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Paving the ways toward sustainable development: the asymmetric effect of economic complexity, renewable electricity, and foreign direct investment on the environmental sustainability in BRICS-T

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Abstract
Previous empirical studies have typically employed carbon dioxide (CO_2) emissions and ecological footprint (EF) as indices of environmental quality; however, these measures ignore supply-side environmental concerns. To overcome this issue, this study uncovers the effect of economic complexity, foreign direct investment, and renewable electricity on the load capacity factor (LCF). The panel nonlinear autoregressive distributed lag (NARDL) method is used to analyze BRICS-T countries for the period 1990–2018. The outcomes reveal that a positive shock in economic complexity has a long-run positive impact on the LCF, but is insignificant in the short-run. Similarly, a negative shock in economic complexity has only a short-run environmental-promoting effect. A negative shock in foreign direct investment improves the LCF in both the short-run and long-run, but a positive shock in foreign direct investment promotes environmental quality only in the long-run. Similarly, renewable electricity improves environmental quality in the both short-run and long-run. Both control variables (i.e., economic growth and fossil fuel consumption) have a negative impact on the LCF in the both short-run and long-run. Also, the findings are robust to advanced econometric methodologies. Based on empirical findings, relevant policy points for improving environmental quality and achieving sustainable development goals are proposed.

Keywords Economic complexity · Foreign direct investment · Renewable electricity · Environmental quality · BRICS-T Countries · Panel NARDL

1 Introduction

Climate change and atmospheric shifts have posed enormous threats to human life and population expansion, such as food shortages, the extinction of biodiversity, and severe weather extremes (Adebayo, 2022; Sharif et al., 2020). Also, it appears that environmental pollution continues to persist as an obstacle to the procedure of sustainable economic

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development since it bears a variety of climatic challenges, such as forest loss, energy reliance, clean water shortages, and air quality, which have been recognized as a major risk since the 1960s (Koç & Buluş, 2020; Ullah et al., 2022). The United Nations (UN) Conference on environmental change has been an important step forward for the collaboration of the world in fighting environmental issues. The Conference of the Parties (COP) twenty-first session (i.e., COP-21) was essential for the international community to recognize that the continued development of economic interests has intensified environmental issues by raising the volume of CO_2 emissions to the atmosphere, hence causing a rise in global warming (Adebayo & Kirikkaleli, 2021). In addition, among UN Sustainable Development Goals (SDGs), SDG-13 aims to incorporate the strategies of governments around the world to fight against climate change rapidly. Also, the SDG-7 is designed to increase accessibility to economical, efficient, and renewable sources of energy to reduce CO_2 emissions and promote sustainable development globally (Adebayo et al., 2022). Thus, the world's economies are pursuing the discovery of different paths leading to environmental sustainability to achieve long-run sustainable environment and development.

In this context, BRICS-T countries are equally devoted to improving their environmental quality by reducing CO_2 emissions and expanding energy holdings, particularly by including renewable sources of electricity in their conventional energy portfolios (Usman & Makhdum, 2021; Adebayo 2022; Ahmed et al., 2022). According to a report by Olivier and Peters (2021), the contribution of China to global environmental degradation is 30.6% among BRICS-T countries, followed by India, Russia, Brazil, South Africa, and Turkey with 7.01%, 4.52%, 1.34%, 1.31%, and 1.13%, respectively. Moreover, BRICS-T countries are responsible for a higher level of CO_2 emissions. For example, China emitted 10,707.2 megatons of CO_2 emissions in 2019, while India, Russia, South Africa, Brazil, and Turkey caused 2,456.3; 1,703.6; 439.6; 434.3; and 396.8 megatons of CO_2 emissions, respectively. These figures make BRICST-T countries the world's highest CO_2 emitters and with the largest EF deficit (WB, 2022). On the other hand, the BRICS-T countries are strengthening their technology structure, resource patterns, economic expansion, and intellectual resource. According to World Bank (WB) statistics, the gross domestic product (GDP) of BRICS-T countries touches $25.5 trillion in 2021 by contributing 26.6% to the global GDP with average GDP growth of 7.1% annually (WB, 2022). This significant increase in economic growth results in a tremendous spike in the use of fossil energy sources that are the primary cause of degradation in environmental quality. These countries accounted for almost 41.8% of the world's entire energy usage in 2021 (British Petroleum-BP, 2022).

Several possible reasons for environmental deterioration have been identified in the research including economic growth, fossil fuel consumption, capital flows, and increased trade volumes (Zhen et al., 2022). However, there are several practical strategies for optimizing resource usage and ensuring the reduction of contaminants. Economic complexity (EC) is one of the crucial factors in the present era to ensure environmental sustainability (Can & Gözgör, 2017). The Economic Complexity Index (ECI) is an indication of the structural change that describes the characteristics, competence, technological knowledge, understanding, and abilities of a specific market, which is proposed by Hidalgo and Hausmann (2009). The economic complexity fosters productivity and the nation's economic competence, making the country more competitive and aiding in the creation of more complex goods and services (Neagu, 2019). To offset the adverse impact on the environment caused by economic activities, countries are focusing to maximize their economic complexity level, which is backed by technological advancement (Chu, 2021). More complex products require higher technical and know-how skills than natural and human resources, thus the level of energy consumption reduces, which has a positive influence on environmental quality (Marco et al., 2022).

Foreign direct investment (FDI) in emerging economies like the BRICS-T has been identified as an important factor in supporting economic growth and development. Global economic interconnectedness and globalization have been fostered through financial flows, trade, technological diffusion, and resource modeling. In the present literature, there is no consensus regarding the effect of FDI on environmental quality (Makki et al., 2004). According to some findings, FDI inflows cause environmental deterioration by boosting industrial activity that creates larger CO_2 emissions (Luo et al., 2021; Ullah et al., 2022). FDI increases production in host countries by raising financial flow, resource consumption, and managerial skills, resulting in stronger economic growth that ultimately causes environmental challenges. On the other hand, some studies claim that increased FDI inflow improves environmental quality (Kisswani & Zaitouni, 2021; Zhang & Zhou, 2016). Such studies demonstrate that detrimental environmental effects of fossil fuel use and economic growth caused by FDI are mitigated through technology diffusion. These imply that FDI will improve environmental quality by increasing energy efficiency, and technology transfer, and reducing nonrenewable energy usage (Islam et al., 2021). In addition, expanding the use of renewable energy (RNE) is recognized as a viable and effective method for reducing emissions that is a form of innovation that involves the integration of competencies and technology, and hence strengthens the environmental quality of a country (Pata, 2021a). An increase in RNE energy resources has been identified as one of the most prominent measures for reducing CO_2 emissions. Several empirical research has demonstrated that RNE energy resources promote environmental quality in countries (Adebayo et al., 2022; Bekhet et al., 2017; Leal & Marques, 2020). As evidenced by the abovementioned study RNE is considered to be a significant factor in endorsing environmental sustainability.

In the past few years, numerous empirical investigations have criticized the use of CO_2 emissions as a measure of environmental degradation (e.g., Adebayo et al., 2023a, 2023b; Ayad et al., 2023; Balsalobre-Lorente et al., 2022; Kartal et al., 2022a, 2022b, 2022c; Pata & Işık, 2021; Zhen et al., 2022). The CO_2 emissions does not consider the actual environmental consequences (Boleti et al., 2021). Then, the researchers emphasize employing EF as a better environment indicator to address this problem. Several researchers have considered the EF as an environmental quality measure (e.g., Awosusi et al., 2022a; Pata & Işık, 2021; Pata, 2021b), yet, more recent studies have shown that the EF just represents the environmental deterioration induced by human consumption of natural resources and ignores the mechanism, in which nature, such as biocapacity, fulfills atmospheric demands (Xu et al., 2022). An improved assessment of environmental quality may be derived from a measure that incorporates both demand and supply elements of nature. Against this context, Pata (2021a) advocates employing the LCF to assess the magnitude of the factors that affect environmental quality. The LCF is derived by dividing biocapacity by EF and taking 1 as the threshold limit for environmental sustainability (Akhayere et al., 2022). Consequently, the LCF, which is smaller than 1, indicates that the existing environmental condition is not sustainable, whereas an LCF value of more than 1 shows that existing resources are sufficient to accommodate the population and human needs can be met with enough resources (Awosusi et al., 2022b).

Various recent studies have uncovered the effect of energy usage on the LCF (e.g., Kartal et al., 2023a, 2023b; Pata & Balsalobre-Lorente, 2022; Pata & Kartal, 2022; Pata et al., 2023; Pata, 2021a; Shang et al., 2022). Nevertheless, no research has yet examined the impact of EC, FDI, and RNE on the LCF. Thus, this research is an attempt to fill in the gap and make a significant contribution to energy and environmental economics literature. Furthermore, this study is the first of its kind in the case of BRICS-T countries, which analyzed the impact of EC, FDI, and RNE on the LCF. On the empirical side, this study makes a vital contribution by estimating the nonlinear impacts of EC and FDI on the LCF for BRICS-T countries by using robust econometric techniques. Additionally, by shifting ahead from environmentally unsustainable human activities and promoting energy technology, outcomes of this study can help BRICS-T countries to accomplish SDGs, particularly, SDG-13.2 (incorporate climate change initiatives into governmental policies and planning), SDG-7.2 (increase renewable energy shares), and SDG-9.5 (promote industrial technologies) by facilitating the enhancement (via EC) and transfer (via FDI) of technologies.

The following parts are organized as follows; Sect. 2 examines the trends of renewable electricity in BRICS-T countries; Sect. 3 is out theoretical background and literature review; data and methodology of the study are provided in Sect. 4; the empirical outcomes of the study are given in Sect. 5; conclusions and policy points of the study are presented in Sect 6.

2 The trend of renewable electricity consumption in BRICS-T countries

The importance of environmental quality has been increasing for countries and people as negative effects of degradation in environmental quality, such as global warming and climate change, have been increasing more worst for societies (Kılıç Depren et al., 2022). In this context, the causes of environmental quality degradation have been concentrated on by many studies. According to the present literature, one of the most important causes is energy usage, which has a significant adverse effect, especially on air quality (Kartal, 2022a, 2022b; Shan et al., 2021). Depending on these conditions, countries have been trying to stimulate the usage of renewable sources in the energy area to limit the adverse effects (Chen & Lei, 2018; Kartal et al., 2022a; Yuping et al., 2021).

Although fossil fuel sources have had an important share in total energy production and consumption, the share of renewable sources has been increasing in this regard. According to BP, renewable sources have a 6.7% share in total energy consumption as of 2021 year-end at the global scale, whereas it was 3.6% in 2015, 2.1% in 2010, and 1.1% in 2005 (BP, 2022). Moreover, electricity has a crucial role in the context of energy consumption because it affects energy production and environmental quality as well as the welfare and well-being of societies. According to WB, accessibility to electricity has become 90.5% as of 2020 year-end at the global scale while it was 86.6% in 2015, 82.8% in 2010, and 80.6% in 2005 (WB, 2022). Based on these figures, it can be stated that most of the world's population can access electricity. In this context, a sustainable increase in renewable electricity generation is crucial to environmental quality.

The share of renewable electricity in total energy electricity generation has become 12.85% as of 2021 year-end, whereas it was 11.7% in the previous year. It has become 27.9% for 2020 and 2021 year-ends as the hydroelectric is included (WB, 2022). Thus, there is no doubt that increasing renewable sources has been supporting access to electricity by enabling renewable electricity consumption. Figure 1 shows the development of renewable electricity production in BRICS-T countries.

When country cases are examined in terms of renewable electricity, it can be seen that it varies according to the country. Among the BRICS-T countries, China has a leading position in terms of total renewable electricity production followed by Brazil, India, Turkey,

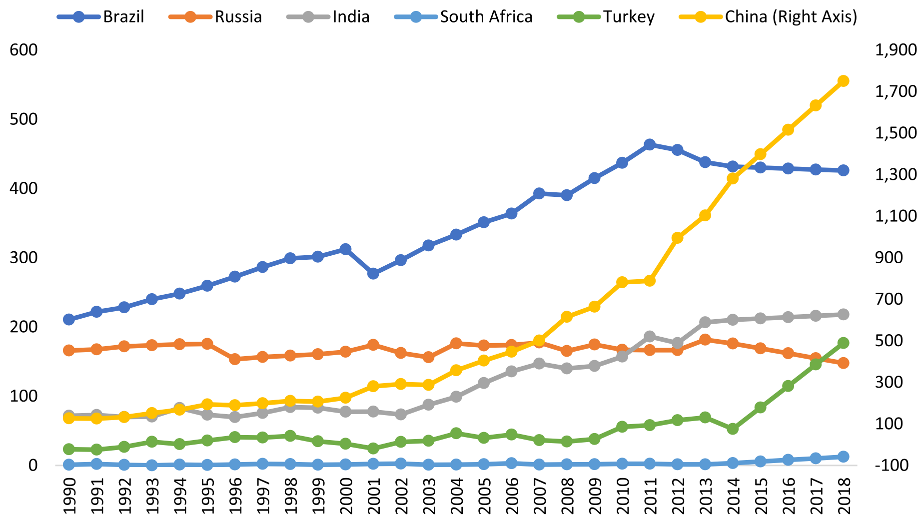

Fig. 1 The Progress of renewable Electricity in BRICS-T Countries. *Notes: Unit for 1,000 kilowatt-hours for all countries,* Source: BP (2022)

Russia, and South Africa, respectively. On the other hand, BRICS-T countries have a 22%, 0.5%, 10%, 13.5%, 6.8%, and 18.8% share of renewable electricity in total electricity generation. Besides, when hydroelectric is added, these shares have become 77.5%, 19%, 19.4%, 28.7%, 7.3%, and 35.5%, respectively (BP, 2022). Hence, it is not important to ignore renewable electricity generation and consumption when dealing with environmental quality in emerging countries, especially for such countries as BRICS-T countries.

3 Theoretical background and literature review

3.1 Theoretical background

Environmental degradation has been causing serious problems, such as global warming, climate change, and biodiversity decline. For this reason, countries have been much more interested in environmental quality by considering the adverse effect of environmental quality degradation on the planet and societies (Irfan et al., 2023; Kartal et al., 2023a, 2023b; Kılıç Depren et al., 2022). In this context, air pollution is one of the main indicators that can be used to monitor environmental quality. In line with collective efforts, such as the climate agreement, countries aim at limiting greenhouse gas (GHG) emissions so that negative effects can be prevented.

Based on recent statistics from WB, China, the United States of America (the USA), India, and Russia were the top countries in terms of total GHG emissions in 2019 (WB, 2022). Also, most of the GHG emissions in these countries resulted from energy consumption according to the 2021 statistics and these countries have a high energy consumption that has an intensive and increasing effect on total GHG emissions (BP, 2022). In such a condition, countries have been trying to increase renewable energy usage (Chen & Lei, 2018) and have a carbon–neutral economy by conversing their economic structure in an environment-friendly manner by considering SDGs, hence decreasing

GHG emissions until a pre-determined specific time (Liu et al., 2022). Although all efforts and increasing share of renewable sources, nevertheless, countries, especially emerging ones, have been still emitting a high amount of GHG emissions due to the dependence on their economic and energy structure.

In the present literature, various indicators have been considered as the proxy for environmental quality. For example, Pata (2018), Ullah et al. (2021), Kartal (2022a), Kartal (2022b), Kartal et al. (2022b), and Nurgazina et al. (2022) consider CO_2 emissions as an environmental quality indicator. Also, relatively new studies, such as Ahmed et al. (2020), Pata (2021a), Pata and Işık (2021), Liu et al. (2023) and Awosusi et al. (2022a), prefer to use the EF as an indicator of environmental quality. Moreover, there is developing literature about the LCF indicator (e.g., Awosusi et al., 2022b; Pata, 2021a; Usman et al., 2023; Xu et al., 2022), which considers both supply and demand side, as a proxy of environmental quality. Hence, by considering that there has been an increasing trend in researching environmental quality by using the LCF indicator, this study considers LCF as an environmental quality indicator. Hence, the present literature is highly rich in terms of the studies that handle environmental quality even if they use different proxy indicators.

Miscellaneous indicators are considered to explore environmental quality. Economic complexity affects environmental quality because it proxies how countries have a production structure in their economies (Boleti et al., 2021). While the economic complexity of countries increases, the production scheme, and production range also will expand. In this process, firstly environmental degradation increases, and later it decreases depending on the increasing research and development activities as well as environment-friendly production and technologies (Neagu & Teodoru, 2019). Hence, increasing economic complexity has a decreasing effect on GHG emissions (proxied by CO_2 & EF). Also, economic complexity makes a decreasing effect on the EF after a threshold (Pata, 2021b). Hence, it can be expected that economic complexity will have a positive (i.e., increasing) effect on environmental quality proxied by the LCF because it decreases GHG emissions.

Foreign direct investments are another indicator that is effective on GHG emissions. According to the pollution halo hypothesis, foreign capitalized companies make a helpful contribution to exporting environment-friendly green technologies to host countries, where foreign direct investments are provided and businesses are conducted (Kisswani & Zaitouni, 2021; Mert & Çağlar, 2020). Thus, an increase in foreign direct investments contributes to developing environmental quality by decreasing GHG emissions. Hence, it can be expected that foreign direct investments will have a positive (i.e., increasing) effect on environmental quality (i.e., LCF) by decreasing GHG emissions.

Also, renewable electricity has a crucial role in terms of environmental quality sustainability because most of the energy consumption is used for electricity production. When fossil fuel energy consumption is higher in the total energy mix, then it will have an adverse effect on environmental quality (Shan et al., 2021). However, renewable energy consumption has a positive effect on environmental quality when it has a high share in energy production (Kartal, 2022a, 2022b; Usman & Radulescu, 2022). Hence, it can be expected that renewable electricity will have a positive (i.e., increasing) effect on environmental quality proxied by the LCF through increasing GHG emissions, whereas fossil fuel consumption will have a decreasing effect on environmental quality through increasing GHG emissions.

Moreover, economic growth is another indicator that is highly important in terms of environmental quality. That is why increasing economic growth results from increasing economic activities. In this process, a high amount of energy and sources is used and a high amount of GHG emissions is caused in turn (Nurgazina et al., 2022; Wang et al., 2023; Wu et al., 2023). Hence, it can be expected that economic growth will have a decreasing effect on environmental quality by causing an increase in GHG emissions.

3.2 Literature review

The environmental quality has been examined by considering various factors in the present literature. Some studies consider the effect of economic complexity as an explanatory variable in the examination of environmental quality. For instance, Can and Gözgör (2017) examined France for the period 1964–2014 by using dynamic ordinary least squares (DOLS) and determined that economic complexity makes a decreasing effect on GHG emissions (proxied by CO_2) in the long-run. Doğan et al. (2019) studied selected 55 countries for the period 1971–2014 by applying panel quantile regression (PQR) and concluded that economic complexity increases mainly CO_2 emissions, whereas it has a mitigating effect in high-income countries. Boleti et al. (2021) investigated selected 88 countries for the period 2002–2012 by using fixed effect ordinary least squares (FE-OLS) and pooled ordinary least squares (P-OLS) and defined that higher economic complexity results in a better overall environmental performance, whereas it is not beneficial for air quality (i.e., CO_2 emissions). Also, Neagu (2019) and Chu (2021) determined an inverted U-shaped relationship between economic complexity and CO_2 emissions for 6 European countries and 118 countries, respectively. Besides, Yılancı and Pata (2020) investigated China for the period 1965–2016 through the Fourier ARDL approach and defined that economic complexity has an increasing effect on the EF in the short-run and long-run. Pata (2021a) examine the USA case for the period 1980–2016 by using Bayer and Hanck (BH) cointegration and Vector Error Correction Model (VECM) and defined that economic complexity makes a decreasing effect on the GHG emissions (proxied by EF) after reaching a threshold. By considering such studies, economic complexity is included as an explanatory indicator.

Some other studies consider the effect of foreign direct investments on environmental quality. For example, Zhang and Zhou (2016) studied China for the period 1995–2010 following a stochastic impact by regression on population, affluence, and technology (STIRPAT) approach and concluded that foreign direct investments have an increasing effect on environmental quality by reducing GHG emissions. Similar results are gathered by Islam et al. (2021) for the Bangladesh case for the period 1972–2016 by applying the dynamic ARDL (DYNARDL) model. Also, Kisswani and Zaitouni (2021) examined four Asian countries for the period 1971–2014 through ARDL and VECM approaches and proved the pollution halo hypothesis (i.e., decreasing effect of foreign direct investment) for Malaysia and Singapore, whereas there is a pollution heaven hypothesis (i.e., increasing effect of foreign direct investment) for the Philippines. However, some studies, such as Ullah et al. (2022) exerted a negative impact of FDI on environmental quality in the Organization for Economic Co-operation and Development (OECD) by employing AMG and CCEMG methods. A similar negative impact of FDI on environmental quality is indicated by Luo et al. (2021) for Asian countries. Shahbaz et al. (2019) for the Middle East and North Africa (MENA) countries, concluded the opposite results that foreign direct investments increase GHG emissions. Hence, there are mixed results about the effect of foreign direct investment on environmental quality in the present literature. By considering these studies, foreign direct investments are included as an explanatory indicator.

Renewable and fossil fuel consumption are also other indicators considered to examine environmental quality. For example, Pata (2021b) examine the USA and Japan for the period 1982–2016 by using the augmented autoregressive distributed lag (ARDL) approach and defined that renewable energy promotes positive development in environmental quality (i.e., LCF). Doğan et al. (2020) used data of BRICS-T for the period 1980 to 2014, applied FMOLS and DOLS methods, and highlight energy structure as a significant determinant of environmental quality. Similarly, Bekhet et al. (2017) examined 4 Arabian countries for the period 1980–2011 by using the ARDL approach; Leal and Marques (2020) studied the highest carbon-emitting 20 OECD countries for the period 1990–2016 by using the ARDL approach; Sharif et al. (2020) uncovered the most polluted ten countries for the period 1990–2017 by applying quantile-on-quantile regression (QQ) and Granger-causality-in-quantile (GC) approaches. Also, Adebayo and Kirikkaleli (2021) investigated Japan for the period 1990/Q1-2015/Q4 by using Multiple Wavelet (MW) and Wavelet Coherence (WC) approaches and Adebayo et al. (2022) examined Portugal for the period 1980–2019 by using similar approaches. Usman and Makhdum (2021) also concluded that renewable energy helps limit the EF in BRICS-T for the period 1990 to 2018 by applying AMG and CCEMG methods. Besides, Zhen et al. (2022) investigated 27 European Union (EU) countries for the period 1980–2018 by applying the cross-sectional ARDL (CS-ARDL) approach. On the other hand, fossil source use increases GHG emissions. For instance, Ali et al. (2021) employed the ARDL testing approach for Vietnam and explained that fossil fuel usage has an adverse impact on environmental quality. Ali et al. (2022) studied China for the period 1990–2019 by using DYNARDL and determined the negative effect of fossil fuel usage on the environment. Similarly, Kartal (2022a) examined the top 5 carbon-causing countries for the period 1965–2019 by using the multivariate adaptive regression splines (MARS) approach and determined that fossil fuel consumption caused a negative effect on environmental quality. Also, Kartal et al. (2022a) reached similar results for the USA for the period 1989–2021 by using WC, GC, QQ, and QR. By considering such studies in the present literature, renewable electricity (as the proxy of renewable energy) and fossil fuel consumption are also included as explanatory indicators.

Moreover, economic growth is frequently used to examine environmental quality in the present literature. Pata (2018) examined Turkey for the period 1971–2014 applying an ARDL model and defined that increasing economic growth causes an increase in CO_2 emissions. Similar results are obtained by Koç and Buluş (2020) for South Korea for the period 1971–2017, and Ullah et al. (2021) for the Vietnam case for the period 1975–2019 by applying also ARDL approach. Also, Nurgazina et al. (2022) focused on the China case for the period 1971–2014 by conducting a DYNARDL simulations approach and determined the adverse effect of economic growth on environmental quality. Similarly, Jianguo et al. (2022) and Nadeem et al. (2022) applied the GMM method for OECD and Asian countries, respectively, and found a negative influence of economic growth on environmental quality. In line with these studies, economic growth is included as an explanatory indicator.

3.3 Gap in literature

In the present literature, studies show the important effects of various indicators, such as economic complexity, foreign direct investments, renewable energy, fossil fuel energy, and economic growth on environmental quality (see, Table 1). Hence, it can be concluded that the effect of such indicators on the environment has been investigated. In some studies, a single country, such as the USA, China, Japan, Bangladesh, Portugal, Korea, France, and Turkey, was uncovered, while China is examined much more intensively concerning other countries. Also, some studies investigated a group of countries such as the EU, MENA, OECD, and selected Asian countries. Furthermore, a variety of econometric methods, such as ARDL, augmented ARDL, BH cointegration, CS-ARDL, DOLS, DYNARDL, Fourier ARDL, GC, MARS, MW, PQR, QQ, QR, WC, WECM, were applied for empirical analyses. When the present literature is examined for studies that include how economic complexity and renewable electricity consumption have an effect by considering also other well-known indicators, it can be seen that there is not any comprehensive study that has such content as well as focusing on BRICS-T countries that have a leading role among emerging countries and significant share in the total world economy. Thus, it is appropriate that the present literature has a gap. For this reason, any new study that research the effect of economic complexity and renewable energy consumption, including important countries in a group like BRICS-T in the same study and applying a panel approach, can contribute to the present literature by filling the literature gap. In this context, this study applies a panel nonlinear ARDL approach and the Dumitrescu-Hurlin panel causality test to determine the effects of explanatory variables on the LCF.

4 Data and methods

4.1 Data

To empirically evaluate the impact of economic complexity, and foreign direct investment on load capacity factor, BRICS-T countries are utilized as a case study. The data for this empirical investigation span between 1990 and 2018. The study also incorporates fossil fuel and renewable electricity consumption as a driver of the load capacity factor.

The data for the LCF is gathered from the Global Footprint Network (GFN, 2022). Also, the ECI data is gathered from OEC (2022). Furthermore, the data for FDI and GDPC are gathered from WB (2022) while the data for RELEC and FF are extracted from BP (2022).

The data for a balanced panel data analysis is taken into consideration when the researchers chose the research period. The regressors are ECI (economic complexity), GDPC (economic growth), FF (fossil fuel), and RELEC (renewable electricity) while the dependent variable is the LCF. Detailed information on the variables and data used is disclosed in Table 2.

In this study, variables are chosen and measured in line with previous research, such as Adebayo et al. (2020), Fareed et al. (2021), Bekun et al. (2021), Öztürk et al. (2021), and Sarkodie et al. (2021).

4.2 Model Specifications

The primary motive of this research is to explore the asymmetric effect of economic complexity and foreign direct investment on the load capacity factor, along with other determinants such as renewable electricity and fossil fuel in BRICS-T countries. The current study improves the study of Adebayo et al. (2021) in formulating the model by exploring the asymmetric effect of economic complexity and foreign direct investment on the load capacity factor. The dependent variable is the LCF while the regressors are ECI, FDI, RELEC, FF, and GDPC. Aside from ECI, a logarithmic form for every variable is used in this study. Utilizing log forms has the goal of preventing difficulties with results estimation. The regression is illustrated as follows after the log form is taken:

Table 1 A summary of present empirical literature

Author (Year)	Scope	Period	Econometric Approach	Result
Zhang and Zhou (2016)	China	1995–2010	STIRPAT	FDI ↑ EQ
Bekhet et al. (2017)	Bahrain, Oman, Qatar, and Saudi Arabia	1980–2011	ARDL	RE ↑ EQ
Can and Gözgör (2017)	France	1964–2014	DOLS	EC ↑ EQ
Pata (2018)	Turkey	1971–2014	ARDL	EG ↓ EQ
Doğan et al. (2019)	55 selected countries	1971–2014	PQR	EC ↑↓ EQ
Shahbaz et al. (2019)	MENA	1990–2015	GMM	FDI ↑ EQ
Koç and Buluş (2020)	Korea	1971–2017	ARDL	EG ↓ EQ
Leal and Marques (2020)	20 OECD countries	1990–2016	ARDL	RE ↑EQ
Sharif et al. (2020)	10 polluted countries	1990–2017	GC, QQ	RE ↑ EQ
Yılancı and Pata (2020)	China	1965–2016	Fourier ARDL	EC ↓ EQ
Adebayo and Kirikkaleli (2021)	Japan	1990–2015	MW, WC	RE ↑ EQ
Ali et al. (2021)	Vietnam	1970–2019	ARDL	FF ↓ EQ
Boleti et al. (2021)	88 selected countries	2002–2012	FE-OLS, P-OLS	EC ↓ EQ
Islam et al. (2021)	Bangladesh	1972–2016	DYNARDL	FDI ↑ EQ
Kisswani and Zaitouni (2021)	Malaysia, Philippines, Singapore, Thailand	1971–2014	ARDL, VECM	FDI ↑ EQ
Luo et al. (2021)	Selected Asian countries	2001–2019	DOLS, FMOLS	FDI ↓ EQ
Pata (2021a)	USA	1980–2016	BH Cointegration, VECM	EC ↑ EQ
Pata (2021b)	USA, Japan	1982–2016	Augmented ARDL	RE ↑ EQ
Ullah et al. (2021)	Vietnam	1975–2019	ARDL	EG ↓ EQ
Adebayo et al. (2022)	Portugal	1980–2019	WC	RE ↑EQ
Ali et al. (2022)	China	1990–2019	DYNARDL	FF ↓ EQ
Jianguo et al. (2022)	OECD	1998–2018	GMM	EG ↓ EQ
Kartal (2022a)	Top-5 carbon-causing countries	1965–2019	MARS	FF ↓ EQ
Kartal et al. (2022a)	USA	1989–2021	WC, GC, QQ, QR	RE ↑ EQ
Nadeem et al. (2022)	Asian countries	2001–2018	GMM	EG ↓ EQ
Nurgazina et al. (2022)	China	1971–2014	DYNARDL	EG ↓ EQ
Ullah et al. (2022)	OECD	1996–2019	AMG, CCEMG	FDI ↓ EQ

Table 1 (continued)

Author (Year)	Scope	Period	Econometric Approach	Result
Zhen et al. (2022)	27 EU countries	1980–2018	CS-ARDL	RE ↑ EQ

ARDL: Autoregressive Distributed Lag; *BH:* Bayer-Hanck; *CO_2:* Carbon Dioxide; *CS-ARDL:* Cross-Sectional ARDL; *DOLS:* Dynamic Ordinary Least Squares; *DYNARDL:* Dynamic ARDL Simulations; *EC:* Economic Complexity; *EF:* Ecological Footprint; *EG:* Economic Growth; *FE-OLS:* Fixed Effect Ordinary Least Squares; *GC:* Granger Causality-in-Quantiles; *MARS:* Multivariate Adaptive Regression Splines; *MW:* Multiple Wavelet; *P-OLS:* Pooled Ordinary Least Squares; *QQ:* Quantile-on-Quantile Regression; *QR:* Quantile Regression; *RE:* Renewable Energy; *STIRPAT:* Stochastic Impacts by Regression on Population, Affluence, and Technology; *WC:* Wavelet Coherence; *VECM:* Vector Error Correction Model

Table 2 Variables' details

Variable	Symbol	Unit	Source
Load capacity factor*	LCF	Per capita	GFN (2022)
Economic complexity	ECI	Index	OEC (2022)
Foreign direct investment	FDI	Current USD	WB (2022)
Renewable electricity	RELEC	Gigawatt-hour (GWh)	BP (2022)
Fossil fuel consumption	FF	Exajoule	BP (2022)
Economic growth	GDPC	Per capita USD	WB (2022)

[*] denotes the dependent variable

$$\mathrm{LCF}_{it} = \beta_0 + \beta_1\mathrm{GDPC}_{it} + \beta_2\mathrm{FF}_{it} + \beta_3\mathrm{RELEC}_{it} + \beta_4\mathrm{ECI}^{+}_{it} + \beta_5\mathrm{ECI}^{-}_{it} + +\beta_6\mathrm{FDI}^{+}_{it} + \beta_7\mathrm{FDI}^{-}_{it} + \varepsilon_{it} \tag{1}$$

In Eq. 1, disintegrate both ECI and FDI are disintegrated into positive and negative shifts (i.e., ECI^{+}, ECI^{-}, FDI^{+}, FDI^{-}). GDPC, RELEC, FF, LCF, and ECI denote economic growth, renewable electricity, fossil fuel, load capacity factor, and economic complexity, respectively. The error term is denoted by ε. The methodological flow of the study is presented in Fig. 2.

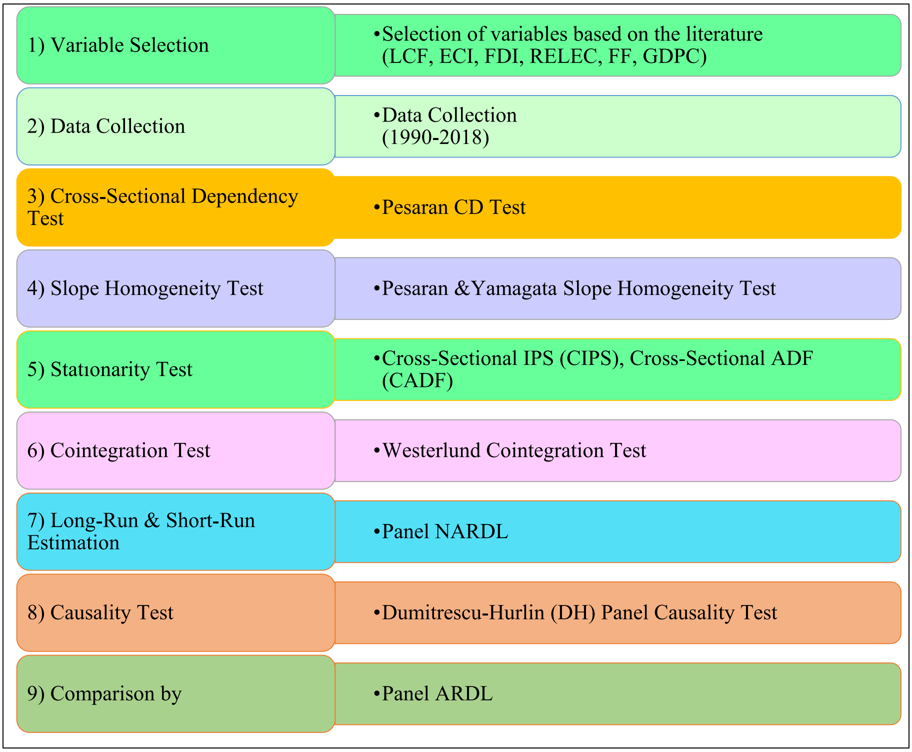

Fig. 2 Methodological Flow of the Study

4.3 Methodology

The empirical approach commences by investigating the cross-sectional dependence (CD) in the dataset. The CD test among variables served as the foundation of our empirical investigation. For this purpose, Pesaran's (2015) test was employed. The likelihood of economies influencing one another has significantly grown with the rise in cross-border mobility (defined as intermarket transition). The markets of the other nations are tied to be readily impacted by a disruption in one of the integrated markets. Globalization has heightened the likelihood that horizontal section dependency in panel data models may occur. Assertions that the analysis's findings demonstrate that "there is no CD" are false without being tested. The CD test was carried out in our research because six nations with comparable economic features were taken into consideration. Furthermore, the slope homogeneity or slope heterogeneity was revealed using the Pesaran-Yamagata (2008) test.

Furthermore, second-generation unit root tests were employed to investigate the order of variable integration. The use of second-generation methods has various benefits. Firstly, it considers the fact that panel analyses may have a CD. They also catch trends and interdependencies in both panel and time series data. Thirdly, second-generation tests ensure excellent estimators, in contrast to first-generation methods. CIPS and CADF tests were used to verify the integration sequence.

In the investigation of the cointegration connection (a crucial step of econometric investigation), Westerlund and Edgerton's (2007) bootstrap panel LM cointegration approach was favored, which takes into account the CD of second-generation methods. The method has several significant benefits, including the ability to provide trustworthy findings using Monte Carlo simulations with small sample sizes and the ability to account for fluctuating variance using autocorrelation.

Non-stationary dynamic panel models from Pesaran and Shin (1995) and Pesaran et al., (1999) were estimated using the Panel ARDL model or PMG. Since it uses both averaging and pooling, the PMG is an intermediary estimator between the Dynamic Fixed Effect (DFE) and Mean Group (MG) estimators. The diverse dynamic problem across nations is estimated using Panel ARDL or PMG, together with the short-run and long-run links between the variables. It is possible to specify the panel as:

$$Y_{it} = \sum_{j=1}^{p} \lambda_{ij} Y_{I,T-J} + \sum_{j=0}^{q} \delta_{ij}^{\prime} X_{i,t-j} + \mu_i + \varepsilon_{it} \tag{2}$$

where the endogenous variable is depicted by Y_{it} and the regressors are denoted by X_{it} $(k \times 1)$. The fixed effect is represented by μi, the dependent variable lag is represented by λij, the independent variables vector coefficient is denoted by δ_{ij} (k × 1), the error term is depicted by εit, and the number of cross sections is shown by i (1, 2, ….., N). A vector error correction model can be re-parameterized for Eq. 2 as follows:

$$\Delta Y_{\text{it}} = \theta_i \text{ECT}_{\text{it}} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,t-j} + \sum_{j=0}^{q-1} \lambda_{ij}^{*\prime} \Delta X_{i,t-j} + \mu_i + \varepsilon_{\text{it}} \tag{3}$$

where $ECT_{it} = \phi_i Y_{i,t-1} - \beta_i^{\prime} X_{i,t-1}$. By using the error correction term (ECT) parameter θi, adjustment speed can be evaluated. The short-run convergence is shown by the ECT's negative sign, and its value indicates the rate at which the parameter is being adjusted toward equilibrium. If the ECT is insignificant, there is no long-run connection. The goal of this research is to investigate the nonlinear effect of economic complexity and foreign direct investment on the load capacity factor. The linear ARDL model presented by Pesaran et al. (2001) and Pesaran and Shin (1999) was used as the basis for the NARDL model developed by Shin et al. (2014). Shin et al. (2014) employed the Schorderet (2003) and Granger and Yoon (2002) methods to separate a stationary indicator into its positive and negative parts. Consequently, the two parts, a partial positive-sum, and a partial negative-sum, for a variable X may be represented as:

$$X^{+} = \sum_{j=1}^{t} \Delta X_{J}^{+} = \sum_{j=1}^{t} \max\left(\Delta X_{j}, 0\right) \tag{4}$$

$$X^{-} = \sum_{j=1}^{t} \Delta X_{J}^{-} = \sum_{j=1}^{t} \min\left(\Delta X_{j}, 0\right) \tag{5}$$

As a result, in a nonlinear paradigm, the long-run relationship between Y and X may be defined as:

$$Y_t = \beta^{+} X_t^{+} + \beta^{-} X_t^{-} + \mu_t \tag{6}$$

$$X_t = X_0 + X_t^{+} + X_t^{-} \tag{7}$$

where the scalars of decomposition partial sums are depicted by X^{+} and X^{-}, and the long-run parameters are depicted by β^{+} and β^{-}.

As a result, this research utilizes the panel NARDL (PNARDL) approach by fusing the NARDL (Shin et al., 2014) and panel ARDL (Pesaran et al., 1999) methodologies. In comparison to Panel ARDL and NARDL, the PNARDL model has the following benefits: firstly, it is more suitable when there is a mixed integration order; secondly, it quantifies the heterogeneity impact in the data; and third, it captures the nonlinear asymmetries in the data. The panel nonlinear ARDL model was used by Salisu and Isah (2017) to examine the nonlinear connection between the variables. Consequently, the PNARDL model is defined as:

$$\Delta Y_{it} = \theta_i \mathrm{ECT}_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,t-j} + \sum_{j=0}^{q-1} \left(\delta_{ij}^{*\iota+} \Delta X_{i,t-j}^{+} + \delta_{ij}^{*\iota-} \Delta X_{i,t-j}^{-} \right) + \mu_i + \varepsilon_{it} \tag{8}$$

where $ECT_{it} = \phi_i Y_{i,t-1} - \left(\beta_i^{\iota+} X_{i,t}^{+} + \beta_i^{\iota-} X_{i,t}^{-} \right)$.

5 Results and discussion

5.1 Cross-sectional dependence and stationarity test results

Examining the CD is considered to be vital in the case of panel data analysis for unbiased outcomes, as suggested by several researchers (e.g., Ali et al., 2022; Ullah et al., 2022; Zhen et al., 2022). Moreover, the traditional estimation techniques are no more valid if there exists a CD problem (Doğan et al., 2020). The CD results given in Table 3 by employing Pesaran (2015) test indicate to rejection of the null hypothesis (no CD) at a 1% significance level in the case of all series and confirm the presence of

Table 3 CD, CIPS, and CADF Tests

Variable	CD Outcome	*p-value*	CIPS outcome		CADF outcome	
			I(0)	I(I)	I(0)	I(I)
LCF	15.290*	0.0000	− 1.874	− 4.740*	− 2.580	− 4.740*
ECI	3.2609*	0.0011	− 1.811	− 5.828*	− 2.247	− 5.810*
FDI	16.795*	0.0000	− 1.790	− 5.810*	− 1.210	− 4.167*
RELEC	9.8274*	0.0000	− 0.873	− 5.067*	− 1.803	− 5.067*
FF	10.601*	0.0000	− 3.085*	–	− 3.136*	–
GDPC	18.927*	0.0000	− 1.620	− 3.430*	− 0.948	− 3.430*

* Denotes a 1% level of significance

cross-sectional dependency in BRICS-T. The presence of CD suggests that any change that occurs in one factor in a country will also influence the other countries in the panel (Bekun et al., 2021). Consequently, the conventional unit root tests for identifying the stationarity level of the variables become invalid in the existence of CD. Thus, second-generation unit roots testing methods, such as CIPS and CADF, were applied. The CIPS and CADF outcomes in Table 3 revealed that all the variables including LCF, ECI, FDI, RELEC, and GDPC are stationary at first difference [I(1)], while FF is stationary at level [I(0)].

5.2 Slope heterogeneity test results

Similarly, testing for slop heterogeneity is also a crucial issue while analyzing the panel dataset (Zhen et al., 2022). For this purpose, the slope heterogeneity test developed by Pesaran and Yamagata (2008) is applied. The results represented in Table 4 indicate the rejection of the null hypothesis (slope homogeneity) and confirm that coefficient slopes are heterogenous in our model.

5.3 Westerlund (2007) cointegration results

Next, the long-run association among LCF, ECI, FDI, RELEC, FF, and GDPC was examined by Westerlund's (2007) cointegration test. The cointegration results revealed in Table 5 support to rejection of the null hypothesis (i.e., no cointegration) by most of the test statistics (Gt, Ga, Pt, Pa), which confirm the presence of a long-run cointegration between variables.

Table 4 Slope heterogeneity test

Δ^	P-value	Δ^_Adjs	*P*-value
8.538*	0.000	9.215*	0.000

*Denotes a 1% level of significance

Table 5 Westerlund cointegration outcomes

Statistics	Value	*Z*-value	*p*-value	Robust *P*-value
Gt	− 3.127	− 2.511	0.006	0.000
Ga	− 8.802	2.694	0.942	0.000
Pt	− 16.974	− 10.863	0.000	0.060
Pa	− 11.968	1.338	0.903	0.000

5.4 Panel nonlinear ARDL results

Finally, the short-run and long-run dynamics of the ECI, FDI, RELEC, FF, and GDPC for the LCF are obtained by applying the panel NARDL approach, and the outcomes are illustrated in Table 6.

A positive shock in ECI improves the environmental quality in the long-run by positively affecting the LCF, where a 1% positive shock in ECI increases the LCF by 0.2983%. However, positive shock in ECI is insignificant to influence the environmental quality in the short-run. In contrast, a negative shock in ECI significantly affects the environmental quality in the short-run only, where a 1% negative shock in ECI increases the LCF by 0.059%. While the negative shock in ECI has an insignificant impact on environmental quality in the long-run. The environmental promoting effect of economic complexity is consistent with the studies of Can and Gözgör (2017), Doğan et al. (2019), and Pata (2021a). ECI reflects a country's skills and knowledge-based efficient production abilities, where a higher ECI value implies an efficient producing capacity (Can & Gözgör, 2017). An efficient and highly complex nation promotes a skilled and knowledge-based industrial system that reduces environmental deterioration through the adoption of environmentally responsible technologies (Pata, 2021b). Complex markets move to modern and specialization-intensive technologies, such as renewable energy production, eco-friendly manufacturing, and resource-efficient products as a result of diversity in the manufacturing and industrial sector, and enhance a country's environmental quality (Doğan et al., 2019).

Table 6 Panel NARDL

Variable	Short-run			Long-run		
	Coefficient	t-statistic	Prob	Coefficient	t-statistic	Prob
ECI^{+}	0.0375	0.6574	0.5132	0.2983***	1.8475	0.0663
ECI^{-}	0.0590***	1.7525	0.0845	− 0.0142	− 0.6553	0.5146
FDI^{+}	0.017	0.0952	0.9245	0.1510*	5.4974	0.0000
FDI^{-}	0.0151**	2.2357	0.0289	0.0153**	2.1780	0.0331
RELEC	0.1907*	2.7268	0.0071	1.4193*	5.2275	0.0000
FF	− 0.1946*	− 2.8118	0.0065	− 1.9134*	− 3.9072	0.0000
GDPC	− 0.2732	− 1.6103	0.1122	− 0.6261*	− 4.9910	0.0000
ECT (-1)	− 0.4125*	− 4.0764	0.0000			
C	–	–		− 0.2284	− 1.1498	0.2545

Significance levels of 10%, 5%, and 1% are shown by ***, **, and * respectively

Similarly, shocks in FDI are also improving the environmental quality in both short-, and long-run. The outcome indicates that positive shock to FDI is significant to impact the environmental quality in the long-run, however, insignificant in short-run. It was noted that a 1% increase in FDI due to positive shock increases the LCF by 0.1510% in long-run. Similarly, the negative shock in FDI also improves the environmental quality by increasing the LCF, both in short-run and long-run. A 1% decrease in FDI due to negative shock respectively increases the LCF by 0.0151% and 0.0153% in short-run and long-run. Overall, the findings suggest that FDI is a significant factor to promote environmental quality following the pollution halo hypothesis in BRICS-T. According to the pollution halo concept, investment firms adopt energy-efficient techniques and green technologies to encourage cleaner industrial processes in the host country (Islam et al., 2021). The outcomes regarding the impact of FDI on environmental quality are comparable to those of Zhang and Zhou (2016), Islam et al. (2021), and Kisswani and Zaitouni (2021), who concluded that foreign enterprises transfer clean technologies to host economy firms that contribute to overall pollution reductions and promotes host nation environmental quality. Furthermore, foreign enterprises have efficient management practices for complex technologies when compared to firms of host nations in terms of environmental sustainability. It suggests that foreign technological spillovers result in lower emissions and, as a result, less environmental deterioration.

Similarly, being a significant factor to enhance the environmental quality, renewable electricity (RELEC) has a positive and significant impact on the LCF, which is consistent with the expectations. A 1% increase in RELEC upsurges the LCF by 0.1907% and 1.4193%, in the short-run and long-run, respectively. The favorable impact of RELEC on environmental quality is justified as RELEC incorporates non-flammable renewable energy sources, such as wind, hydropower, and solar, that does not exhaust any pollution and enhance environmental quality in turn (Leal & Marques, 2020). Furthermore, the growth of renewable technologies expands energy generation and diminishes reliance on imported fossil fuels, resulting in the improvement of energy effectiveness, which also has a positive impact on environmental health. Besides, RELEC can improve environmental sustainability and individuals' health by supplying heat and light without the use of combustion activities (Adebayo & Kirikkaleli, 2021). Consequently, geothermal, solar PV, wind energy, and thermal motors are the most effective methods for reducing pollution caused by combustion. The positive impact of RELEC on environmental quality can be seen in several empirical studies (e.g., Kartal et al., 2023a, 2023b; Pata et al., 2023; Pata, 2021a; Zhen et al., 2022).

In opposition to the environmental promoting impact of ECI, FDI, and RELEC, the short-run and long-run impact of fossil fuel consumption (FF) and economic growth (GDPC) are negative and significant on environmental quality in BRICS-T. Where, a 1% increase in FF decreases the LCF by 1.9134% in the long-run and 0.1946% in the short-run, consistent with the studies of Ali et al. (2021), Ali et al. (2022), Kartal (2022a), and Kartal (2022b). As discussed by Ullah et al. (2021), the consumption of fossil fuels (gas, oil, and coal) entails combustion activities, which discharge several greenhouse gasses and cause environmental damage. Similarly, a 1% increase in GDPC decreases the LCF by 0.6261% and 0.2732% in the short-run and long-run, respectively. It is well-known fact that higher economic growth is the result of higher economic and industrial activities that require significant use of energy as an input factor (Koç & Buluş, 2020). Since the share of fossil fuel consumption in total energy is higher worldwide, the larger consumption of fossil energy resources to maximize economic growth level hampers the environmental quality (Zhen et al., 2022). The environmental impeding influence of economic growth can also be seen in the studies of Ullah et al. (2021), Nadeem et al. (2022), and Nurgazina et al. (2022). Moreover, the ECT term indicates the error correction speed to attain the long-run equilibrium, which is significant. The coefficient value of 0.4125 suggests a speed of 41% annual adjustment.

5.5 Panel linear ARDL results

Moreover, the panel NARDL approach was applied to capture the linear association between the LCF and the regressors. The results regarding the influence of ECI, FDI, RELEC, FF, and GDPC on the LCF are provided in Table 7.

It can be observed in Table 7 that all of the explanatory variables are significantly affecting the LCF in the short-run and long-run, while the short-run impact of ECI, RELEC, and GDPC is insignificant. Also, the trend (positive/negative) of the impact of all explanatory variables on the LCF is consistent with those, which were estimated through the panel NARDL approach. In addition, the ECT term is also significant and shows a 37% annual adjustment to the long-run equilibrium.

5.6 Panel Dumitrescu-Hurlin panel causality results

Furthermore, the Dumitrescu-Hurlin causality test was applied to examine the causal effect between LCF and all other explanatory variables, and the results are provided in Table 8. According to the outcomes in Table 8, there is a unidirectional causality running from ECI (positive and negative), FDI (positive and negative), and RELEC to LCF, while a bidirectional causality is confirmed between FF and LCF, and GDPC and LCF.

6 Conclusion and policy implications

It is now a well-recognized fact that governments across the globe are attempting to reform and enhance their economic and industrial structure to promote environmental sustainability, which is also a dominant concern of SDGs. To this end, countries are increasingly depending on more sustainable resources that will encourage technological spillovers and

Table 7 Comparison by panel ARDL

Variable	Short-Run			Long-Run		
	Coefficient	t-statistic	Prob	coefficient	t-statistic	Prob
ECI	−0.0662	−1.2339	0.2196	0.1415*	4.1104	0.0000
FDI	0.0139***	1.8475	0.0671	0.0070***	1.7373	0.0802
RELEC	0.0636	1.3400	0.1828	0.2225*	3.6145	0.0004
FF	−0.0413***	−1.6937	0.0923	−0.5663*	−4.9226	0.0000
GDPC	−0.0131	−0.0713	0.9432	−0.0939*	−3.3403	0.0011
ECT (-1)	−0.3707*	−4.8345	0.0000			
C	–	–		1.1042	1.6833	0.0949

Significance levels of 10%, 5%, and 1% are shown by ***, **, and * respectively

Table 8 Panel Dumitrescu-Hurlin panel causality tests

Null Hypothesis	W-Stat	Z bar-Stat	Prob	Result
$ECI^{+} \neq$ LCF	4.35219	4.86706	0.0000	ECI^{+} Granger cause of LCF
LCF $\neq ECI^{+}$	1.62288	0.79884	0.4244	LCF Doesn't Granger cause of EC^{+}
$ECI^{-} \neq$ LCF	2.40990	1.97194	0.0486	ECI^{-} Granger cause of LCF
LCF $\neq ECI^{-}$	0.66409	−0.63032	0.5285	LCF Doesn't Granger cause of EC^{-}
$FDI^{+} \neq$ LCF	2.43672	1.8936	0.0418	FDI^{+} Granger cause of LCF
LCF $\neq FDI^{+}$	1.45776	0.55111	0.5816	LCF Doesn't Granger cause of FDI^{+}
$FDI^{-} \neq$ LCF	4.35219	4.86706	0.0000	FDI^{-} Granger cause of LCF
LCF $\neq FDI^{-}$	2.12115	1.54153	0.1232	LCF Doesn't Granger cause of FDI^{-}
RELEC $\neq$ LCF	2.81305	2.57287	0.0101	RELEC Granger cause of LCF
LCF $\neq$ RELEC	0.69382	−0.70273	0.5829	LCF Doesn't Granger cause of RELEC
FF $\neq$ LCF	6.24099	7.68246	0.0000	FF Granger cause of LCF
LCF $\neq$ FF	7.3685	8.2507	0.0000	LCF Granger cause of FF
GDPC $\neq$ LCF	6.53748	8.12439	0.0000	GDPC Granger cause of LCF
LCF $\neq$ LGDPC	8.21340	10.6225	0.0000	LCF Granger cause of GDPC

renewable energy consumption, ultimately favoring environmental quality. Swift economic growth and large consumption of fossil fuels have created several challenges to the world economies not only to ensure environmental sustainability but also to achieve some SDGs, such as SDG-7 (clean and affordable energy) and SDG-13 (actions on climate change). This is significantly true in the case of BRICS-T countries given their rapidly growing economies and having a large share of global income and population. Based on the prior empirical literature, which suggests several indicators to promote environmental quality, the impact of economic complexity, foreign direct investment, and renewable electricity on environmental sustainability for BRICS-T countries for the period between 1990 and 2018 was examined. This study fills the significant gap in the environmental economics literature, which recently criticize carbon dioxide emissions and ecological footprint as environmental quality measures as they do not take into account the supply-side environmental issues, by using load capacity factor as an environmental quality indicator. Owing to the cross-sectional dependency and slope heterogeneity, the second-generation tests are used to identify the stationarity order of the variables, and the presence of a long-run relationship. The short-run and long-run dynamics of the explanatory variables are estimated by the panel nonlinear autoregressive distributed lag method. Furthermore, the findings are compared with the panel ARDL approach and the causality nexus of the variables is examined by the Dumitrescu-Hurlin panel causality test.

The empirical results of the study indicate that positive shock in the economic complexity index is significant to influence the LCF in the long-run, while insignificant in the short-run. On the other hand, negative shock in the economic complexity index significant and positive impact in the short-run, whereas the long-run impact of negative shock in the economic complexity index on the LCF is insignificant in the long-run. Similarly, the positive shock in foreign direct investment is significant and positively significant to affect the LCF in the long-run only, however, the negative shock in foreign direct investment is positively impacting the LCF in both the short-run and long-run. According to estimates, renewable electricity has a positive impact on the LCF in the short-run and long-run. In contrast, fossil fuel consumption has an adverse impact on the LCF in both the short-run and long-run, whereas, a significant and negative influence of economic growth on the LCF is noted in the long-run only. In short, empirical findings suggest an environmental promoting impact of economic complexity index, foreign direct investment, and renewable electricity, while fossil fuel and economic growth are estimated to have a harmful impact on the environmental quality of BRICS-T countries, which is further confirmed by employing the panel ARDL method. In addition, a unidirectional causality is noted from the economic complexity index, foreign direct investment, and renewable electricity to the LCF, whereas a bidirectional causality is discovered between economic growth and LCF, and fossil fuel and LCF.

These empirical findings provide a crucial roadmap to formulate some important policy points that the BRICS-T countries can follow to enhance their environmental quality, which assists them to achieve the SDGs. Economic complexity is linked with research and development and innovation activities that contribute to the production of sophisticated and complex goods. Regarding the policy implications for a cleaner atmosphere and climate impact, the outcomes for economic complexity are quite novel and positive. When formulating energy and economic policies, the policymakers of the BRICS-T countries should consider the product complexities in their production framework. SDG-13 can be met with the assistance of innovative techniques if the nation's policies target a cleaner and greener environment are accomplished.

Similarly, the environmental advantages of foreign direct investment can be realized by incentivizing green inventions and transferring technology from industrialized countries. From an environmental policies standpoint, BRICS-T countries must place a higher emphasis on attracting larger inflows of foreign investments for the long-run execution of their environmental quality development programs. Foreign direct investment can be biased toward the generation of clean energy technologies, such as wind, solar, and biomass. The government should also stress developing economic, political, and social relationships with foreign countries and their investment entities to encourage these nations and their businesses to adopt renewable energy technology to preserve the environmental quality in BRICS-T countries. Finally, BRICS-T countries should implement plans to promote the development of renewable and clean energy technology based on innovative ideas. To achieve this, research and development efforts should be enforced and financially fostered in the direction of modernizing and greening the country. Furthermore, BRICS-T countries can aid institutions and businesses in their exploration of cleaner fuels and technologically transform, as this will serve as an alternative to the usage of fossil fuels. Such initiatives may be favorable to the production of clean, and affordable energy, thereby contributing to the accomplishment of SDG-7. In addition, to improve environmental quality, the government must adopt a pragmatic strategy to ensure the smart usage of primary macroeconomic indicators, such as energy consumption and economic growth.

An essential limitation of the analysis is that this study does not consider any regulatory and institutional factors, which might influence environmental and energy strategies, as institutional arrangements have a key impact on the economic growth, energy infrastructure, and environmental legislation of a country. Secondly, future research can be conducted on the economic complexity-energy-finance-environment relationship within the STIRPAT and Environmental Kuznets Curve frameworks, which will provide evidence for researchers to reach more concise and exhaustive results. This will be important for more focused policy implications.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare that they have no competing interests.

Ethical approval TThe authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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