewable energy infrastructure, such as transmission losses and intermittent power generation, further diminish its effectiveness. Simultaneously, the expansion of non-renewable energy sources to meet rising energy demand offsets the environmental gains from renewables. Moreover, the manufacturing and installation of renewable energy systems generate indirect emissions, reducing their overall environmental benefits. Policy and regulatory challenges, including weak enforcement and delays in renewable energy initiatives, also play a significant role. Furthermore, non-energy factors such as urbanisation, deforestation, and poor waste management often overshadow the potential positive effects of renewable energy on EQ. Given these findings, it is advisable for Indian authorities to prioritise alternative energy sources over fossil fuels to promote environmental sustainability. This observation aligns with the conclusions drawn from studies in various developing countries, where the effective utilisation of renewable energy sources remains a challenge (Dong *et al.*, 2020; Pata and Caglar, 2021; Pata and Kartal, 2023).

The empirical research findings on the impact of non-renewable energy on sustainable EQ in India reveal a statistically significant and negative effect, persisting in both the long and short run. This result aligns with the research findings of Apergis *et al.* (2023) for Uzbekistan, AlNemer *et al.* (2023) for Saudi Arabia and Ali *et al.* (2023) for emerging Asian economies, all of which indicate that non-renewable energy usage contributes to environmental degradation. As of 2022, fossil fuels constitute approximately 6,074 kWh in India's energy mix primarily fueling industrial and production activities. India's heavy

dependence on fossil fuels leads to waste generation and exerts environmental pressure by contaminating the atmosphere, diminishing soil quality and polluting aquatic bodies.

6.1 Diagnostic assessment of residuals and tests for stability

To assess the reliability of our findings, we conducted diagnostic tests, the results of which are summarised in Table 6. The LM test fails to reject the null hypothesis, indicating the absence of serial correlation. In addition, we conducted tests for heteroscedasticity and normality. The corresponding test statistics indicate the absence of heteroskedasticity, and the sample statistics follow a normal distribution. To further ensure the stability of parameters, we used CUSUM and Square of CUSUM tests, as illustrated in Figure 3(a) and (b). The graphs remain within the 5% critical bounds, indicating the stability of the model. To scrutinise the functional form of the model, we applied "Ramsey's Regression Specification Error Term (RESET) test", and the test statistics affirm that the model is correctly specified.

The examination of causality analysis within a time domain framework is conducted using the TY test. Table 7 presents a synoptic view of the TY causality test. Our study found unidirectional causality running from LLCF to LPGDP, $LPGD^2$, LREN and LFF, respectively. In a similar fashion, we found a unidirectional causality running from LFNDX to LLCF.

Furthermore, as a means of validating the overarching theoretical framework endorsed by this study, the FD causality technique proposed by Breitung and Candelon (2006) is used as a robustness check. This analytical approach facilitates the examination of causality measures across distinct frequencies, thereby enhancing the comprehensiveness of our evaluation. Figure 4(a)–(j) encapsulates the outcomes observed over the entire duration of the sample

Table 6. Diagnostic test results

Diagnostic test	Types of tests	Prob.
Breusch–Godfrey LM test	Serial correlation	0.4553
Ramsey RESET test	Functional form	0.7262
Jarque–Bera	Normality	0.4806

Source: Authors' own calculations

(a) **(b)**

Source: Authors' own creation

Figure 3. Graphical view of CUSUM and CUSUM square

Table 7. Time domain causality test results

Null hypothesis	χ^2 statistic	df	Prob	Results
LPGDP ≠ LLCF	1.658	2	0.4365	No causality
LLCF ≠ LPGDP	9.042**	2	0.0109	LLCF → LPGDP
$LPGDP^2$ ≠ LLCF	3.084	2	0.2139	No causality
LLCF ≠ $LPGDP^2$	9.634**	2	0.0081	LLCF → $LPGDP^2$
LREN ≠ LLCF	1.345	2	0.5099	No causality
LLCF ≠ LREN	7.033**	2	0.0297	LLCF → LREN
LFNDX ≠ LLCF	9.492***	2	0.0087	LFNDX → LLCF
LLCF ≠ LFNDX	1.228	2	0.5410	No causality
LFF ≠ LLCF	0.163	2	0.9217	No causality
LLCF ≠ LFF	5.282*	2	0.07113	LLCF → LFF

Notes: ***, ** and * represent statistical significance at 1, 5 and 10% levels, respectively. → implies unidirectional causality; ≠ implies does not Granger cause
Source: Authors' own calculations

period under consideration. The magenta and green solid lines in the graphical representation signify the significance levels of 5% and 10%, respectively, while the *T*-statistics derived through this methodology are represented by the long-dash-dotted line.

The GC examinations carried out between LLCC and LPGDP demonstrate the null hypothesis rejection within the permanent frequency periods, particularly in instances where the causal relationship emanates from LLCF to LPGDP. Nevertheless, no substantiating evidence of causality is discerned across any FDs when the causal direction is posited from LPGDP to LLCF. Figure 4(a) indicates that it requires approximately seven years or longer duration for LLCF to exert a notable causal impact on LPGDP in India. Figure 4(b) illustrates a wavelength of approximately seven years or more for LLCC to exhibit a substantial causal influence on LPGDP.

The GC examinations undertaken between LLCF and $LPGDP^2$ yield the rejection of the null hypothesis within permanent frequency intervals, irrespective of the causality direction. Therefore, the discerned causality between LLCF and $LPGDP^2$ is bidirectional and exhibits statistical significance exclusively in the long-term. As illustrated in Figure 4(c) and (d), a discernible wavelength of approximately 10 years or more is identified for $LPGDP^2$ to exert a substantial causal influence on LLCF, while an estimated period of 8 years or beyond is indicated for a significant reverse impact.

The GC analyses conducted between LLCF and the LFNDX led to the rejection of the null hypothesis during distinct frequency periods, irrespective of the causality direction. Hence, the causative relationship between LLCF and LFNDX is bidirectional and holds statistical significance more exclusively in the long-term context. Figure 4(e)–(f) delineates a wavelength of approximately eight years or more for LFNDX to exert a significant causal influence on LLCF, while an estimated duration of approximately five years or beyond is indicated for a consequential reverse impact to manifest. This suggests that FNDX serves as a significant indicator for predicting short-term, medium-term and long-term levels of LLCF on a global scale. This assertion is supported by the observation that FINDX contributes to the mitigation of environmental degradation.

Regarding the causal nexus between LLCF and LFF, we fail to accept the null hypothesis of no causality from LFF to LLCF in the short run. Contrarily, we observe a substantiated causal relationship between LLCF and LFF in both the short and long terms when the directionality of causation is postulated from LLCF to LFF. This implies that both variables

emerge as significant predictors of each other, particularly in the context of short-term occurrences. Figure 4(g)–(h) asserts a wavelength of approximately four years or more for LFF to exert a significant causal impact on LLCF, and a consequential reverse impact takes around five years or longer to manifest.

Finally regarding the causal linkage between LLCF and LREN, our investigation establishes a significant causal relationship from LREN to LLCF over low frequency. Conversely, we discern a well-supported causal connection between LLCF and LREN across short-, medium- and long-term intervals. This suggests that both variables exhibit

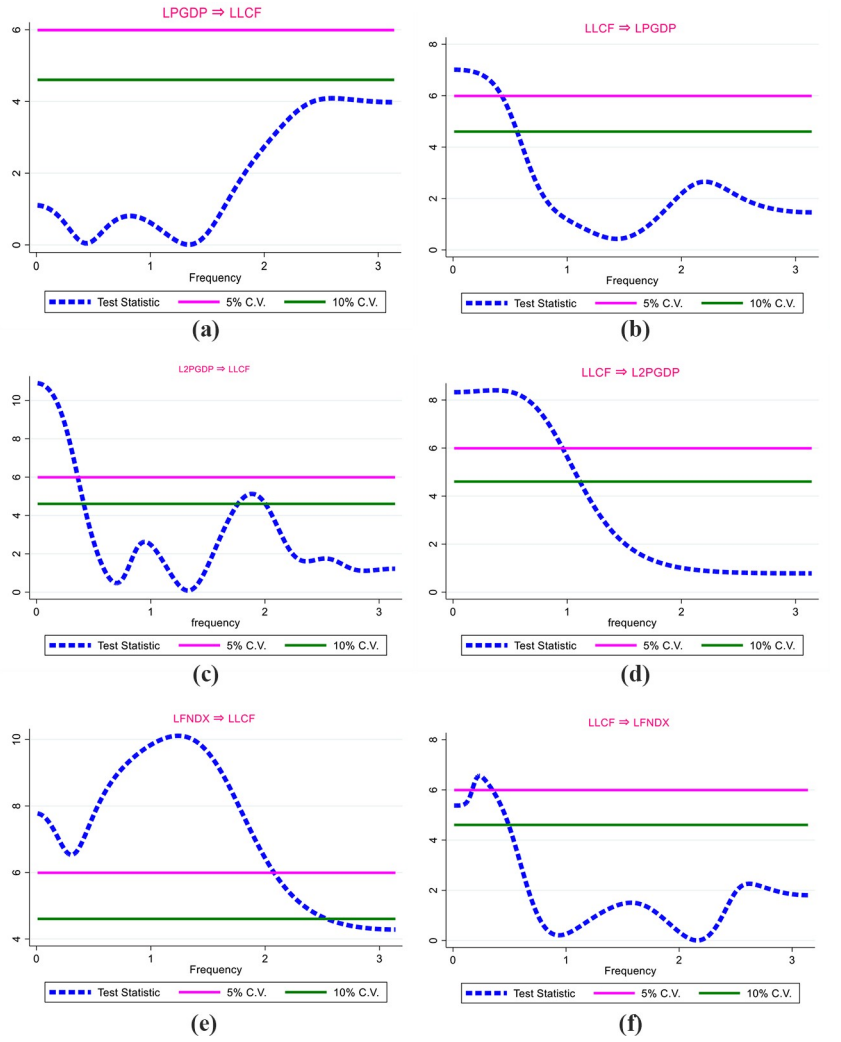


Figure 4. Graphical view of frequency domain causality analysis

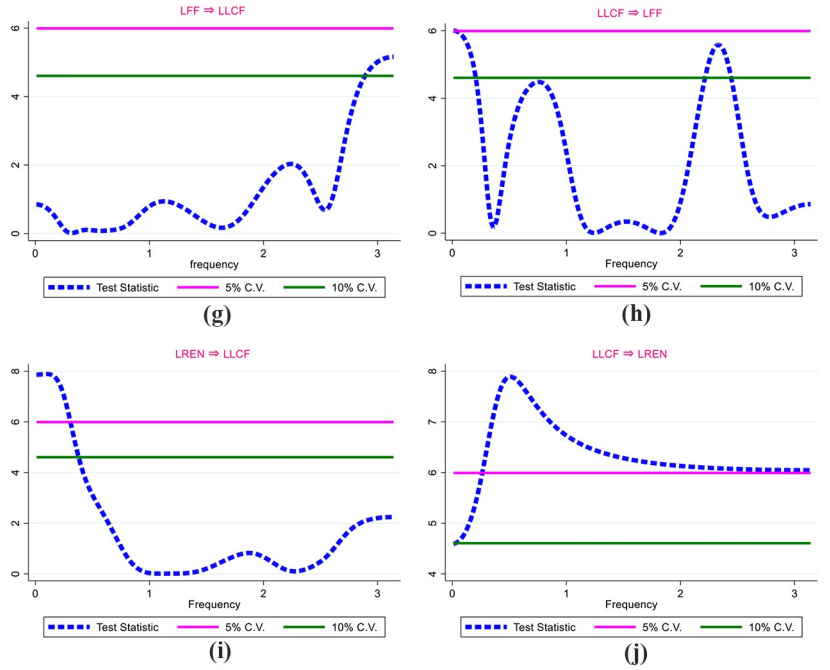


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Figure 4. Continued

substantial predictability for each other, particularly in the realm of prolonged occurrences. Figure 4(i)–(j) illustrates that it takes approximately six or more years for LREN to induce a substantial causal impact on LCF, and a consequential reverse impact takes around four years or longer to manifest.

7. Conclusion and policy implications

In this investigation, we delve into the interplay among income, financial development, renewable energy consumption, non-renewable energy consumption and the LCF in India from 1980 to 2021. The study is structured around three specific objectives. Firstly, it aims to ascertain the validity of the recently proposed LCC hypothesis in elucidating the connection between per capita income and LCF in India. Secondly, the study seeks to scrutinise the influence of financial development, renewable energy consumption and non-renewable energy consumption on LCF in the Indian economy. Thirdly, the research endeavours to evaluate the causality direction between the variables over distinct time periods, thereby delineating pathways for formulating mitigation policies. Unlike prior studies that primarily focused on the demand side of ecological accounting, using the footprint metric to gauge environmental sustainability in India, this study adopts a unique approach by incorporating the LCF. By integrating both the supply and demand facets of EQ, the LCF provides a more comprehensive framework for assessing environmental sustainability. In this regard, the study used novel econometric techniques such as AARDL, time and FD causality tests.

The results from the econometric exercise proved the existence of the LCC hypothesis in the Indian economy using both necessary and sufficient conditions. The minimum inflexion point for the LCF, at which EQ begins to increase, was set at $1530.47. Similarly, our findings revealed a positive and statistically significant relationship between financial development and the LCF. On the contrary, our research outcomes found a negative and statistically significant association between non-renewable energy consumption and the LCF. However, our study did not find any evidence of a nexus between renewable energy consumption and LCF.

Concerning the time domain causality approach, our research revealed one-way causality from LLCF to LPGDP, $LPGD^2$, LREN and LFF, respectively. Likewise, we identified unidirectional causality from LFNDX to LLCF. In the context of the FD causality approach, our study reveals a unidirectional causality running from LLCF to LPGDP in the long term. Besides this, our study identified bidirectional causality between LLCF and $LPGDP^2$ at low frequencies only, i.e. no short-run causality was established. Likewise, we found a bi-directional causal nexus between LLCF and LFNDX at low frequency, i.e. only long-run causality was established. However, one-way causality from LFNDX to LLCF is found at all frequencies. Furthermore, bidirectional causality is reported between LLCF and LREN at low frequencies only. In addition, unidirectional causality from LLCF to LREN is reported at all frequencies i.e. short, medium and long run. As a final point, our study has shown that a bidirectional causal relationship exists between non-renewable energy consumption and LCF only in the short run.

The aforementioned findings give rise to several significant policy recommendations.

The validation of the LCC hypothesis in India suggests that economic growth could enhance EQ. India is projected to experience rapid growth (7.2% on average from 2021 to 2025), with potential benefits of $1tn by 2030 and $15tn by 2070 through a transition to a net-zero economy (Focus Economics, 2021). The commitment India made at COP26 to attain net-zero targets by 2070 underlines the need for strategic economic expansion through investments in renewable energy, carbon capture technology, water pollution mitigation and afforestation. The government of India must provide financial assistance to environmental organisations to enhance the efficiency and sustainability of resource utilisation, which is essential for maintaining a balanced load capacity and fostering economic growth. Implementing green growth strategies can ensure that economic expansion does not come at the cost of environmental degradation.

The Indian economy needs to prioritise sustainable growth in its financial sector by aligning it with ongoing transformative processes for sustainable development. This involves advocating for green finance, exploring sustainable investments and providing targeted credit facilities for renewable energy and electric vehicles. The strategy includes reducing support for fossil fuel-dependent products and creating a customised "credit finance strategy" tailored to India's resource allocation and criteria. Encouraging banks and financial institutions to offer green loans and sustainable investment options can further align financial growth with environmental objectives.

To achieve the SDGs pertaining to EQ, it is imperative for the Indian economy to diminish its reliance on fossil fuels. Initiating and endorsing policies that promote and invest in non-fossil fuel sources can generate spillover effects, contributing to the realisation of these sustainability objectives across the entirety of the Indian economy. To enhance the impact of renewable energy consumption on EQ in India, policymakers should focus on increasing the share of renewables in the energy mix through aggressive targets and investment incentives, while phasing out fossil fuel-based technologies. Upgrading infrastructure, such as grid systems, and reducing transmission losses is essential to improve

efficiency. Sustainable manufacturing practices for renewable energy equipment should be promoted to minimise indirect emissions. In addition, stricter enforcement of environmental regulations and timely implementation of renewable energy policies are crucial. Addressing non-energy factors, such as urbanisation-related pollution, deforestation and poor waste management, alongside raising public awareness about the environmental benefits of renewables, can further strengthen their positive impact.

Nevertheless, it is important to acknowledge certain potential limitations that may be subject to investigation in future research endeavours. A notable limitation of this study lies in its exclusive focus on India. Future research can enhance the study's analytical framework by incorporating panel data analysis methods. The current study used Augmented ARDL and FD causality techniques to scrutinise the causal relationships among the chosen variables. Subsequent empirical investigations may consider exploring alternative models and methodologies, such as Quantile ARDL regression (QARDL), NARDL and STAR models, to further enrich the analytical approaches used in the research domain.

References

Ali, A., Radulescu, M. and Balsalobre-Lorente, D. (2023), "A dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth, and carbon dioxide emissions: evidence from Asian emerging economies", *Energy and Environment*, Vol. 34 No. 8, p. 958305X231151684.

Ali, M., Tursoy, T., Samour, A., Moyo, D. and Konneh, A. (2022), "Testing the impact of the gold price, oil price, and renewable energy on carbon emissions in South Africa: novel evidence from bootstrap ARDL and NARDL approaches", *Resources Policy*, Vol. 79, p. 102984.

Al-Mulali, U., Saboori, B. and Ozturk, I. (2015), "Investigating the environmental Kuznets curve hypothesis in Vietnam", *Energy Policy*, Vol. 76, pp. 123-131.

AlNemer, H.A., Hkiri, B. and Tissaoui, K. (2023), "Dynamic impact of renewable and non-renewable energy consumption on CO2 emission and economic growth in Saudi Arabia: fresh evidence from wavelet coherence analysis", *Renewable Energy*, Vol. 209, pp. 340-356.

Apergis, N., Kuziboev, B., Abdullaev, I. and Rajabov, A. (2023), "Investigating the association among CO2 emissions, renewable and non-renewable energy consumption in Uzbekistan: an ARDL approach", *Environmental Science and Pollution Research*, Vol. 30 No. 14, pp. 39666-39679.

Aydin, M., Koc, P. and Sahpaz, K.I. (2023), "Investigating the EKC hypothesis with nanotechnology, renewable energy consumption, economic growth and ecological footprint in G7 countries: panel data analyses with structural breaks", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 18 No. 1, p. 2163724.

Aye, G.C. and Edoja, P.E. (2017), "Effect of economic growth on CO2 emission in developing countries: evidence from a dynamic panel threshold model", *Cogent Economics and Finance*, Vol. 5 No. 1, p. 1379239.

Bandyopadhyay, A. and Rej, S. (2021), "Can nuclear energy fuel an environmentally sustainable economic growth? Revisiting the EKC hypothesis for India", *Environmental Science and Pollution Research*, Vol. 28 No. 44, pp. 63065-63086.

Boukhelkhal, A. (2022), "Impact of economic growth, natural resources and trade on ecological footprint: do education and longevity promote sustainable development in Algeria?", *International Journal of Sustainable Development and World Ecology*, Vol. 29 No. 8, pp. 875-887.

Bozkaya, Ş. and Duran, M.S. (2022), "The impacts of energy usage and economic growth on the ecological footprint and CO2 emissions: the case of G-7 countries", *Multidimensional Strategic Outlook on Global Competitive Energy Economics and Finance*, Emerald Publishing, Bingley, pp. 113-126.

Breitung, J. and Candelon, B. (2006), "Testing for short-and long-run causality: a frequency-domain approach", *Journal of Econometrics*, Vol. 132 No. 2, pp. 363-378.

Charfeddine, L. (2017), "The impact of energy consumption and economic development on ecological footprint and CO2 emissions: evidence from a Markov switching equilibrium correction model", *Energy Economics*, Vol. 65, pp. 355-374.

Cheng, J., Gil Kim, Y., Shamansurova, Z. and Lanre Ibrahim, R. (2023), "Financing sustainable environment in the wake of global warming for E7 economies: heterogeneous analyses based on NARDL and quantile regression", *International Journal of Sustainable Development and World Ecology*, Vol. 31 No. 3, pp. 1-16.

Dada, J.T., Ajide, F.M., Arnaut, M. and Adeiza, A. (2023), "On the shadow economy-environmental sustainability nexus in Africa: the (IR) relevance of financial development", *International Journal of Sustainable Development and World Ecology*, Vol. 30 No. 1, pp. 6-20.

Deng, S., Tiwari, S., Khan, S., Hossain, M.R. and Chen, R. (2023), "Investigating the load capacity curve (LCC) hypothesis in leading emitter economies: role of clean energy and energy security for sustainable development", *Gondwana Research*, Vol. 128, pp. 283-297.

Dong, K., Dong, X. and Jiang, Q. (2020), "How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels", *The World Economy*, Vol. 43 No. 6, pp. 1665-1698.

Erdogan, S. (2023), "Linking natural resources and environmental sustainability: a panel data approach based on the load capacity curve hypothesis", *Sustainable Development*, Vol. 32 No. 4, pp. 3182-3194.

Eregha, P.B., Adeleye, B.N. and Ogunrinola, I. (2022), "Pollutant emissions, energy use and real output in Sub-Saharan Africa (SSA) countries", *Journal of Policy Modeling*, Vol. 44 No. 1, pp. 64-82.

Fakher, H.A. and Ahmed, Z. (2023), "Does financial development moderate the link between technological innovation and environmental indicators? An advanced panel analysis", *Financial Innovation*, Vol. 9 No. 1, p. 112.

Focus Economics (2021), "The world's fastest growing economies", available at: www.focus-economics.com/blog/fastest-growing-economies-in-the-world/#:%7E:text=1.,India%26text=India%20is%20expected%20to%20record,over%20the%20next%20five%20years (accessed 20 October 2023).

Fu, H., Huang, P., Xu, Y. and Zhang, Z. (2023), "Digital trade and environmental sustainability: the role of financial development and ecological innovation for a greener revolution in China", *Economic Research-Ekonomska Istraživanja*, Vol. 36 No. 2, p. 2125889.

Geweke, J. (1982), "Measurement of linear dependence and feedback between multiple time series", *Journal of the American Statistical Association*, Vol. 77 No. 378, pp. 304-313.

Hakkak, M., Altintaş, N. and Hakkak, S. (2023), "Exploring the relationship between nuclear and renewable energy usage, ecological footprint, and load capacity factor: a study of the Russian Federation testing the EKC and LCC hypothesis", *Renewable Energy Focus*, Vol. 46, pp. 356-366.

Hosoya, Y. (1991), "The decomposition and measurement of the interdependency between second-order stationary processes", *Probability Theory and Related Fields*, Vol. 88 No. 4, pp. 429-444.

Huilan, W., Akadiri, S.S., Haouas, I., Awosusi, A.A. and Odu, A.T. (2024), "Impact of trade liberalization and renewable energy on load capacity factor: evidence from novel dual adjustment approach", *Energy and Environment*, Vol. 35 No. 2, pp. 795-814.

Hussain, M.M., Pal, S. and Villanthenkodath, M.A. (2023), "Towards sustainable development: the impact of transport infrastructure expenditure on the ecological footprint in India", *Innovation and Green Development*, Vol. 2 No. 2, p. 100037.

IPCC (2022), "Impacts of 1.5°C global warming on natural and human systems", available at: www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Chapter_3_HR.pdf

Itoo, H.H. and Ali, N. (2023), "Analysing the causal nexus between CO2 emissions and its determinants in India: evidences from ARDL and EKC approach", *Management of Environmental Quality: An International Journal*, Vol. 34 No. 1, pp. 192-213.

Javeed, S., Siddique, H.M.A. and Javed, F. (2023), "Ecological footprint, globalisation, and economic growth: evidence from Asia", *Environmental Science and Pollution Research*, Vol. 30 No. 31, pp. 1-16.

Jie, H., Khan, I., Alharthi, M., Zafar, M.W. and Saeed, A. (2023), "Sustainable energy policy, socio-economic development, and ecological footprint: the economic significance of natural resources, population growth, and industrial development", *Utilities Policy*, Vol. 81, p. 101490.

Khan, M. and Ozturk, I. (2021), "Examining the direct and indirect effects of financial development on CO2 emissions for 88 developing countries", *Journal of Environmental Management*, Vol. 293, p. 112812.

Khanday, I.N., Wani, I.U. and Tarique, M. (2023), "Do financial development and institutional quality matter for ecological sustainability in the long run? Evidence from India", *Management of Environmental Quality: An International Journal*, Vol. 34 No. 6, pp. 1668-1689.

Kostakis, I., Armaos, S., Abeliotis, K. and Theodoropoulou, E. (2023), "The investigation of EKC within CO2 emissions framework: empirical evidence from selected cross-correlated countries", *Sustainability Analytics and Modeling*, Vol. 3, p. 100015.

Lee, C.C., Yahya, F. and Razzaq, A. (2023), "Greening South Asia with financial liberalisation, human capital, and militarisation: evidence from the CS-ARDL approach", *Energy and Environment*, Vol. 34 No. 6, pp. 1957-1981.

Liu, W. (2020), "EKC test study on the relationship between carbon dioxide emission and regional economic growth", *Carbon Management*, Vol. 11 No. 4, pp. 415-425.

McNown, R., Sam, C.Y. and Goh, S.K. (2018), "Bootstrapping the autoregressive distributed lag test for cointegration", *Applied Economics*, Vol. 50 No. 13, pp. 1509-1521.

Mehmood, U. (2022), "Examining the role of financial inclusion towards CO2 emissions: presenting the role of renewable energy and globalisation in the context of EKC", *Environmental Science and Pollution Research*, Vol. 29 No. 11, pp. 15946-15954.

Mesagan, E.P. and Olunkwa, C.N. (2022), "Heterogeneous analysis of energy consumption, financial development, and pollution in Africa: the relevance of regulatory quality", *Utilities Policy*, Vol. 74, p. 101328.

Mitić, P., Fedajev, A., Radulescu, M. and Rehman, A. (2023), "The relationship between CO2 emissions, economic growth, available energy, and employment in SEE countries", *Environmental Science and Pollution Research*, Vol. 30 No. 6, pp. 16140-16155.

Muhammad, B. (2019), "Energy consumption, CO2 emissions and economic growth in developed, emerging and middle East and North Africa countries", *Energy*, Vol. 179, pp. 232-245.

Murshed, M. and Dao, N.T.T. (2022), "Revisiting the CO2 emission-induced EKC hypothesis in South Asia: the role of export quality improvement", *GeoJournal*, Vol. 87 No. 2, pp. 535-563.

Narayan, P.K. (2005), "The saving and investment nexus for China: evidence from cointegration tests", *Applied Economics*, Vol. 37 No. 17, pp. 1979-1990.

Nathaniel, S.P., Adeleye, N. and Adedoyin, F.F. (2021), "Natural resource abundance, renewable energy, and ecological footprint linkage in MENA countries", *Estudios de Economía Aplicada*, Vol. 39 No. 2.

Neifar, M., Ghorbel, A. and Bouaziz, K. (2023), "Caring for environment sustainability: how human capital, natural resources and economic growth interact with ecological footprint in Morocco?", *Management of Environmental Quality: An International Journal*, Vol. 35 No. 3, pp. 525-546.

Ozturk, I. and Ullah, S. (2022), "Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? An empirical analysis", *Resources, Conservation and Recycling*, Vol. 185, p. 106489.

Pata, U.K. and Caglar, A.E. (2021), "Investigating the EKC hypothesis with renewable energy consumption, human capital, globalisation and trade openness for China: evidence from augmented ARDL approach with a structural break", *Energy*, Vol. 216, p. 119220.

Pata, U.K. and Isik, C. (2021), "Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting", *Resources Policy*, Vol. 74, p. 102313.

Pata, U.K. and Samour, A. (2022), "Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor", *Progress in Nuclear Energy*, Vol. 149, p. 104249.

Pata, U.K. and Kartal, M.T. (2023), "Impact of nuclear and renewable energy sources on environment quality: testing the EKC and LCC hypotheses for South Korea", *Nuclear Engineering and Technology*, Vol. 55 No. 2, pp. 587-594.

Pata, U.K. and Tanriover, B. (2023), "Is the load capacity curve hypothesis valid for the top ten tourism destinations?", *Sustainability*, Vol. 15 No. 2, p. 960.

Pata, U.K., Shahzad, F., Fareed, Z. and Rehman, M.A. (2022), "Revisiting the EKC hypothesis with export diversification and ecological footprint pressure index for India: a RALS-Fourier cointegration test", *Frontiers in Environmental Science*, Vol. 10, p. 886515.

Pesaran, H.H. and Shin, Y. (1998), "Generalized impulse response analysis in linear multivariate models", *Economics Letters*, Vol. 58 No. 1, pp. 17-29.

Pesaran, M.H., Shin, Y. and Smith, R.J. (2001), "Bounds testing approaches to the analysis of level relationships", *Journal of Applied Econometrics*, Vol. 16 No. 3, pp. 289-326.

Petrović, P. and Lobanov, M.M. (2022), "Impact of financial development on CO2 emissions: improved empirical results", *Environment, Development and Sustainability*, Vol. 24 No. 5, pp. 6655-6675.

Sahoo, M., Gupta, M. and Srivastava, P. (2021), "Does information and communication technology and financial development lead to environmental sustainability in India? An empirical insight", *Telematics and Informatics*, Vol. 60, p. 101598.

Sam, C.Y., McNown, R. and Goh, S.K. (2019), "An augmented autoregressive distributed lag bounds test for cointegration", *Economic Modelling*, Vol. 80, pp. 130-141.

Sampene, A.K., Li, C., Khan, A., Agyeman, F.O., Brenya, R. and Wiredu, J. (2023), "The dynamic nexus between biocapacity, renewable energy, green finance, and ecological footprint: evidence from South Asian economies", *International Journal of Environmental Science and Technology*, Vol. 20 No. 8, pp. 8941-8962.

Shang, Y., Razzaq, A., Chupradit, S., An, N.B. and Abdul-Samad, Z. (2022), "The role of renewable energy consumption and health expenditures in improving load capacity factor in ASEAN countries: exploring new paradigm using advance panel models", *Renewable Energy*, Vol. 191, pp. 715-722.

Shehzad, K., Zaman, U., Ahmad, M. and Kocak, E. (2023), "Governance, financial development, and environmental degradation: evidence from symmetric and asymmetric ARDL", *Environment, Development and Sustainability*, Vol. 25 No. 12, pp. 14643-14660.

Siche, R., Pereira, L., Agostinho, F. and Ortega, E. (2010), "Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study", *Communications in Nonlinear Science and Numerical Simulation*, Vol. 15 No. 10, pp. 3182-3192.

Sinha, A. and Shahbaz, M. (2018), "Estimation of environmental Kuznets curve for CO2 emission: role of renewable energy generation in India", *Renewable Energy*, Vol. 119, pp. 703-711.

Sun, Y., Usman, M., Radulescu, M., Pata, U.K. and Balsalobre-Lorente, D. (2023), "New insights from the STIPART model on how environmental-related technologies, natural resources and the use of the renewable energy influence load capacity factor", *Gondwana Research*, Vol. 129, pp. 398-411.

Toda, H.Y. and Yamamoto, T. (1995), "Statistical inference in vector autoregressions with possibly integrated processes", *Journal of Econometrics*, Vol. 66 Nos 1/2, pp. 225-250.

Uche, E., Das, N. and Bera, P. (2023), "Re-examining the environmental Kuznets curve (EKC) for India via the multiple threshold NARDL procedure", *Environmental Science and Pollution Research*, Vol. 30 No. 5, pp. 11913-11925.

Usman, O., Iorember, P.T. and Olanipekun, I.O. (2019), "Revisiting the environmental Kuznets curve (EKC) hypothesis in India: the effects of energy consumption and democracy", *Environmental Science and Pollution Research*, Vol. 26 No. 13, pp. 13390-13400.

Usman, A., Ozturk, I., Naqvi, S.M.M.A., Zafar, S.M. and Javed, M.I. (2023), "Green versus conventional growth in the EKC framework of top pollutant footprint countries: evidence based on advanced panel data techniques", *Geological Journal*, Vol. 58 No. 9, pp. 3368-3384.

Wang, Y., Villanthenkodath, M.A. and Haseeb, M. (2023a), "The dynamic link between eco-innovation and ecological footprint in India: does the Environmental Kuznets Curve (EKC) hold?", *Management of Environmental Quality: An International Journal*, Vol. 34 No. 5, pp. 1225-1247.

Wang, S., Zafar, M.W., Vasbieva, D.G. and Yurtkuran, S. (2023b), "Economic growth, nuclear energy, renewable energy, and environmental quality: investigating the environmental Kuznets curve and load capacity curve hypothesis", *Gondwana Research*, Vol. 129, pp. 490-504.

Wang, R., Usman, M., Radulescu, M., Cifuentes-Faura, J. and Balsalobre-Lorente, D. (2023c), "Achieving ecological sustainability through technological innovations, financial development, foreign direct investment, and energy consumption in developing European countries", *Gondwana Research*, Vol. 119, pp. 138-152.

Wu, L., Adebayo, T.S., Yue, X.G. and Umut, A. (2023), "The role of renewable energy consumption and financial development in environmental sustainability: implications for the Nordic countries", *International Journal of Sustainable Development and World Ecology*, Vol. 30 No. 1, pp. 21-36.

Yang, M., She, D., Abbas, S., Ai, F. and Adebayo, T.S. (2023), "Environmental cost of financial development within the framework of the load capacity curve hypothesis in the BRICS economies: do renewable energy consumption and natural resources mitigate some burden?", *Geological Journal*, Vol. 58 No. 10, pp. 3915-3927.

Zhou, R., Abbasi, K.R., Salem, S., Almulhim, A.I. and Alvarado, R. (2022), "Do natural resources, economic growth, human capital, and urbanisation affect the ecological footprint? A modified dynamic ARDL and KRLS approach", *Resources Policy*, Vol. 78, p. 102782.

Further reading

Antonakakis, N., Chatziantoniou, I. and Filis, G. (2017), "Energy consumption, CO2 emissions, and economic growth: an ethical dilemma", *Renewable and Sustainable Energy Reviews*, Vol. 68, pp. 808-824.

Rej, S. and Nag, B. (2022), "Investigating the role of capital formation to achieve carbon neutrality in India", *Environmental Science and Pollution Research*, Vol. 29 No. 40, pp. 60472-60490.

Shahbaz, M. and Sinha, A. (2019), "Environmental Kuznets curve for CO2 emissions: a literature survey", *Journal of Economic Studies*, Vol. 46 No. 1, pp. 106-168.

World Economic Forum (2021), "Mission 2070: a green new deal for a net zero India", available at: www3.weforum.org/docs/WEF_Mission_2070_A_Green_New_Deal_for_a_Net_Zero_India_2021.pdf

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