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Impact of banking development and renewable energy consumption on environmental sustainability in Germany: Novel findings using the bootstrap ARDL approach

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ABSTRACT

This study examines the effects of banking development, economic growth and consumption of renewable energy on carbon dioxide (CO_2) emissions and load capacity factor (LCF). Previous empirical studies have assessed the interrelationship between banking development and CO_2 emissions; however, these studies have ignored supply-side ecological issues. To overcome this issue, this study evaluates the effect of banking development on LCF, which is considered to be one of the most comprehensive ecological proxies to date, including both biocapacity and ecological footprint (EF). Using the bootstrap autoregressive distributed lag model, the study reveals that renewable energy improves ecological quality in Germany. The results of the investigation demonstrate that the environmental Kuznets curve hypothesis is valid in Germany using CO_2 emissions and LCF indicators. Furthermore, this study demonstrates that banking growth and renewable energy in Germany correlate with improved environmental quality. These findings provide policymakers with important insights. In this context, the study advises the banking industry and government authorities to leverage banking expansion to support green energy to achieve the national goal of zero CO_2 emissions by 2045.

1. Introduction

Increasing ecological pollution is one of the most significant and pressing challenges confronting the planet [1]. This issue has become a priority, multiple protocols have been implemented and meetings have been organised to mitigate ecological pollution, such as the Kyoto Protocol and the 2015 Paris Agreement [2]. According to these agreements, national governments have pledged to

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mitigate ecological pollution to limit the increase in the level of global temperature. In this context, the prime objective of the Paris Agreement is to keep the increase in the global temperature well below 2 °C above the pre-industrial level [3]. Subsequently, carbon dioxide (CO_2) effluence became a focus of attention for researchers and policymakers, as it hinders economic development worldwide. Energy usage is a major contributor to CO_2 emissions across many countries, and this issue is of great concern for researchers and policymakers to understand the reasons for advanced global warming and environmental degradation.

Various studies have focused on variables or factors that determine ecological sustainability [4–11]. Previous studies have evaluated the impacts of economic expansion and energy using CO_2 emissions and ecological footprint (EF) as indicators to capture environmental sustainability; however, these proxies do not consider nature's response to human environmental degradation. For example, EF is basically an indicator that measures humans' pressure on environmental sustainability; therefore, empirical analyses that are based only on CO_2 emissions or EF neglect nature's supply side. Siche [12] suggested the load capacity factor (LCF) to address this issue, which is captured by dividing biocapacity/EF, to simultaneously evaluate human pressure on air and water quality. Some recent empirical studies [13–17] have used the LCF to capture ecological quality; however, these studies have not considered the influence of the banking sector on the LCF. Therefore, this study tests the impact of the banking-sector development on the LCF for the first time. In this context, the research endeavours to answer two research questions: (i) What is the effect of banking-sector development, economic growth, and renewable energy consumption (REC) on CO_2 emissions in Germany? And (ii) What is the effect of banking-sector development, economic growth and REC on the LCF in Germany?

In the contemporary world, Germany stands as the fourth largest economic power and is positioned as second in exports around the globe [18], and Germany also boasts superior economic mass and international trade. The nation is currently striving to reduce CO_2 emissions, seeking to achieve the target of zero or at least minimal greenhouse gas (GHG) emissions. Notably, Germany's CO_2 emissions have fallen significantly over the years, with a considerable reduction of 4.9% from the 2012 level. Germany has improved its reduction of CO_2 emissions remarkably in the past decade to combat climate change challenges and attain a safer environment [19]. The LCF is considered to be one of the comprehensive ecological proxies to date, and examining biocapacity and EF reveals that it has increased from 0.22 in 1972 to 0.35 in 2021 (Fig. 1).

Furthermore, an evaluation of the contribution made by Germany in non-trade sectors reveals that some CO_2 emissions mitigation in Germany was achieved by transferring carbon-intensive production factories to least-developed economies. Germany has also been a forerunner in adopting updated renewable energy technology [20]. The methods used to transform the German energy sector are based on government-controlled, policy-centred structural changes to shift from an energy system based on fossil fuels to renewable energy [21,22]. Through massive reduction of harmful CO_2-emitting plants, Germany could serve as an exemplary standard for other nations.

Germany is an ideal case to investigate the impact of banking expansion on environmental quality. The German banking sector has continuously made a massive contribution to the nation's economy. The cumulative assets of German investment banks are up to 1.2 billion euros, with access to more massive customers through denser branch networks [23]. Furthermore, cooperative and public banks in Germany comprise a widespread, locally grounded network which helps branches remain updated regarding the prospective business of the companies with which they collaborate. Notably, Germany's 111 billion euros worth of annual financial services contribute a 4% share to the nation's gross domestic product (GDP) [24].

This study contributes to the literature in three ways. First, although several previous studies have assessed the impact of economic growth and energy on ecological pollution [9–11,14,16], limited research has focused on the impact of the banking sector on environmental sustainability. Specifically, previous studies have not addressed the effect of the banking sector on ecological sustainability in Germany. In addition, these studies have not addressed the linkage between the LCF and banking development. To the best of the author's knowledge, this is the first study to assess the effect of the banking-sector on the LCF, which is considered to present a novel indicator of ecological sustainability, which captures the supply- and demand-side aspects of environmental sustainability. If the LCF is higher than 1, it indicates that exceeds EF and the country's current supply of natural resources is sufficient to maintain ecological quality. In contrast, if LCF is lower than 1, the country's environmental quality is at risk [25]. Although Germany has improved its environmental quality indicators remarkably over the last decades, its LCF still remains at less than one (Fig. 1), meaning that biocapacity is lower than the current EF and the nation's environmental quality is unsustainable. This issue remains a primary significant challenge for the country, and it is essential to examine the determinants of Germany's LCF.

Second, this study retests the environmental Kuznets curve (EKC) hypothesis [26] by introducing Germany's banking-sector

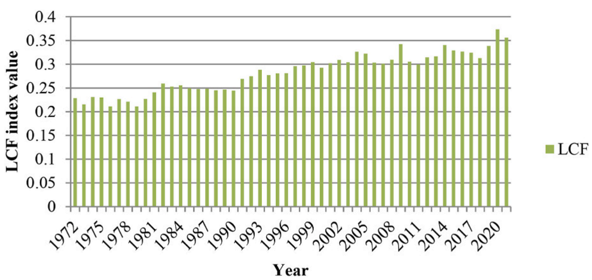

Fig. 1. The LCF in Germany over the period from 1972 to 2021.
Source: Global Footprint Network (2021).

development. For comprehensive analysis, we used two proxies to capture ecological quality, including CO_2 emissions as a traditional indicator and the LCF as a novel indicator. The study also uses principal component analysis (PCA) to construct a banking-sector development index including three proxies, which include private credit in the deposit money banking sector as a share of GDP, banks' deposit money assets as a share of GDP (%) and liquid liabilities as a share of GDP. Most of the studies have used data till 2018 to measure the LCF, and we provide the first study using updated data from 1972 to 2021 which are obtained from the Global Footprint Network (GFN) website, as published in June 2023.

Third, this study provides some critical insights and policy implications for German policymakers towards advancing sustainable environmental development that fully leverages banking-sector development. This sector has a key role in allocating finances for economic functioning and advancement. Given the high expenditures and funds required for green energy investment, the sector has a pivotal role; therefore, environmental plans which are implemented without considering how banking development contributes to ecological contamination and might hinder the achievement of sustainable development. Nevertheless, the impact of the banking sector on ecological sustainability could be positive or negative depending on how this sector promotes applications of environmentally friendly and green energy sources. For example, the banking-sector development may promote environmental sustainability by introducing more capital to flow and actively promoting advanced technologies and green projects, offering low finance costs to projects that support and use green energy sources to mitigate emissions [27,28]. Conversely, banking-sector development may help the German economy increase production and manufacturing activities by lowering borrowing costs. Conversely, the absence of stringent ecological regulations could allow firms and individuals to consume and produce more energy-intensive products, increasing ecological pollution through ambient air pollution.

It is essential to investigate the impact of banking-sector development on environmental sustainability in Germany. As noted above, this study focuses on the LCF to clearly demonstrate how banking-sector expansion affects the sustainability of the nation's environment. In this context, this study determines that the banking sector can have a significant influence on ecological sustainability in three ways. (i) Channelling private investment and production towards the green transition by mobilising funds at a lower borrowing cost for investment in energy-efficient technologies. This transition can be advanced by channelling energy production and consumption systems that are high in GHG emissions to clean energy sources with low or zero CO_2 emissions, which will positively affect ecological sustainability. (ii) By continuously evaluating the influence of banking regulations and policies on ecological sustainability and implementing targeted green regulations, the banking sector can redistribute funds from less energy-efficient technologies to environmentally friendly technologies. These regulations must be managed by the central banks to ensure the positive role of the banking sector in promoting environmentally friendly investment. (iii) Increasing research and development (R&D) investments and advanced technologies that facilitate the expanded use of green energy sources. This can be achieved with strategic financing structures in the banking sector, such as green mortgages and investment loans.

Finally, we employ Zivot–Andrews (ZA) unit root and Perron and Vogelsang (PV) tests to evaluate unit roots and adopt the novel bootstrap autoregressive distributed lag (ARDL) technique. This approach combines an F-test on the estimated coefficients of the variables employed and an F-test on the estimated coefficient of the independent selected variable. The test also includes a *t*-test on the estimated coefficient of the dependent selected variable. This approach confirms the stability of the results in the conventional co-integration approaches to produce robust findings with notable policy implications.

The remainder of this paper is organised as follows. Section 2 presents a literature review; sections 3 and 4 detail the empirical model, data employed, methodology and empirical findings. We examine and discuss the results in section 5, and the conclusion is presented in section 6.

2. Literature review

2.1. Theoretical foundation of the study

A number of studies have examined the connection between economic development and environmental pollution [27–31]. Some of

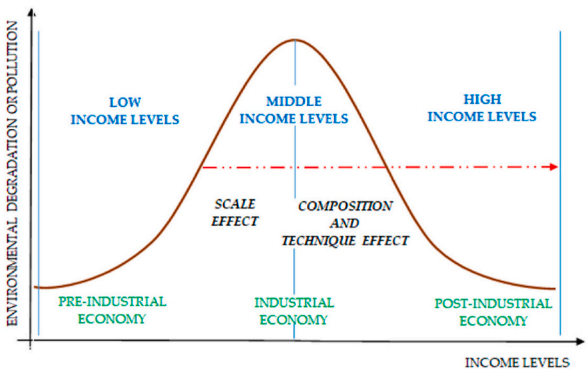

Fig. 2. Relationship between economic growth and environmental deterioration (EKC hypothesis): Phases of environmental deterioration [26].

these works have focused on the EKC framework which illustrates an inverted U-shaped linkage between pollution and per capita income. The primary justification behind the EKC framework contends that the initial phases of economic expansion raise the level of CO_2 emissions; therefore, a trade-off between economic expansion and ecological pollution can be expected during the initial economic expansion phase [28]. The effect of economic expansion on environmental neutrality can be explained in three different ways within the EKC approach [8]. During the initial economic growth period, economic development activities may increase ecological pollution, representing the scale effect of economic development [2]. In the later phase, economic development will lead to a transition from energy-intensive production towards increasing environmentally friendly services. Eventually, the economy shifts towards information-based services and industries which are less carbon-polluting. This is the trajectory of economic expansion impact [32]. Increased environmentally friendly production techniques may mitigate ecological pollution [33], indicating the effect of economic expansion. The EKC framework is illustrated in Fig. 2.

Although the traditional EKC approach has focused on the link between economic development and ecological pollution, several empirical studies have assessed the role of energy within the EKC framework [1,2,7,29,30]. According to these studies, energy utilisation is the primary driver of climate change, suggesting that traditional energy systems such as fossil fuel (oil, gas and gas) positively affect CO_2 emissions, whereas green energy negatively affects CO_2 emissions. Some recent studies have tested the effects of the banking sector on ecological pollution within the EKC framework [27,33,34], indicating that the banking sector is likely to affect economic development as well as energy utilisation, indirectly affecting ecological pollution.

When banks enable more loan disbursements to households and enterprises at reduced financing costs, the banking industry develops. Zafar et al. [27] suggest that banking-sector development makes it easier for consumers and companies to obtain loans, promoting economic development and industrialisation. However, this economic development can raise energy use level and may increase ecological pollution through ambient air pollution. In contrast, further improvement in the banking sector could stimulate increased energy innovation, raising clean energy consumption and mitigating ecological pollution. Sadorsky [28] and Çoban and Topcu [35] proposed that banking expansion positively influences economic development by lowering borrowing costs, alleviating the level of financial risk and allowing investors to expand investments, increasing energy utilisation. In this context, banking development positively impacts industrialisation and investment, which may positively affect fossil fuel consumption and ecological pollution.

Moreover, the banking sector may support ecological sustainability by supporting R&D investments and advanced technologies to expand the use of green energy sources. This can be achieved through strategic finance structures in the banking sector, such as reserves of loan loss and green loan guarantees, facilitating low-risk green investments, introducing more capital to the economy and promoting advanced technologies and green projects by offering low financing costs for projects that support and use green energy sources [25]. This finance structure results in more green energy being deployed at a lower cost provided by the banking sector. In this context, consumers and firms can invest more in projects that use green energy sources, replacing polluting energy investment with green investment, which will increase green energy consumption and promote environmental quality. More green regulations in the banking sector can promote environmental sustainability. In contrast, the absence of green policies can negatively affect ecological sustainability through increased lending for high polluting projects [27].

2.2. Empirical literature

2.2.1. Economic growth, energy and environmental quality

The EKC framework has been extensively applied to evaluate economic growth's impact on ecological quality. In this context, Saboori et al. [36] evaluated the association between CO_2 emissions and GDP in Malaysia, revealing an inverse U-shaped nexus in the short- and long-term, validating the EKC hypothesis. Gao and Zhang [29] investigated the connection between CO_2 and economic growth in Sub-Saharan Africa, finding a positive correlation. Likewise, Cerdeira Bento and Moutinh [31] and Zoaka et al. [37] confirmed the EKC hypothesis in Italy and Brazil, Russia, India, China and South Africa (BRICS), respectively. These findings suggest that a rise in countries' real output increases ecological pollution, with a positive role in promoting ecological neutrality in later stages. Ganda [38] applied panel data generalised least squares and demonstrated that economic expansion positively influences ecological pollution in BRICS nations. Wang et al. [39] also found that the EKC framework is valid for G7 countries. Conversely, some studies have assessed the impact of economic growth on the LCF. For example, Awosusi et al. [13] used the ARDL method, revealing a negative link between economic expansion and the LCF in South Africa, and Shang et al. [14] demonstrated that economic growth negatively affects the LCF in ASEAN countries. Similar results were found by Pata [40] for Japan and the United States (US), Fareed et al. [17] in Indonesia and Ni et al. [41] in highly resource-consuming economies. Cheng et al. [42] examined global CO_2 emissions from all countries using annual data from 1970 to 2019. According to the authors, the EKC framework is not powerful enough to be generalised to every country or location.

In addition, multiple studies have explored the influence of energy utilisation on environmental quality in the US, France, China and Pakistan, establishing a unidirectional association between energy use and CO_2 emissions applying Granger causality, the vector error correction model (VECM) and the ARDL model [6–9,42–45]. Other researchers [46–49] and [50] have established a bi-directional association between energy utilisation and CO_2 emissions by applying ARDL-VECM in China, Pakistan, India and Sweden. Dogan and Seker [51] suggested that REC is crucial for lowering pollution levels (CO_2) in the US. Ma et al. [8] tested the impact of REC on ecological neutrality in Germany from 1995 to 2015, determining that REC significantly reduces CO_2 emissions in Germany. Awosusi et al. [13] suggested that REC positively promoted the LCF in South Africa from 1980 to 2019. Pata [40] assessed the impact of REC on the LCF in the US. The scholars proposed a positive connection between REC and the LCF. Shang et al. [14] suggested that REC and health expenditure promote the LCF in the case of ASEAN economies from 1980 to 2018. Pata and Samour [33] used the ARDL method, determining that REC has no long-term effects on the LCF in France. Agila et al. [15] suggested a causal interrelationship between REC and the LCF in South Korea from 1970 to 2018. Pata et al. [52] assessed the impact of REC on the LCF in Germany, finding that REC promotes the LCF from 1974 to 2018.

2.2.2. Banking-sector development and environmental quality

Several studies have examined the correlation between financial expansion and economic growth. For instance, some studies [30, 52,53] and [54,55] have illustrated that a significant improvement in the finance sector positively affects the rate of economic growth, which eventually affects energy utilisation and ecological quality. Other studies have examined the correlation between financial development and ecological quality. For example, Shahbaz et al. [56] illustrated that the impact of financial expansion on Cis positive in the case of Malaysia. Zafar et al. [57] demonstrated a positive link between finance growth and Cin some selected countries in Asia. For the years 1990–2017, Zoaka et al. [37] employed the augmented mean group technique in BRICS nations, demonstrating that the rates of CO_2 are favourably impacted by improvement in the financial sector. The above studies focused on the interlink between financial development and ecological quality; however, limited research has assessed the connection between banking development and environmental quality. Zafar et al. [27] used the LM bootstrap panel co-integration method, illustrating that the banking sector has a positive impact on environmental quality in G-7 and N-11 economies from 1990 to 2016. Samour [58] applied the ARDL approach and demonstrated that a significant improvement in the banking sector has a powerful influence on environmental quality in Turkey from 1980 to 2014. Radulescu et al. [59] applied the method of moments quantile regression approach to assess the impact of banking development on the EF in economies in the Organisation for Economic Development and Co-operation (OECD) from 1990 to 2018, finding that the banking sector negatively impacts ecological quality in OECD nations. In contrast to earlier research, this study assesses the correlation between banking development and environmental quality using the LCF and is the first to identify how banking development affects the LCF. To the best of our research knowledge, no previous empirical study has examined the correlation between banking development and LCF.

2.3. Gaps in the literature

The following main perspectives emerged from the literature review summary above. First, the commonly applied techniques used to scrutinise the associations among variables have included Granger causality, VECM, ARDL-VECM and NARDL [6–10,37,38,45]. Second, the predominant indicators employed in previous studies have included CO_2 emissions and EF. Minimal research has used the LCF indicator, and the influence of banking development on ecological sustainability in Germany has not yet been empirically examined. Furthermore, a gap remains in the lack of studies exploring the effects of banking development on ecological sustainability in the context of the LCF. Therefore, this is the first study to fill the gap in the energy and environment literature by exploring the correlation between banking development and the LCF for the first time. Previous studies have only focused on CO_2 emissions and EF to measure the pressure of human activity on environmental sustainability, neglecting to include the supply side of nature. To overcome this issue, few studies have used the LCF to capture ecological quality [15–19,43,53]. The LCF is considered to be a unique measure of environmental quality which is used to incorporate supply and demand sides of ecological sustainability. This study also fills the gap by using the most recently available LCF data, whereas most empirical studies have only used the data till 2018 to measure the LCF. Therefore, we provide the first study to use updated data from 1972 to 2021.

3. Methodology and data sources

3.1. Data and model

Grossman and Krueger (1995) proposed the first theoretical linkage between CO_2 emissions and economic growth. Since that time, different variables have been introduced into the EKC framework such as renewable energy, financial development and international trade [2630]. Based on these studies, the EKC framework is formulated as follows in equation (1):

$$\ln CO_{2\,t} = \beta_0 + \Upsilon_1 \ln Y_t + \Upsilon_2 \ln {Y^2}_t + \varepsilon_t \tag{1}$$

According to the EKC framework, Υ_1 is expected to be positive and Y^2 is expected to be negative [27,34,57]. indicated that it is essential to consider banking-sector development as a potential determinant of environmental quality. In this context, this study evaluates the influence of the banking sector, GDP, squared GDP and renewable energy on ecological quality. In contrast to existing research, this study tests the impact of banking-sector development on Germany's environmental quality using the LCF in addition to the traditional indicator of CO_2 emissions.

To understand the effect of banking expansion on ecological sustainability and provide a comprehensive analysis of the influence of the banking sector on ecological sustainability, we employ four individual models within the EKC framework. The first model evaluates the impact of the banking sector, GDP, squared GDP and renewable energy on the LCF. The second model assesses the impact of the banking sector, GDP, squared GDP and renewable energy on CO_2 emissions. The structure of these models is formulated as follows in equations (2) and (3):

$$\text{Model 1}: \ln LCF_{it} = \beta_0 + \gamma_1 InGDP_{it} + \gamma_2 InGDP^2_{it} + \gamma_3 InBSD_{it} + \gamma_4 InREC_{it} + \varepsilon_t \tag{2}$$

$$\text{Model 2}: \ln CO2_{it} = \beta_0 + \gamma_1 InGDP_{it} + \gamma_2 InGDP^2_{it} + \gamma_3 InBSD_{it} + \gamma_4 InREC_{it} + \varepsilon_t \tag{3}$$

where ln CO_{2it} denotes emissions (metric tonnes per capita) in Germany [58]. $InGDP_{it}$ is total GDP (2015 = 100) in USD [52]. $InGDP_{it}^2$ is GDP squared. $InREC_{it}$ is REC captured in terawatt-hours (TWh) per year [60]. LCF_{it} is LCF, captured as biocapacity/EF [33]. $InBSD_{it}$ represents banking-sector development, which is constructed combining three proxies, which include private credit in the savings and loan banking sector as a share of GDP, banks' deposited financial assets as a share of GDP (%) and banks' liquid liabilities as a share of GDP using PCA to improve BSD representation [27]. PCA is an effective technique that decreases a dataset to lower dimensions while keeping as much information from the original dataset as possible. The PCA information is presented in Appendix Table A1. Components with an eigenvalue exceeding 1 are selected in this analysis. The eigenvalues imply that the first and second principal components significantly capture BSD; thus, the first and second components are considered as the BSD index in our estimation models. We obtained the data from the GFN website, World Bank Open Data, the World Bank Global Financial Development Database and the Our World in Data website, which are widely cited in top journals' articles [e.g. [60, 61,62].

All the variables in this study are in natural log form using the three noted indicators in the first and second models to capture banking-sector development. We apply two additional models to provide robust findings regarding the influence of banking expansion on ecological quality, using private credit as a single index to capture banking-sector development. The structure of these models is as follows in equations (4) and (5):

$$\text{Model 3}: \text{lnLCF}_{it} = \beta_0 + \gamma_1 \text{InGDP}_{it} + \gamma_2 \text{InGDP}_{it}^2 + \gamma_3 \text{InPC}_{it} + \gamma_4 \text{InREC}_{it} + \varepsilon_t \tag{4}$$

$$\text{Model 4}: \text{lnCO2}_{it} = \beta_0 + \gamma_1 \text{InGDP}_{it} + \gamma_2 \text{InGDP}_{it}^2 + \gamma_3 \text{InPC}_{it} + \gamma_4 \text{InREC}_{it} + \varepsilon_t \tag{5}$$

where $InPC_{it}$ is the proportion of private credit in the savings and loan banking sector to GDP [58]. This study's data cover the period from 1972 to 2021. The tested variables, measurements and sources of data are presented in Table 1.

3.2. Stationarity and Co-integration tests

This study employs the ZA unit root test suggested by Ref. [63] and the PV unit root test suggested by Ref. [64] to assess stationarity among the variables. In contrast to traditional tests, the primary advantage of these assessments is the consideration of structural breakdowns to capture the structural changes in the tested data.

This study uses the upgraded ARDL approach introduced by Ref. [65], raising the power of the 't'-test and 'F'-test, to explore the interaction among banking development, GDP, GD, REC and environmental quality in Germany. McNown et al. [65] employed Monte Carlo simulations, arguing that this updated method introduces a reasonable size. In conventional ARDL testing, an F-test ($F\text{statistic}_{ov}$) on the lagged level variables (H_0: $\gamma_1\ \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ (, and a lagged level-dependent *t*-test on the studied variable, (H_0: $\gamma_1 = 0$), are used to evaluate the long-term connections amid the focused variables. However, the upgraded ARDL method suggests an additional F-test (H_0: $\gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ (on the independent variables examined considering the following three statistical assessments: (i) an F-test ($F\text{statistic}_{ov}$) on the estimated coefficients of all the employed variables; (ii) an F-test ($F\text{statistic}_{IDV}$) on the estimated coefficient of the independent selected variable; and (iii) a *t*-test ($t\text{statistic}_{DV}$) on the estimated coefficient of the dependent selected variable. These assessments are essential and will yield robust findings to affirm co-integration between the chosen variables.

The critical values (CVs) in the upgraded method of the ARDL combines the combined integration of features for each studied series using bootstrap ARDL. This approach confirms the stability of the results using the conventional co-integration approaches. In this regard, one independent tested variable is allowed to be endogenous to apply the ARDL approach, and the CVs of the conventional ARDL method accept it, allowing for the endogeneity of multiple tested variables. Moreover, the upgraded ARDL method is suitable for the empirical model to include more than one tested variable. The co-integration between the banking sector, GDP, GD P^2, REC and ecological quality indicators (LCF and CO_2) will be determined if the values of ($F\text{statistic}_{ov}$), ($t\text{statistic}_{DV}$) and ($F\text{statistic}_{IDV}$) exceed the CV of the bootstrap approach. This approach is formulated as follows from equations (6)–(9):

Table 1
The tested variables, measurement, and sources of data.

Sign	Tested variables	Measurement	Source of the data
LCF	Load Capacity Factor	An indicator to assess the ecological quality through dividing biocapacity (per-capita) by the EF (Global hectares per capita	Global Footprint Network (GFN)
CO_2	Carbon Emissions	Carbon emissions (metric tons per capita)	Our world in data
REC	Renewable energy consumption	REC measured in terawatt-hours (TWh) per year	Our world in data
GDP	Economic growth	GDP-Per capita (Constant-2015 US$).	World Bank -Open Data
BSD	Banking Sector development	BSD index is constructed from three proxies (private credit by deposit money banking sector as a share of GDP, deposit money banks' assets as a share of GDP (%), and liquid liabilities as a share of GDP) using PCA	The Global Financial Development Database- World Bank
PC	Banking Sector development "Private credit"	Private credit by deposit money banking sector a percentage of GDP	The Global Financial Development Database- World Bank

$$\Delta \ln LCF_{it} = \alpha_0 + \sum_{i=1}^{r} \varnothing_1 \Delta \ln LCF_{t-j} + \sum_{i=1}^{r} \varnothing_2 \Delta \ln BSD_{t-j} + \sum_{i=1}^{r} \varnothing_3 \Delta \ln GDP_{t-j} + \sum_{i=1}^{r} \varnothing_4 \Delta InGDP^2_{t-j} + \sum_{i=1}^{r} \varnothing_5 \Delta \ln REC_{t-j} + \delta_1 \ln LCF_{t-1} + \delta_2 \ln BSD_{t-1} + \delta_3 \ln GDP_{t-j} + \delta_4 InGDP^2_{t-j} + \delta_5 \ln REC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \tag{6}$$

$$\Delta \ln CO_{2it} = \alpha_0 + \sum_{i=1}^{r} \beta_1 \Delta \ln CO_{2t-j} + \sum_{i=1}^{r} \beta_2 \Delta \ln BSD_{t-j} + \sum_{i=1}^{r} \beta_3 \Delta \ln GDP_{t-j} + \sum_{i=1}^{r} \beta_4 \Delta InGDP^2_{t-j} + \sum_{i=1}^{r} \beta_5 \Delta \ln REC_{t-j} + \gamma_1 \ln CO_{2t-1} + \gamma_2 \ln BSD_{t-1} + \gamma_3 \ln GDP_{t-j} + \gamma_4 InGDP^2_{t-j} + \gamma_5 \ln REC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \tag{7}$$

$$\Delta \ln LCF_{it} = \alpha_0 + \sum_{i=1}^{r} \varnothing_1 \Delta \ln LCF_{t-j} + \sum_{i=1}^{r} \varnothing_2 \Delta \ln PC_{t-j} + \sum_{i=1}^{r} \varnothing_3 \Delta \ln GDP_{t-j} + \sum_{i=1}^{r} \varnothing_4 \Delta InGDP^2_{t-j} + \sum_{i=1}^{r} \varnothing_5 \Delta \ln REC_{t-j} + \delta_1 \ln LCF_{t-1} + \delta_2 \ln PC_{t-1} + \delta_3 \ln GDP_{t-j} + \delta_4 InGDP^2_{t-j} + \delta_5 \ln REC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \tag{8}$$

$$\Delta \ln CO_{2it} = \alpha_0 + \sum_{i=1}^{r} \beta_1 \Delta \ln CO_{2t-j} + \sum_{i=1}^{r} \beta_2 \Delta \ln PC_{t-j} + \sum_{i=1}^{r} \beta_3 \Delta \ln GDP_{t-j} + \sum_{i=1}^{r} \beta_4 \Delta InGDP^2_{t-j} + \sum_{i=1}^{r} \beta_5 \Delta \ln REC_{t-j} + \gamma_1 \ln CO_{2t-1} + \gamma_2 \ln PC_{t-1} + \gamma_3 \ln GDP_{t-j} + \gamma_4 InGDP^2_{t-j} + \gamma_5 \ln REC_{t-j} + \omega ECT_{t-1} + \varepsilon_{1t} \tag{9}$$

where ε_{1t} is the error term; Δ represents first operation; denoted the constant term; $\varnothing_1, \varnothing_2, \varnothing_3, \varnothing_{4,} \varnothing_5$ and $\delta_1, \delta_2, \delta_{3,} \delta_4, \delta_5$ in the first model refer to coefficients of the LCF, BSD, PC, GDP, GD P^2 and REC in the short and long terms. $\beta_1, \beta_2, \beta_3, \beta_{4,} \beta_5$ and $\gamma_1, \gamma_2, \gamma_{3,} \gamma_4, \gamma_5$ the second model refers to coefficients of the CO_2, GDP, GD P^2 and REC and banking-sector development in the short and long terms. R represents the lag selections, and ωECT_{t-1} is the error correction term that presents the adjustment velocity between the explored variables.

This study applies several statistical diagnostic tests to assess the robustness of the our model, including the Ramsey RESET test (R^{-X}) the ARCH test (A^{-X}), the Breush heteroscedasticity test (B^{-X}) and the normality test (N^{-X}) to affirm that the examined model is robust and free from auto-correlation. Furthermore, we employed CUSUM and CUSUM-squared tests to confirm that the model is empirically accurate.

We also use Fully modified ordinary least squares (FMOLS) and canonical cointegrating regression (CCR) to reinforce outcomes of the ARDL approach. These methods use different corrective techniques except for non-centrality and the bias of the second order. The FMOLS assessment corrects all genetic projections, while the CCR assessment corrects data and selects an association that reflects the correct canonical class association. These tests are considered to be nonparametric assessments that allow for serial correlation of the examined time series.

We also apply the pairwise Granger causality technique which was proposed by Ref. [66] to capture the causal connections between variables. This approach is a paired sample test that capturing the significance of the predictive power of one tested time series variable on another. If one-series 'Y' can help predict the future of another tested time series 'X', then Y Granger causes X. These two variables' time series determine data length (T), containing X_t and Y_t ($t = 1, 2, \dots T$) indicating their outcomes at time t. The following bivariate autoregressive model (in equations (10) and (11)) is employed to construct X_t and Y_t:

$$X_t = \beta_1 + \sum_{i=1}^{p} \varnothing_i Y_t -_i + \sum_{i=1}^{p} \delta_i X_t -_1 \Big) + \varepsilon_t \tag{10}$$

$$Y_t = \beta_2 + \sum_{i=1}^{p} \varphi_i Y_t -_1 + \sum_{i=1}^{p} \infty_i X_t -_i \Big) + \epsilon_t \tag{11}$$

where p is the number of lags, ε_t and ϵ_t are residual terms, as stipulated by the data measures $\boldsymbol{\beta}1$, $\boldsymbol{\beta}2$, $\varnothing_i, \delta_i, \varphi_i, \infty_i$ as factors for evaluation. The coefficients are captured using OLS, and X and Y are estimated using F tests.

Table 2
Descriptive statistics.

	Mean	Median	Maximum	Minimum	Std. Dev.
$\ln LCF_t$	−1.27574	−1.23612	−0.98472	−1.55567	0.150871
$\ln CO_{2t}$	2.440172	2.442368	2.663569	2.037704	0.155116
$\ln GDP_t$	10.34024	10.37508	10.67555	9.858569	0.243439
$\ln BSD_t$	−4.20E-08	−0.009477	5.478669	−1.775727	1.343897
$\ln PC_t$	4.491054	4.481758	4.731831	4.278487	0.136281
$\ln REC_t$	0.477254	−0.09263	2.163395	−0.6201	0.937466

4. Results

Table 2 presents the descriptive statistics of our series of investigations, including values, showing how the variables are dispersed. Fig. 3 depicts a concentrated time series plot illustrating different economic events and shifts in Germany.

The outcomes of the unit root tests are presented in Tables 3 and 4, confirming that the selected variables of this study (LCF, CO_2, BSD, PC, GDP, GDP^2, and REC) are integrated and stationery at the first level (Δ) and are integrated at the I (1) operation level.

The outcomes of the upgraded ARDL co-integration method are presented in Table 5, confirming that the F.statistic$_{-OV}$, t.statistic$_{-DV}$ and Fstatistic$_{-IDV}$ values exceed the CVs of the upgraded ARDL method. These results indicate that the co-integration between the CO_2, BSD, PC, LCF, GDP, GDP^2 and REC is valid.

Table 6 presents the results of model 1 (GDP, GD P^2, BSD, REC and LCF) in short- and long-term analysis, demonstrating that the BSD positively and significantly affects the LCF. A 1% improvement in the banking sector in Germany is accompanied by a 0.015% and 0.020% significant increase in LCF in the short and long run, respectively. The findings from FMOLS and CCR (Tables 9 and 10) present similar results that BSD affects the LCF positively and significantly in the long run.

The findings also demonstrate that the GDP has a negative impact on the LCF in the short- and long-term. A 1% increase in real output in Germany is accompanied by a 1.508% and 0.075% significant decrease in the LCF in the short- and long-term. In contrast, the results show that GD P^2 is positive and significantly correlated with the LCF in the short- and long-term. A 1% increase in GD P^2 in Germany is accompanied by a 0.481% and 0.250% significant increase in the LCF in both the short- and long-term. These findings are validated by FMOLS and CCR testing models (Tables 9 and 10). According to these tests, a 1% augment in real output in Germany is accompanied by a 0.929%–0.983% decrease in the LCF. While a 1% increase in GD P^2 is accompanied by a 0.429%–0.910% increase in the LCF. The results also show that a 1% increase in REC promotes the LCF in Germany by 0.111% and 0.014% in the short- and long-

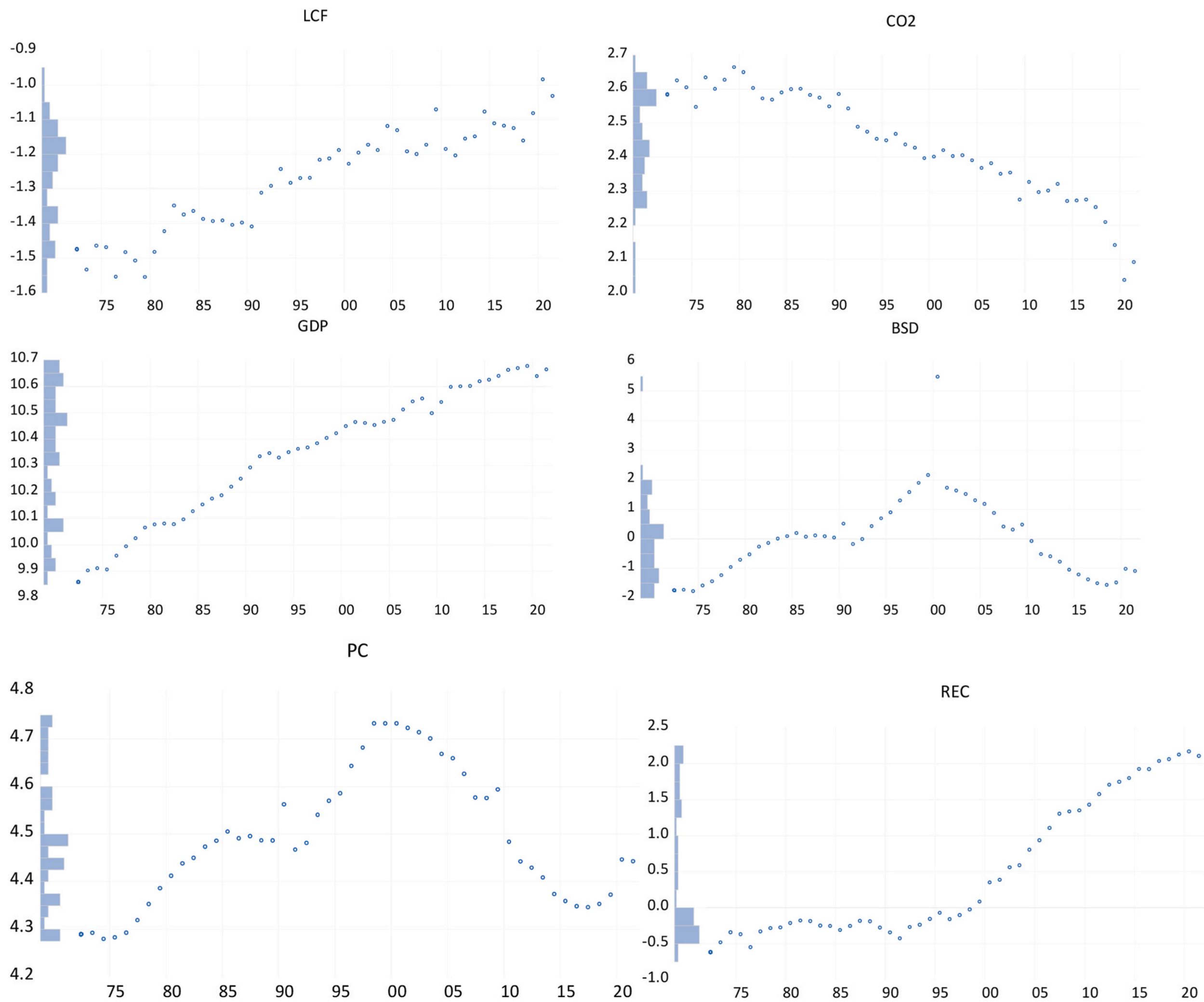

Fig. 3. Time series plot of the tested series. Note: X axis describes the logarithmic value of each variables and Y axis denotes the Year.

Table 3
The ZA unit root test results.

Level			First differences		
Variables	$t_{.}^{STAT}$	DSB[1]	Variables	t_{-}^{STAT}	DSB[1]
$\ln LCF_t$	−3.893134	2000	$\Delta \ln LCF_t$	−5.790086[a]	1991
$\ln CO_{2t}$	−3.353702	1984	$\Delta \ln CO_{2t}$	−8.985297[a]	2000
$\ln GDP_t$	−3.031143	1998	$\Delta \ln GDP_t$	−7.146731[a]	1993
$\ln BSD_t$	−3.604966	2004	$\Delta \ln BSD_t$	−5.666240[a]	2001
$\ln PC_t$	−3.142104	2010	$\Delta \ln PC_t$	−6.705712[a]	1999
$\ln REC_t$	−2.815816	2004	$\Delta \ln REC_t$	−5.609071[a]	1998

[a] Symbolizes the significance level at "1%". DSB symbolizes the dates of a structural break.

Table 4
The PV unit root test results.

Level			First differences		
Variables	$t_{.}^{STAT}$	DSB[1]	Variables	t_{-}^{STAT}	DSB[1]
$\ln LCF_t$	−2.980269	1990	$\Delta \ln LCF_t$	−8.832707[a]	1976
$\ln CO_{2t}$	−0.893562	1990	$\Delta \ln CO_{2t}$	−9.344597[a]	2017
$\ln GDP_t$	−2.612167	1975	$\Delta \ln GDP_t$	−7.261602[a]	1991
$\ln BSD_t$	−3.262777	2010	$\Delta \ln BSD_t$	−8.467300[a]	2002
$\ln PC_t$	−3.562990	1990	$\Delta \ln PC_t$	−6.551122[a]	1998
$\ln REC_t$	−3.273716	1999	$\Delta \ln REC_t$	−7.055959[a]	1991

[a] Symbolizes the significance level at "1%". DSB symbolizes the dates of a structural break.

Table 5
The bootstrap ARDL co-integration approach.

	$F.statistic_{-OV}$	$t.statistic_{-DV}$	$F.statistic_{-IDV}$
Model 1 (LCF, GDP, GD P^2, BSD, REC)	8.675**	−5.263**	6.748**
Bootstrap-based table CV 5%	6.283	−2.202	2.860
Model 2 (CO_2, GDP, GD P^2, BSD, REC)	9.677**	−3.805**	4.377**
Bootstrap-based table CV 5%	6.480	−2.146	2.015
Model 3 (LCF, GDP, GD P^2, PC, REC)	6.876**	−4.551**	3.928**
Bootstrap-based table CV 5%	6.141	−2.486	2.909
Model 4 (CO_2, GDP, GD P^2, PC, REC)	9.122**	−3.430**	3.917**
Bootstrap-based table CV 5%	7.024	−2.062	2.492

Note: $tstatistic_{-DV}$, *and* $Fstatistic_{-IDV}$ mean lagged variables F-test; *t*-test on the lagged "dependent & independent" variables, respectively. ** means significance at "5%" and CV means critical value.

Table 6
ARDL testing results from Model 1, and 2.

Variables	Model 1 (LCF, GDP, GD P^2, BSD, REC)			Model 2 (CO_2, GDP, GD P^2, BSD, REC)		
	Coefficient	t-stat	P-value	Coefficient	t-stat	P-value
$\Delta \ln GDP_t$	−1.508282***	−3.713324	0.0010	0.962481***	5.035582	0.0000
$\Delta \ln GDP_t^2$	0.481619***	6.443371	0.0000	−0.344581***	−3.226302	0.0027
$\Delta \ln BSD_t$	0.015640**	2.081074	0.0474	−0.018611***	−8.001743	0.0000
$\Delta \ln RECI_t$	0.111546**	2.103489	0.0421	−0.024167**	−2.274716	0.0290
$\ln GDP_t$	−0.075066*	−1.789651	0.0852	2.381333***	2.826100	0.0076
$\ln GDP_t^2$	0.250201***	11.15315	0.0000	−1.386385***	−3.392988	0.0017
$\ln BSD_t$	0.020089***	8.477826	0.0000	−0.008496*	−1.916308	0.0633
$\ln RECI_t$	0.014157***	3.037727	0.0054	−0.097235***	−5.144025	0.0000
ECT_{t-1}	−0.778515***	−8.557532	0.0000	−0.248546***	−5.501106	0.0000

Note: *, ** and *** symbolize significances at "1%,5%, and 10%" levels.

term, respectively.

The findings of model 2 (GDP, GD P^2, BSD, PC, REC and CO_2) are also presented in Table 6, indicating that banking-sector development is negative and significantly affects CO_2 emissions. A 1% improvement in the banking sector in Germany is accompanied by a 0.018% and 0.008% significant decline in CO_2 emissions in the short and long run, respectively. Furthermore, the results

Table 7
ARDL testing results from Model 3, and 4.

Variables	Model 3 (LCF, GDP, GD P^2, PC, REC)			Model 4 (CO_2, GDP, GD P^2, PC, REC)		
	Coefficient	t-stat	P-value	Coefficient	t-stat	P-value
$\Delta lnGDP_t$	−1.466432***	−5.576416	0.0000	0.668805***	3.165448	0.0037
$\Delta lnGDP_t^2$	0.298291***	2.752801	0.0091	−0.457240***	−4.314123	0.0002
$\Delta lnBSD_t$	0.205396**	2.475810	0.0180	−0.181565*	−1.813356	0.0805
$\Delta lnRECI_t$	0.042675*	1.922595	0.0623	−0.033928*	−2.022325	0.0528
$lnGDP_t$	−0.290029***	−3.065715	0.0040	1.142668***	12.15172	0.0000
$lnGDP_t^2$	0.328588***	8.454579	0.0000	−0.781205***	−15.34911	0.0000
$lnBSD_t$	0.226258***	6.942216	0.0000	−0.025990**	−1.864554	0.0728
$lnRECI_t$	0.047009***	5.582704	0.0000	−0.057967***	−15.83423	0.0000
ECT_{t-1}	−0.90779***	−9.684217	0.0000	−0.585301***	−9.078496	0.0000

*, ** and *** symbolize significances at “1,5,10” percents.
Source: Authors’ calculation.

Table 8
Diagnostic tests findings.

	Model 1		Model 2		Model 3		Model 4	
Tests	F-statistics	p-value	F-statistics	p-value	F-statistics	p-value	F-statistics	p-value
Ramsey	0.437	0.665	1.145	0.152	0.589	0.558	0.338	0.737
Heteroskedasticity	0.878	0.601	0.716	0.690	1.109	0.379	0.791	0.670
ARCH	0.718	0.401	0.039	0.842	2.198	0.145	0.311	0.579
Normality	0.441	0.802	1.650	0.438	0.041	0.979	1.102	0.576

demonstrate that the GDP has a positive effect on CO_2 emissions. A 1% rise in GDP in Germany is accompanied by a 0.962% increase in CO_2 emissions in the short term and a 2.381% increase in the long term. In contrast, the outcomes demonstrate that GD P^2 is negative and significantly correlated with CO_2 emissions in the short- and long-term. A 1% increase in GD P^2 in Germany is accompanied by a 0.344% and 1.386% decrease in CO_2 emissions in the short- and long-term. The findings also indicate a positive correlation between REC and CO_2, indicating that a 1% increase in REC decreases CO_2 emissions in Germany by 0.024% and 0.097% in the short and long terms, respectively. The findings from FMOLS and CCR approaches also confirm that BSD and REC have a negative and significant effect on Germany’s CO_2 emissions (Tables 9 and 10), and GDP increases the level of CO_2 emissions in Germany.

To confirm the findings of models 1 and 2, we employ two additional models to assess the impact of REC, GDP, GD P^2 and the banking sector on the LCF and CO_2 emissions. In these models, we use the proportion of private credit in the savings and loan banking sector in Germany’s GDP to measure the sector’s development. The findings of models 3 and 4 (Table 7) confirm that GDP has an adverse impact on ecological quality, while GD P^2 has a positive impact on ecological quality in the short- and long-term. The findings also confirm the positive influence of REC in promoting ecological sustainability in the country. The main results in models 3 and 4 also demonstrate that banking-sector development has a positive influence in promoting environmental sustainability. We confirm the significant role of banking-sector development in ecological sustainability in Germany. ECT_{t-1} indicates that the production functions move to a longer term equilibrium, with speeds of 77.85%, 24.85%, 90.77% and 58.53% from short-to long-term in the estimated models.

We apply some diagnostic tests to ensure the stability of the models employed in this study. The diagnostic assessment results are presented in Table 8. The results of the heteroscedasticity test (B^{-X}) confirm that no serial auto-correlation exists in the models. The normality test (N^{-X}) also indicates that the models have a normal distribution and the Ramsey RESET test (R^{-X}) confirms that the models are statistically stable. The CUSUM and CUSUM-squared assessments are presented in Fig. 4, and the blue line falls between the red presented lines, indicating that the models are formulated correctly.

Granger causality analysis is presented in Table 11. The results reveal a unidirectional causal link from GDP to the LCF and from GDP^2 to the LCF, also confirming a causal association from REC to the LCF. In addition, we find a unidirectional causal link from GDP,

Table 9
Findings of FMOLS approach.

	Model 1	Model 2	Model 3	Model 4
	Coefficient	Coefficient	Coefficient	Coefficient
$lnGDP_t$	−0.983232*	1.595014***	−0.604520***	0.080078***
$lnGDP_t^2$	0.429619*	−0.680742**	0.514814***	−0.214748***
$lnBSD_t$	0.039623***	−0.034342**	–	–
$lnPC_t$	–	–	0.191813*	−0.014284*
$lnREC_t$	0.125278***	−0.197322***	0.033918***	−0.050178***

Note: *, ** and *** symbolizes significances at “1%, 5%, and 10%, respectively.”

Table 10
Findings of CCR approach.

	Model 1	Model 2	Model 3	Model 4
	Coefficient	Coefficient	Coefficient	Coefficient
$lnGDP_t$	−0.929186***	1.184422***	−0.622565***	0.079376***
$lnGDP_t^2$	0.910567***	−0.979269***	0.523145***	−0.177114***
$lnBSD_t$	0.125310***	−0.067994***	–	–
$lnPC_t$	–	–	0.189009***	−0.030981***
$lnREC_t$	0.025663*	−0.130348***	0.033995*	−0.066191***

Note: *, ** and *** symbolizes significances at “1%, 5%, and 10%, respectively.”

GDP^2 to CO_2, from BSD to CO_2 and from REC to CO_2. These findings confirm the significant connection between Germany’s REC, banking-sector development, economic growth and environmental quality.

5. Findings and discussion

This study investigates the correlations between banking-sector development, REC, economic growth, and ecological quality in Germany, filling the research gap by evaluating the impact of banking development variables on CO_2 emissions and the LCF in Germany. We also employ the novel bootstrap ARDL approach proposed by McNown et al. [65]. The findings reveal that GDP in Germany positively affected environmental pollution from 1972 to 2021, while GDP^2 affected environmental pollution negatively, confirming that the EKC framework is valid in the tested country, indicating that an increase in GDP will lead to an initial rise in environmental pollution in the early stage of economic development, and will later have a significant role in promoting ecological sustainability. These outcomes align with [17] who demonstrated a positive link between real output and the LCF in Indonesia, and [52] who revealed the positive correlation between GDP and CO_2 emissions in some selected counties in Germany. In contrast, the findings contradict [67], who used annual data from 1970 to 2019, finding that the EKC approach is only accepted in some tested countries.

This study finds that REC in Germany has a positive influence on promoting ecological quality. This result aligns with critical statistics provided by Ref. [68], who suggested that REC has a powerful impact on reinforcing the LCF. In contrast, the findings contradict [33], who used the ARDL approach and determined that REC has no significant effects on LCF in France. These findings could be explained by Germany’s continuous improvement of environmental quality by introducing and heavily relying on renewable energy sources rather than fossil fuels and ratcheting renewable energy sources to an approximate 45% share. 2020 is considered a banner year for Germany in terms of high-renewable energy production of approximately 45% and lowering CO_2 emissions to 42% in comparison to 1990. Another critical concern in achieving environmental quality is economic development. Germany has committed itself to producing sustainable energy sources, accelerating the nation’s energy policy to advance the transition to renewable forms, which is crucial to produce clean electricity in the contemporary world.

Our findings also reveal that the banking sector negatively influences environmental degradation in Germany, mirroring [58] who asserted that banking development significantly influences the level of CO_2 emissions in Turkey. Conversely, the results contradict [69] who suggested that financial expansion has a significant negative impact on the LCF in the US, arguing that the financial system might expand finance channels, which increases energy consumption. Hence, increase energy utilisation and resultantly cause a significant impact on CO_2 emissions. In contrast, our study suggests that the banking sector may support ecological sustainability by supporting R&D investment and development of advanced technologies that increase the use of green energy sources. This can be achieved by strategically developing green finance structures in the banking sector such as reserves of loan loss or green loan guarantees, low-risk green investments for firms, more capital to flow and promote advanced clean technologies and green projects and offering low financing costs for projects that support and use green energy sources. Hence, introducing more green regulations in the banking sector will promote environmental sustainability. In contrast, the absence of green regulations in this sector will adversely affect ecological sustainability, increasing high-pollution projects and investments.

This present study indicates that banking development in Germany has a positive influence on promoting green energy and technological innovation. These results are attributable to continuous positive improvement in Germany’s banking sector from 1974 to 2021. In this context, the total credit from the banks in Germany to the overall market as a share of GDP in 2018 was roughly seven times higher than the GDP value in 1990. Furthermore, the country’s CO_2 emissions declined significantly in the past few years, and Germany’s banking sector is confirmed to be an active player in advancing the energy shift from non-renewable to renewable energy sources. Therefore, Germany’s banking sector actively participating in advancing the nation’s low-carbon and high-renewable energy by providing funds for green energy projects and investments. The outcomes of this study provide significant insights for German policymakers to advance the sustainable banking sector by diversifying its energy approach and promoting green policies in investment. We recommend that the German government leverage banking-sector growth to enhance investment in clean energy to reach the target of zero CO_2 emissions by 2045. The findings of the study indicate that Germany should diversify its energy finance formula by promoting more green energy sources. Furthermore, the findings provide a clear indication for countries with low environmental quality to expand banking sectors to decrease fossil fuel energy generation and increase renewable energy generation to improve environmental quality.

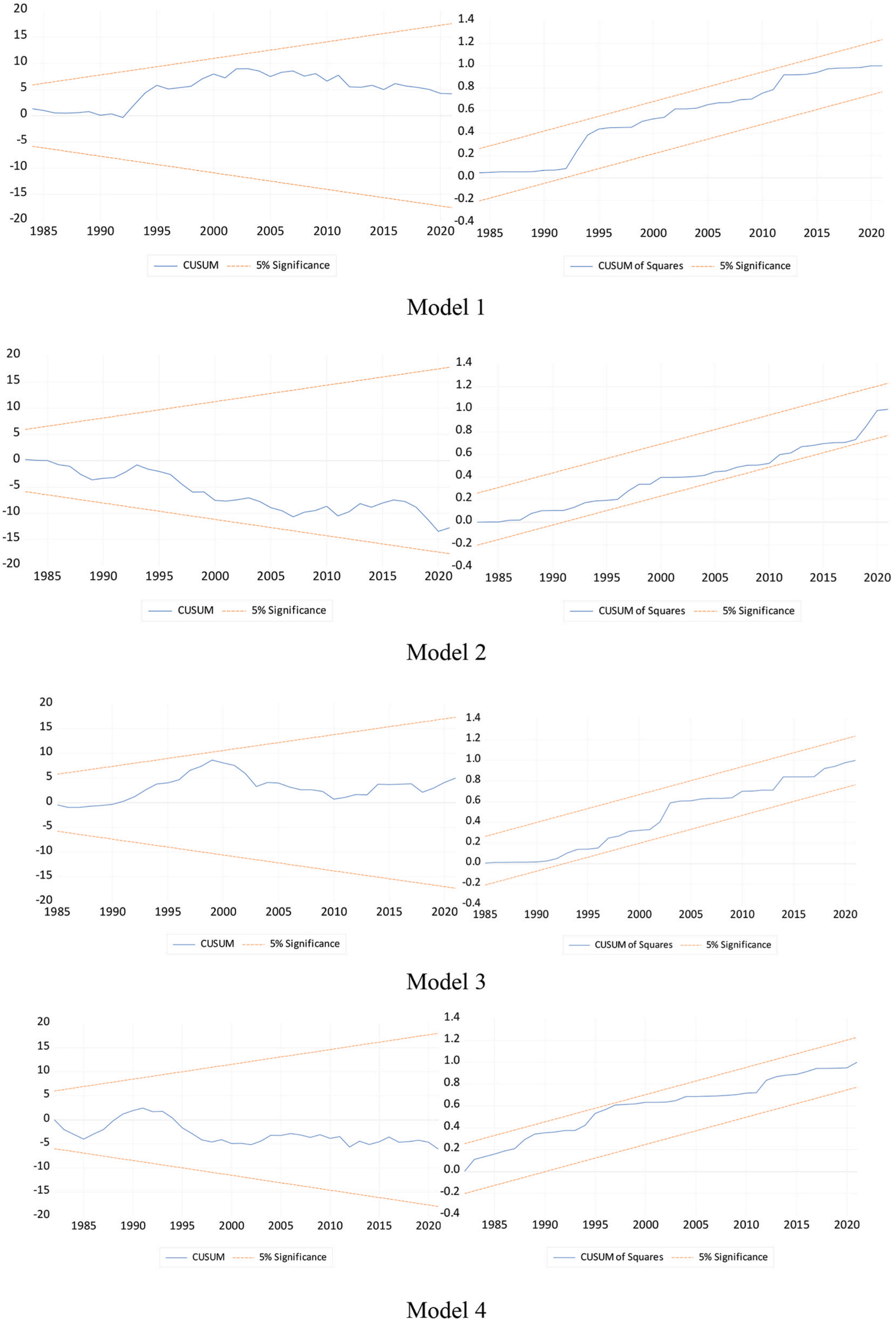

Fig. 4. CUSUM and CUSUM square tests for models 1, 2, 3 and 4.

Table 11
Pairwise Granger causality analysis.

	Model 1			Model 2	
Path of causality	F-Statistic	P value	Path of causality	F-Statistic	P value
GDP →LCF	7.51440	0.000	GDP→CO_2	2.48276	0.095
LCF →GDP	1.53249	0.220	CO_2→GDP	0.64936	0.527
GD P^2 →LCF	3.75577	0.018	GD P^2 → CO_2	5.74641	0.006
LCF → GD P^2	1.98532	0.131	CO_2→ GD P^2	1.67162	0.199
BSD→LCF	0.39699	0.755	BSD→ CO_2	12.7653	0.000
LCF →BSD	0.23447	0.871	CO_2→BSD	0.14969	0.861
REC→LCF	3.99858	0.014	REC→ CO_2	3.16653	0.052
LCF →REC	0.58067	0.631	CO_2→REC	1.65537	0.203
	Model 3			Model 4	
GDP→LCF	7.51440	0.000	GDP→ CO_2	2.48276	0.095
LCF →GDP	1.53249	0.220	CO_2→GDP	0.64936	0.527
GD P^2 →LCF	3.75577	0.018	GD P^2 → CO_2	5.74641	0.006
LCF → GD P^2	1.98532	0.131	CO_2→ GD P^2	1.67162	0.199
PC→LCF	0.47829	0.699	PC→ CO_2	0.29065	0.749
LCF →PC	0.75074	0.528	CO_2→PC	1.41441	0.254
REC→LCF	0.58067	0.631	REC→ CO_2	4.74371	0.013
LCF →REC	3.99858	0.014	CO_2→REC	0.74802	0.479

6. Conclusions and policy implications

6.1. Conclusions

Energy and ecological research have widely assessed the correlations between energy, economic growth, financial development and CO_2 emissions, with most empirical studies using CO_2 and EF to measure ecological quality. Recently, some empirical studies [34,42,64,65] have used the LCF as an indicator to capture ecological quality; however, no research has assessed banking development and environmental quality using the LCF as a proxy for ecological neutrality. By doing so, this study presents novel evidence testing the impact of banking development on the LCF from 1972 to 2021. To the best of the author's knowledge, this is the first study to reveal the impact of banking development on the LCF, employing ZA and PV unit root tests to evaluate unit roots. In addition, this study provides robust empirical findings on the correlation between the selected variables by employing advanced testing techniques, including the novel bootstrap ARD method to capture the correlations between the variables explored. Moreover, we use FMOLS and CCR models for robustness tests and Granger causality analysis to evaluate the causal links among the selected variables.

The study's findings demonstrate that renewable energy positively enhances the LCF and mitigates CO_2 emissions. In addition, GDP negatively affects environmental quality, while square GDP positively affects environmental quality, indicating that the EKC framework is accepted in the case of Germany using two environmental proxies of LCF and CO_2 emissions. The findings show that economic development activities initially increase ecological pollution, and this development will later move towards the service sector and promote cleaner economic activities, subsequently mitigating the level of ecological pollution. The primary finding of this study reveals a positive association between banking development and the LCF and a negative link between banking development and CO2 emissions in Germany. These findings demonstrate that the banking sector in Germany has a positive role in promoting ecological sustainability, findings suggesting that the finance sector can promote environmentally friendly applications, increasing the proportion of renewable energy projects. Another notable implication is that financial incentives from the banking sector significantly impact green investment through provisions such as low-interest rates on green energy projects may mitigate the country's ecological pollution.

6.2. Policy implications

The findings obtained by analysing selected panel data demonstrate that banking development and REC enhance ecological quality, whereas economics lower ecological quality. Based on the results, the study identifies three policy implications for German policymakers.

First, the primary conclusion of the study is that it will be challenging for the country to meet zero carbon targets in 2045 if the banking sector is not included in the ecological strategies. These strategies must be supported by a green energy transition plan to guide the people and economy towards greater sustainability. For these strategies to be effective, the banking sector and government policymakers must collaboratively implement and supervise this transition by continuously evaluating the impact of banking regulations and policies on ecological sustainability. German policymakers must promote investment in green projects and restrict polluting technologies and projects using finance channels. In this context, the banking sector can significantly influence Germany's ecological quality. Policymakers concerned with this sector must introduce new upgraded finance mechanisms to promote green projects. For instance, the banking industry can be required to determine the degree of environmental risk in any funding assessment. Additionally, lower interest rates can be provided for green investments.

First, policymakers must prioritise policies to reduce ecological pollution, establishing regulations to reinforce energy efficiencies and green energy production and consumption. Policymakers must design strategies to increase green energy and lower CO2 emissions in Germany. This could be accomplished by incorporating strategic policies such as carbon tax laws and boosting household and investors' ability to incorporate green energy use in household activities and investments. To support these activities, policymakers must establish a congenial environment that provides access to clean energy and prospects for green investment to household consumers and investors. This growth could also be fostered by removing barriers to investments and trades in green energy sources and reducing tensions between investors and municipal authorities. Ensuring robust investments in renewable energy sources to enable widespread clean energy consumption is the only way to advance this goal.

Finally, German government must pay close attention to ecological considerations and regulations in economic growth to enhance environmental sustainability and achieve sustainable economic growth and the United Nations 2030 agenda for sustainable development.

6.3. Limitations and future research direction

This research has some limitations. First, we focused only on Germany. For this reason, future empirical studies can apply our model to panel data such as G7 and BRICS economies. Second, we consider an index that includes proxies of savings and loan banks' private credit to GDP, banks' financial assets to GDP (%) and banks' liquid liabilities as a share of GDP to measure the influence of banking-sector development using PCA. Future empirical studies can employ other variables such as total assets to capture the impact of banking development on ecological sustainability. Third, we employed bootstrap ARDL to capture the correlations between the selected variables. Future research can adopt other models and techniques, such as the method of moments quantile regression and nonlinear ARDL to provide novel empirical evidence on the banking sector–environment linkage. Finally, we used data sets from 1972 to 2021 to investigate the correlations among the tested variables due to data availability limitations, particularly in terms of the LCF; therefore, future studies can use updated data to test other economic variables on the LCF to provide fresh empirical results on the associated determinants.

Data availability statement

The data is publicly available on the following websites: https://data.worldbank.org/data. footprintnetwork.org/. https://ourworldindata.org/databank.worldbank.org.

CRediT authorship contribution statement

Xiangyu Wang: Conceptualization, Data curation, Formal analysis, Writing – original draft. **Bushra Sarwar:** Data curation, Formal analysis, Methodology, Writing – original draft. **Mohammad Haseeb:** Formal analysis, Resources, Software, Writing – original draft. **Ahmed Samour:** Data curation, Formal analysis, Investigation, Writing – original draft. **Md Emran Hossain:** Supervision, Validation, Visualization, Writing – original draft. **Mustafa Kamal:** Formal analysis, Funding acquisition, Validation, Writing – original draft. **Mohammad Faisal Khan:** Project administration, Resources, Writing – original draft, Writing – review & editing.

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.

Appendix

Table A1
Principal component analysis for Banking Sector Development Index (BSD)

Principal component	Eigen-value	Proportion	Cumulative
Comp1	1.80606	0.6020	0.6020
Comp2	1.00125	0.3338	0.9358
Comp3	0.19269	0.0642	1
BSD Indicators/components	Comp1	Comp2	Comp3
Private credit by deposit money banks as a % of GDP	0.6996	0.1479	−0.6991
Deposit money banks' assets as a share of GDP	0.7074	−0.0051	0.7068
Liquid liabilities as a share of GDP	−0.1010	0.9890	0.1081

References

[1] P. D'Orazio, M.W. Dirks, Exploring the effects of climate-related financial policies on carbon emissions in G20 countries: a panel quantile regression approach, Environ. Sci. Pollut. Res. 29 (5) (Jan. 2022) 7678–7702, https://doi.org/10.1007/s11356-021-15655-y.
[2] M. Murshed, N.T.T. Dao, Revisiting the CO2 emission-induced EKC hypothesis in South asia: the role of export quality improvement, Geojournal 87 (2) (2022) 535–563, https://doi.org/10.1007/s10708-020-10270-9. Apr.
[3] W. Bakry, G. Mallik, X.-H. Nghiem, A. Sinha, X.V. Vo, Is green finance really 'green'? Examining the long-run relationship between green finance, renewable energy and environmental performance in developing countries, Renew. Energy 208 (May 2023) 341–355, https://doi.org/10.1016/j.renene.2023.03.020.
[4] J.B. Ang, CO2 emissions, energy consumption, and output in France, Energy Pol. 35 (10) (Oct. 2007) 4772–4778, https://doi.org/10.1016/j.enpol.2007.03.032.
[5] Hao Yu, Yi-Ning Huang, Exploring the nexus of energy consumption structure and CO2 emissions in China: empirical evidence based on the translog production function, Pol. J. Environ. Stud. 27 (6) (Nov. 2018) 2541–2551, https://doi.org/10.15244/pjoes/81071.
[6] F.M. Mirza, A. Kanwal, Energy consumption, carbon emissions and economic growth in Pakistan: dynamic causality analysis, Renew. Sustain. Energy Rev. 72 (May 2017) 1233–1240, https://doi.org/10.1016/j.rser.2016.10.081.
[7] S. Sarwar, U. Shahzad, D. Chang, B. Tang, Economic and non-economic sector reforms in carbon mitigation: empirical evidence from Chinese provinces, Struct. Change Econ. Dynam. 49 (Jun. 2019) 146–154, https://doi.org/10.1016/j.strueco.2019.01.003.
[8] X. Ma, N. Ahmad, P.-Y. Oei, Environmental Kuznets curve in France and Germany: role of renewable and nonrenewable energy, Renew. Energy 172 (Jul. 2021) 88–99, https://doi.org/10.1016/j.renene.2021.03.014.
[9] F. Ganda, The influence of growth determinants on environmental quality in Sub-Saharan Africa states, Environ. Dev. Sustain. 23 (5) (May 2021) 7117–7139, https://doi.org/10.1007/s10668-020-00907-7.
[10] F. Ganda, Carbon emissions, energy consumption and economic growth in Zimbabwe: investigating the existence of the environmental Kuznets curve within a developing economy context, Int. J. Sustain. Econ. 10 (3) (Jan. 2018) 226–248, https://doi.org/10.1504/IJSE.2018.092860.
[11] F. Ganda, The non-linear influence of trade, foreign direct investment, financial development, energy supply and human capital on carbon emissions in the BRICS, Environ. Sci. Pollut. Res. 28 (41) (Nov. 2021) 57825–57841, https://doi.org/10.1007/s11356-021-14704-w.
[12] R. Siche, L. Pereira, F. Agostinho, E. Ortega, Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study, Commun. Nonlinear Sci. Numer. Simul. 15 (10) (Oct. 2010) 3182–3192, https://doi.org/10.1016/j.cnsns.2009.10.027.
[13] A.A. Awosusi, et al., A Roadmap toward achieving sustainable environment: evaluating the impact of technological innovation and globalization on load capacity factor, Int. J. Environ. Res. Publ. Health 19 (6) (Jan. 2022), https://doi.org/10.3390/ijerph19063288. Art. no. 6.
[14] Y. Shang, A. Razzaq, S. Chupradit, N. Binh An, Z. Abdul-Samad, The role of renewable energy consumption and health expenditures in improving load capacity factor in ASEAN countries: exploring new paradigm using advance panel models, Renew. Energy 191 (May 2022) 715–722, https://doi.org/10.1016/j.renene.2022.04.013.
[15] T. Abdulmagid Basheer Agila, W.M.S. Khalifa, S. Saint Akadiri, T.S. Adebayo, M. Altuntaş, Determinants of load capacity factor in South Korea: does structural change matter? Environ. Sci. Pollut. Res. 29 (46) (Oct. 2022), 69932 https://doi.org/10.1007/s11356-022-20676-2. –69948.
[16] D. Xu, et al., Load capacity factor and financial globalization in Brazil: the role of renewable energy and Urbanization, Front. Environ. Sci. 9 (2022). Accessed: Feb. 22, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fenvs.2021.823185.
[17] Z. Fareed, S. Salem, T.S. Adebayo, U.K. Pata, F. Shahzad, Role of export diversification and renewable energy on the load capacity factor in Indonesia: a fourier quantile causality approach, Front. Environ. Sci. 9 (2021). Accessed: Jan. 12, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fenvs.2021.770152.
[18] H.M. Lübker, D.J. Abson, M. Riechers, Discourses for deep transformation: perceptions of economic growth in two rural communities in Lower Saxony, Germany, Sustain. Sci. 16 (6) (2021) 1827–1840, https://doi.org/10.1007/s11625-021-01039-1. Nov.
[19] R. Li, Q. Wang, X. Wang, Y. Zhou, X. Han, Y. Liu, Germany's contribution to global carbon reduction might be underestimated – a new assessment based on scenario analysis with and without trade, Technol. Forecast. Soc. Change 176 (Mar. 2022), 121465, https://doi.org/10.1016/j.techfore.2021.121465.
[20] A. Pegels, W. Lütkenhorst, Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV, Energy Pol. 74 (Nov. 2014) 522–534, https://doi.org/10.1016/j.enpol.2014.06.031.
[21] Q. Wang, F. Zhang, What does the China's economic recovery after COVID-19 pandemic mean for the economic growth and energy consumption of other countries? J. Clean. Prod. 295 (May 2021), 126265 https://doi.org/10.1016/j.jclepro.2021.126265.
[22] K. Steinbacher, S. Röhrkasten, An outlook on Germany's international energy transition policy in the years to come: solid foundations and new challenges, Energy Res. Social Sci. 49 (Mar. 2019) 204–208, https://doi.org/10.1016/j.erss.2018.10.013.
[23] T. Kortsch, R. Rehwaldt, M.E. Schwake, C. Licari, Does Remote work make people happy? Effects of flexibilization of work location and working hours on happiness at work and affective commitment in the German banking sector, Int. J. Environ. Res. Publ. Health 19 (15) (Jan. 2022), https://doi.org/10.3390/ijerph19159117. Art. no. 15.
[24] A. Tunc, M. Kocoglu, A. Aslan, Time-varying characteristics of the simultaneous interactions between economic uncertainty, international oil prices and GDP: a novel approach for Germany, Resour. Pol. 77 (2022), 102658, https://doi.org/10.1016/j.resourpol.2022.102658. Aug.
[25] U.K. Pata, A. Samour, Assessing the role of the insurance market and renewable energy in the load capacity factor of OECD countries, Environ Sci Pollut Res, Feb (2023), https://doi.org/10.1007/s11356-023-25747-6.
[26] G.M. Grossman, A.B. Krueger, Environmental Impacts of a North American Free Trade Agreement. Working Paper No. 3914, National Bureau of Economic Research, Cambridge, 1991.
[27] M.W. Zafar, S.A.H. Zaidi, A. Sinha, A. Gedikli, F. Hou, The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: insights from G-7 and N-11 countries, Resour. Pol. 62 (Aug. 2019) 427–436, https://doi.org/10.1016/j.resourpol.2019.05.003.
[28] P. Sadorsky, The impact of financial development on energy consumption in emerging economies, Energy Pol. 38 (5) (May 2010) 2528–2535, https://doi.org/10.1016/j.enpol.2009.12.048.
[29] J. Gao, L. Zhang, Electricity consumption–economic growth–CO2 emissions nexus in sub-saharan Africa: evidence from panel cointegration, Afr. Dev. Rev. 26 (2) (2014) 359–371, https://doi.org/10.1111/1467-8268.12087.
[30] U. Al-Mulali, B. Saboori, I. Ozturk, Investigating the environmental Kuznets curve hypothesis in Vietnam, Energy Pol. 76 (Jan. 2015) 123–131, https://doi.org/10.1016/j.enpol.2014.11.019.
[31] J.P. Cerdeira Bento, V. Moutinho, CO2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy, Renew. Sustain. Energy Rev. 55 (Mar. 2016) 142–155, https://doi.org/10.1016/j.rser.2015.10.151.
[32] D. Kaika, E. Zervas, The Environmental Kuznets Curve (EKC) theory—Part A: concept, causes and the CO2 emissions case, Energy Pol. 62 (Nov. 2013) 1392–1402, https://doi.org/10.1016/j.enpol.2013.07.131.
[33] U.K. Pata, A. Samour, Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor, Prog. Nucl. Energy 149 (2022), 104249, https://doi.org/10.1016/j.pnucene.2022.104249. Jul.
[34] A. Samour, Testing the impact of banking sector development on Turkey'S CO2 emissions, Appl. Ecol. Environ. Res. 17 (3) (2019), https://doi.org/10.15666/aeer/1703_64976513.
[35] S. Çoban, M. Topcu, The nexus between financial development and energy consumption in the EU: a dynamic panel data analysis, Energy Econ. 39 (Sep. 2013) 81–88, https://doi.org/10.1016/j.eneco.2013.04.001.
[36] B. Saboori, J. Sulaiman, S. Mohd, Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the Environmental Kuznets Curve, Energy Pol. 51 (Dec. 2012) 184–191, https://doi.org/10.1016/j.enpol.2012.08.065.
[37] J.D. Zoaka, D.C. Ekwueme, H. Güngör, A.A. Alola, Will Financial Development and Clean Energy Utilization Rejuvenate the Environment in BRICS Economies? Business Strategy and the Environment, 2022.

[38] F. Ganda, The nexus of financial development, natural resource rents, technological innovation, foreign direct investment, energy consumption, human capital, and trade on environmental degradation in the new BRICS economies, Environ. Sci. Pollut. Res. 29 (49) (Oct. 2022) 74442–74457, https://doi.org/10.1007/s11356-022-20976-7.
[39] Q. Wang, T. Yang, R. Li, Does income inequality reshape the environmental Kuznets curve (EKC) hypothesis? A nonlinear panel data analysis, Environ. Res. 216 (Jan. 2023), 114575, https://doi.org/10.1016/j.envres.2022.114575.
[40] U.K. Pata, Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: a sustainability perspective, Renew. Energy 173 (Aug. 2021) 197–208, https://doi.org/10.1016/j.renene.2021.03.125.
[41] Z. Ni, J. Yang, A. Razzaq, How do natural resources, digitalization, and institutional governance contribute to ecological sustainability through load capacity factors in highly resource-consuming economies? Resour. Pol. 79 (2022), 103068 https://doi.org/10.1016/j.resourpol.2022.103068. Dec.
[42] Z. Wang, L. Gao, Z. Wei, A. Majeed, I. Alam, How FDI and technology innovation mitigate CO2 emissions in high-tech industries: evidence from province-level data of China, Environ. Sci. Pollut. Res. 29 (3) (Jan. 2022) 4641–4653, https://doi.org/10.1007/s11356-021-15946-4.
[43] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon emissions in the United States, Ecol. Econ. 62 (3) (May 2007) 482–489, https://doi.org/10.1016/j.ecolecon.2006.07.009.
[44] A.Z. Isiksal, A. Samour, N.G. Resatoglu, Testing the impact of real interest rate, income, and energy consumption on Turkey's CO2 emissions, Environ. Sci. Pollut. Control Ser. 26 (20) (2019) 20219–20231.
[45] M.T. Kartal, A. Samour, T.S. Adebayo, S.K. Depren, Do nuclear energy and renewable energy surge environmental quality in the United States? New insights from novel bootstrap Fourier Granger causality in quantiles approach, Prog. Nucl. Energy 155 (2023), 104509.
[46] A. Mujtaba, P.K. Jena, F.V. Bekun, P.K. Sahu, Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries, Renew. Sustain. Energy Rev. 160 (May 2022), 112300, https://doi.org/10.1016/j.rser.2022.112300.
[47] S.S. Wang, D.Q. Zhou, P. Zhou, Q.W. Wang, CO2 emissions, energy consumption and economic growth in China: a panel data analysis, Energy Pol. 39 (9) (Sep. 2011) 4870–4875, https://doi.org/10.1016/j.enpol.2011.06.032.
[48] M. Javid, F. Sharif, Environmental Kuznets curve and financial development in Pakistan, Renew. Sustain. Energy Rev. 54 (Feb. 2016) 406–414, https://doi.org/10.1016/j.rser.2015.10.019.
[49] A. Ahmad, et al., Carbon emissions, energy consumption and economic growth: an aggregate and disaggregate analysis of the Indian economy, Energy Pol. 96 (Sep. 2016) 131–143, https://doi.org/10.1016/j.enpol.2016.05.032.
[50] N. Bazarcheh Shabestari, Energy consumption, CO2 emissions and economic growth, Sweden's case (2018) [Online]. Available, https://urn.kb.se/resolve?urn=urn:nbn:se:sh:diva-35502. (Accessed 13 May 2023).
[51] E. Dogan, F. Seker, Determinants of CO2 emissions in the European Union: the role of renewable and non-renewable energy, Renew. Energy 94 (Aug. 2016) 429–439, https://doi.org/10.1016/j.renene.2016.03.078.
[52] U.K. Pata, M.T. Kartal, S. Erdogan, S.A. Sarkodie, The role of renewable and nuclear energy R&D expenditures and income on environmental quality in Germany: scrutinizing the EKC and LCC hypotheses with smooth structural changes, Appl. Energy 342 (2023), 121138, https://doi.org/10.1016/j.apenergy.2023.121138. Jul.
[53] B.K. Guru, I.S. Yadav, Financial development and economic growth: panel evidence from BRICS, Journal of Economics, Finance and Administrative Science 24 (47) (Jan. 2019) 113–126, https://doi.org/10.1108/JEFAS-12-2017-0125.
[54] S. Erdoğan, D.Ç. Yıldırım, A. Gedikli, Natural resource abundance, financial development and economic growth: an investigation on Next-11 countries, Resour. Pol. 65 (Mar. 2020), 101559, https://doi.org/10.1016/j.resourpol.2019.101559.
[55] C.-Y. Cheng, M.-S. Chien, C.-C. Lee, ICT diffusion, financial development, and economic growth: an international cross-country analysis, Econ. Modell. 94 (Jan. 2021) 662–671, https://doi.org/10.1016/j.econmod.2020.02.008.
[56] M. Shahbaz, S. Khan, M.I. Tahir, The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis, Energy Econ. 40 (Nov. 2013) 8–21, https://doi.org/10.1016/j.eneco.2013.06.006.
[57] M.W. Zafar, S.A.H. Zaidi, N.R. Khan, F.M. Mirza, F. Hou, S.A.A. Kirmani, The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States, Resour. Pol. 63 (Oct. 2019), 101428, https://doi.org/10.1016/j.resourpol.2019.101428.
[58] A. Samour, Testing the impact of banking sector development on Turkey'S CO2 emissions, Appl. Ecol. Environ. Res. 17 (3) (2019), https://doi.org/10.15666/aeer/1703_64976513. Art. no. 3.
[59] M. Radulescu, D. Balsalobre-Lorente, F. Joof, A. Samour, T. Türsoy, Exploring the impacts of banking development, and renewable energy on ecological footprint in OECD: new evidence from method of moments quantile regression, Energies 15 (24) (Jan. 2022), https://doi.org/10.3390/en15249290. Art. no. 24.
[60] N. Apergis, B. Kuziboev, I. Abdullaev, A. Rajabov, Investigating the association among CO2 emissions, renewable and non-renewable energy consumption in Uzbekistan: an ARDL approach, Environ. Sci. Pollut. Res. 30 (14) (2023) 39666–39679, https://doi.org/10.1007/s11356-022-25023-z. Mar.
[61] D. Ben Amara, J. Qiao, M. Zada, How to reconcile the climate change issue with economic growth? Spatial dual mediating effects of carbon emissions and foreign investment, J. Clean. Prod. 411 (2023), 137285, https://doi.org/10.1016/j.jclepro.2023.137285. Jul.
[62] H.B. Furkan, K.M.R. Hasan, M.J. Uddin, Greenhouse gas emission, GDP, tertiary education, and rule of law: a comparative study between high-income and lower-middle income countries, Heliyon 9 (6) (2023), https://doi.org/10.1016/j.heliyon.2023.e16265. Jun.
[63] E. Zivot, D.W.K. Andrews, Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis, J. Bus. Econ. Stat. 20 (1) (Jan. 2002) 25–44, https://doi.org/10.1198/073500102753410372.
[64] P. Perron, T.J. Vogelsang, Nonstationarity and level shifts with an application to purchasing power parity, J. Bus. Econ. Stat. 10 (3) (1992) 301–320, https://doi.org/10.1080/07350015.1992.10509907. Jul.
[65] R. McNown, C.Y. Sam, S.K. Goh, Bootstrapping the autoregressive distributed lag test for cointegration, Appl. Econ. 50 (13) (Mar. 2018) 1509–1521, https://doi.org/10.1080/00036846.2017.1366643.
[66] C.W.J. Granger, Investigating causal Relations by econometric models and cross-spectral methods, Econometrica 37 (3) (1969) 424–438, https://doi.org/10.2307/1912791.
[67] N. Kaya Kanlı, B. Küçükefe, Is the environmental Kuznets curve hypothesis valid? A global analysis for carbon dioxide emissions, Environ. Dev. Sustain. 25 (3) (Mar. 2023) 2339–2367, https://doi.org/10.1007/s10668-022-02138-4.
[68] A. Samour, T.S. Adebayo, E.B. Agyekum, B. Khan, S. Kamel, Insights from BRICS-T economies on the impact of human capital and renewable electricity consumption on environmental quality, Sci. Rep. 13 (1) (2023), https://doi.org/10.1038/s41598-023-32134-1. Art. no. 1, Mar.
[69] U.K. Pata, M.T. Kartal, T.S. Adebayo, S. Ullah, Enhancing environmental quality in the United States by linking biomass energy consumption and load capacity factor, Geosci. Front. 14 (3) (May 2023), 101531, https://doi.org/10.1016/j.gsf.2022.101531.