INTERNATIONAL JOURNAL OF SUSTAINABLE ENERGY
2024, VOL. 43, NO. 1, 2281038
https://doi.org/10.1080/14786451.2023.2281038

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REVIEW ARTICLE

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# How green-technology, energy-transition and resource rents influence load capacity factor in South Africa

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**ABSTRACT**

Climate change is gradually rising to a level that portends an existential threat to humanity. Nevertheless, environmental modellers, particularly in South Africa, still rely on restrictive environmental quality metrics for policy insights. Here, a comprehensive metric (load capacity factor [LCF]) that captures both the demand and supply sides of environmental qualities was activated. With the dataset (1970–2018), estimates of autoregressive distributive lag and quantile-ARDL underscored the varied effects of the selected factors on LCF. It was unravelled that green-technology significantly improved LCF only at the upper quantile but remained ineffective afterwards. Notably, LCF improved substantially at some quantiles following the transition to clean energy. Resource rents promoted LCF partially at the upper and middle quantiles but ineffective towards the lower quantile of the distributions. Economic growth improved LCF within the upper and middle quantiles, whereas it minimised LCF at the upper quantiles. We have provided relevant policy insights therein.

**ARTICLE HISTORY**
Received 1 August 2023
Accepted 25 October 2023

**KEYWORDS**
Green-technology; energy-transition; load capacity factor; resources rent; QARDL; South Africa

## 1. Introduction

Among other African countries, the Republic of South Africa (RSA) has remained committed and consistent in the push towards the evolution of sustainable environments. In 2012, RSA articulated within its national development plan 'our future make it work' policy option conducive to mitigating climatic change and its associated environmental pollutions. Interestingly, RSA's policy template precedes the African Union's (AU) 'Africa we want' agenda 2063. It also precedes the United Nations (UN) Sustainable Development Goals (SDGs). However, it is imperative to underscore that RSA's development plan aligns consistently with the development policies of both the AU and the UN. Within the national development policy template of RSA, chapter eight (8) specifically highlights the need for the enthronement of an environmental ecosystem that is both sustainable and resilient. The article provides specific policy objectives to ensure resilient environments in RSA. Among the objectives are efficient monitoring and utilisation of natural resources, increased land and ocean protection, and zero-emission building standards by 2030. It also considers absolute reductions in annual waste disposal in landfill areas, as well as the contraction of at least 20 000MW of renewable energy by 2030.[1]

As highlighted above, the objective of a sustainable and resilient environment in RSA is in tandem with the UN's SDGs 7, 11, 12, 13 and 14. Specifically, SDGs 7, 11, 12, 13 and 14 emphasised unrestricted access to modern electricity and increased reliance on renewable energy for all

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humankind by 2030. To ensure that human settlements and cities are friendly, resilient and sustainable by 2030. The agenda also emphasises efficient management of natural resources through sustainable consumption and production. The UN SDGs also underscored the importance of sustainable waste management, integration of climate change policies into national development plans, and the need to strengthen the adaptive and resilient capacities to hazards associated with climate change. Suffice it to highlight that the UN SDGs set a comprehensive development agenda that rectifies several policy options for global economies, of which the RSA is a committed partner.

Despite RSA's national development plan and the country's averred commitment to the UN SDGs framework. However, available facts suggest that several issues need to be ratified to enthrone climate change-resilient ecosystem in the republic. Among such critical issues is that RSA is among the global economies still battling with ecological imbalances. Specifically, based on the evidence available at Global Footprint Network (GFN), RSA has maintained an ecological deficit of 282%. In this case, the country is notable for having an ecological footprint over its biocapacities. This situation highlights a case where the available biocapacity of a nation is under-supplied compared to its population's ecological footprints. This highlights that SA is engaged in importing biocapacities and liquidating available national ecological assets. The country is also involved in emitting hazardous carbon dioxide ($CO_2$) into the already compromised environments (GFN 2023). Figures 1 and 2 are graphical/pictorial illustrations of the peculiarities of RSA pertaining to her prevailing environmental challenges.

Figure 1 illustrates explicitly the imbalance between South Africa's ecological footprint and her biocapacity. On the other hand, figure 2 demonstrates the prevailing load capacity factor (LCF) in South Africa. In this instance, the graph clearly highlights the dwindling LCF in the republic, which is far fellow the sustainability point (1). A country's LCF is obtained by dividing its biocapacity by its ecological footprint (Adebayo & Samour, 2023; Guloglu, Caglar, and Pata 2023; Pata et al. 2023). LCF, proposed by Siche et al. (2010), represents a comprehensive indicator of environmental quality that, unlike others, considers both the demand and supply sides of environmental trajectories. It highlights simultaneously, the ability of the available natural ecosystem to withstand and sustain the pressures mounted on it through human activities on air, water and soil (Guloglu, Caglar,

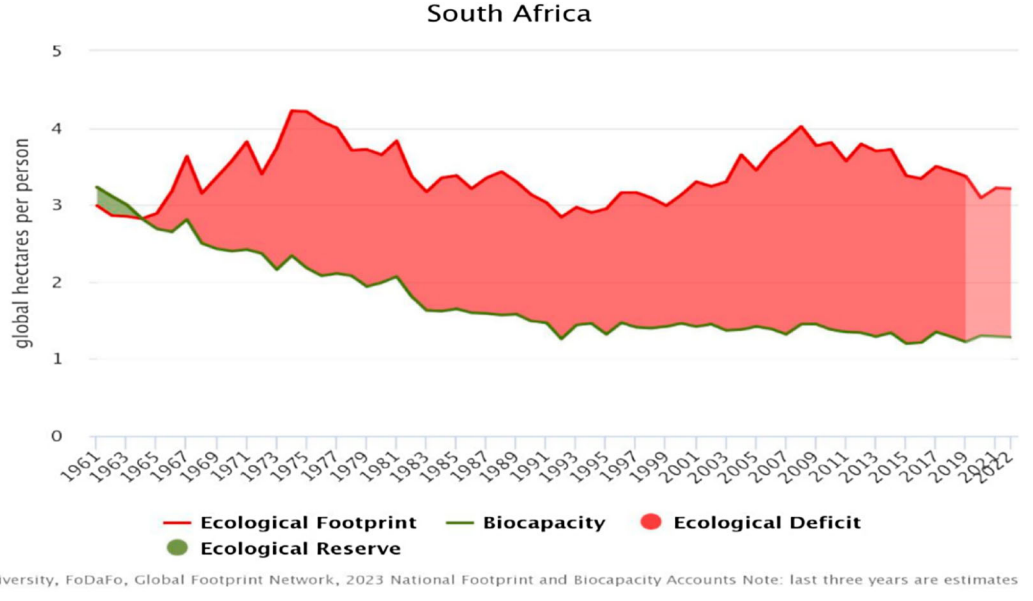



**Figure 1.** South Africa's ecological footprint. Source: Global Footprint Network (GFN).

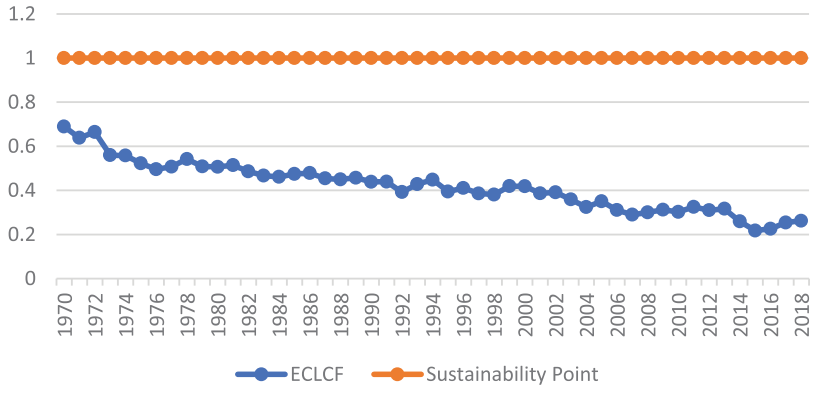



**Figure 2.** Ecological load capacity factor in South Africa. Source: Authors' computation.

and Pata 2023). Meanwhile, a country's ecological condition is considered sustainable if its LCF is about '1', whereas it is considered unsustainable when it is less than 1. In the case of RSA, its LCF has been consistently less than one over the years, thereby confirming the highlighted ecological imbalance in the country.

Given the above instances, there is an urgent need to provide comprehensive empirical insights about the relevant factors to abate the prevailing ecological imbalances in the republic. Unfortunately, existing studies failed to consider the specific instance of South Africa in their enquiries. Notwithstanding, few studies (Adebayo and Samour 2023; Awosusi et al. 2022; Ullah et al. 2023) probed the instances of BRICS economies. However, streamlined policy insights peculiar to specific economies are only obtainable when country-specific studies are conducted. Likewise, these studies also failed to factor in the influence of green-innovation into their studies. When an essential environmental quality determinant like green technology is neglected, vital information to aid ecological resilience is concealed. Besides, other studies (Nathaniel, Bekun, and Faizulayev 2021; Udeagha and Muchapondwa 2022) focusing on RSA relied on sets of uncomprehensive environmental quality indicators like ecological footprint and $CO_2$. It is also imperative to highlight that the assertions of these prior investigations are not without equivocations, which directly undermines policy prescriptions.

The current study seeks to rectify the effects of green-innovation, energy transition, and natural resource utilisations on environmental quality in South Africa. In this case, the current study's novelty lies in its ability to, for the first time, consider LCF as an environmental quality indicator specifically for RSA. Furthermore, unlike prior studies, the present investigation updates policy trajectories by factoring in green-innovation into environmental quality modelling in the case of South Africa. The current study also took advantage of the most updated data in GFN. Nonetheless, the applications of both the traditional autoregressive distributed lag (ARDL) and the quantile autoregressive distributed lag (QARDL) models distinguished the current study from others. Notably, unlike the traditional ARDL procedure, the recently introduced QARDL (Cho, Kim, and Shin 2015) is a time-variant econometric toolkit that explores the effects of explanatory variables across the quantile distributions of the explained variable (Hashmi et al. 2022; Omoke and Uche 2021). Likewise, the QARDL technique probes the potential heterogeneous (asymmetric) relationship both in the short and long term, therefore, facilitating broad-based policy alternatives. These notable steps are lacking in prior investigations particularly for RSA. Hence, due to its broad-based and holistic approaches, unique policy insights capable of invoking ecological balance in the republic are expected. Thus, policymakers in RSA are provided with an additional barometer to verify the progress of the national development plan and the eventual enthronement of living environments that are both sustainable and resilient.

The next section of the study is related literature, followed by the applicable methodologies and data description section. The penultimate section distils the empirical analysis and discussions, whereas the last section provides the summary and policy recommendations.

## 2. Review of related literature

A Plethora of empirical investigations has attempted to establish the relationship between environmental sustainability and its relevant predictors. In particular, the environmental Kuznets curve hypothesis (EKC [Kuznets 2019]) has remained the dominant and most established theoretical foundation for predicting environmental integrity (Alola, Özkan, and Usman 2023; Uche, Das, and Bera 2023). In light of the present study, the connectedness between the ecological load capacity factor and its determinants is established through the recently proposed load capacity curve (LCC) hypothesis attributable to Dogan and Pata (2022). Like EKC theory, LCC proposes a U-Shaped relationship between economic expansion and load capacity factor. Notably, LCC predicts a dynamic situation whereby increased income improves ecological load capacity in the long term, having deteriorated it in the short run (Pata and Kartal 2023). This study probes the validity of the LCC hypothesis by determining the influence of green-technology, energy transition and natural resources utilisation on the ecological load capacity factor for South Africa.

Based on the aforementioned dynamic structure between environmental quality and anthropogenic activities, several studies have lent their opinions towards shaping policy orientations. For clarity, we have partitioned this part of the study into three thematic components to trace the effects of green-technology, energy-transitions, and resource rents on LCF as articulated in recent studies.

### *2.1. Green-innovations – ecological load capacity factor*

As earlier highlighted, prior studies failed to trace the potential effects of green innovations on the ecological load capacity factor for South Africa and other economies. The notable drawbacks of these studies are that they have consistently adopted other environmental quality indicators like ecological footprint and $CO_2$ in their investigations. For instance, Karimi Alavijeh et al. (2023) probed the influence of technological innovation on environmental degradation ($CO_2$) in EU countries. Based on the estimates of the MMQR, the study rectifies the improving effects of the environment through technological innovations. In a related study, Uche, Das, and Bera (2023) confirmed that environmental-control technology warranted only short-term environmental quality-enhancing effects in India. A similar submission was provided in Udeagha and Muchapondwa (2022) in the case of South Africa. Another similar study (Awosusi et al. 2022) inferred that technological advancements improved the environmental quality in South Africa. However, Uche et al. (2023) admitted that environmental-control technology dampened environmental quality in BRICS countries.

In the case of Brazil, Liu et al. (2022) aligned with some submissions haven noted that technological innovations enhanced Brazil's ecological load capacity factor. In a supporting submission, Dogan and Pata (2022) illustrated that technological advancements ensure sustainable ecological balance in the case of G7 countries. Ni, Yang, and Razzaq (2022) extended similar assertions. Accordingly, the study informed that technological innovativeness magnifies LCF in highly resource-consuming economies. Likewise, Kihombo et al. (2021) and Yang, Jahanger, and Ali (2021) emphasised technological innovations' environmental quality soothing effects in West Africa and BICS economies. However, Destek and Manga (2021) argued that technological diffusion increases ecological footprint and reduces $CO_2$ emissions in big emerging markets.

Pata et al. (2023) reemphasized that technological innovations are only effective in reducing $CO_2$ emissions, whereas it minifies the load capacity factor in Germany. More discordant analogies are evident in most previous studies pertaining to the influence of technological innovations on

environmental quality. For instance, Adebayo and Kirikkaleli (2021), Su et al. (2021), Usman and Hammar (2021) and Rout, Gupta, and Sahoo (2022) reported that technological innovations failed to improve ecological footprints in Japan, Brazil, Asian Pacifica Economic Cooperation nations and BRICS countries, respectively. In summary, past studies failed to establish a common ground on the innovations – environmental quality nexus. Likewise, only a few considered LCF, whereas South Africa's cases were seldom investigated. Therefore, to further clarify the objectives of the present investigation, we hypothesised that green-innovation is a positive predictor of LCF in South Africa,

### 2.2. Energy transition – ecological load capacity factor

Previous studies have not been able to quell the controversies bordering on energy transition (low-carbon energy) – load capacity factors interactions. Unfortunately, the discordant analogies still persist even in recent studies. For clarity, Khan et al. (2023), via the estimates of the CS-ARDL procedure, admitted that renewable energy increases LCF in both G7 and E7 countries. Similar submissions prevailed in Iorember et al. (2021) for South Africa, Adebayo and Kirikkaleli (2021) for Spain, Dogan and Pata (2022) for G7 countries, Obiakor, Uche, and Das (2022) in the case of West Africa, Liu et al. (2022) in Brazil, for ASEAN economies, as well as Uche et al. (2022) in the case of E7 countries. Recent studies eulogised the enhancing effects of renewable energy on LCF. Accordingly, Adebayo (2023) informed that renewable energy increases LCF in BRICS nations. Likewise, Adebayo and Samour (2023), Alola, Özkan, and Usman (2023), Guloglu, Caglar, and Pata (2023), Pata et al. (2023), Samour et al. (2023) and Ullah et al. (2023) extended affirmative analogies in the instances of BRICS, India, OECD countries, Germany and BRICS-T economies, respectively.

Notwithstanding the overwhelming submissions of many prior studies on the appealing effects of renewable energy on LCF, there are still some divergent perspectives. In this instance, Pata and Isik (2021) demonstrated through an ARDL analysis that renewable energy improves ELCF in the US, whereas it has no significant effects in the case of Japan. Beyond this, Huilan et al. (2022) applied the fully modified ordinary least squares process. The study admitted that renewable energy minifies LCF in Mexico. Likewise, Pata and Samour (2022) illustrated that renewable energy dampens LCF, particularly in France. This assertion is supported by the submission of Xu et al. (2022), which, based on the estimates of the ARDL toolkit, reported that renewable energy failed to improve LCF in Brazil.

Nonetheless, Pata and Kartal (2023) reaffirmed that renewable energy could not improve LCF in South Korea. Based on the prevailing review, it is imperative to underscore that the perspective of RSA vis-à-vis renewable energy – LCF nexus was neglected. Likewise, there are notable discordant viewpoints in extant studies regarding the nexus. To this end, we hypothesised that energy transition improves LCF in South Africa.

### 2.3. Natural resource – ecological load capacity factor

The empirical literature revealed that few studies had probed the potential effects of natural resource utilisation on LCF. However, the few studies in this perspective also failed to establish a common ground about the nexus. Accordingly, based on the empirical estimates of the ARDL, Akadiri et al. (2022) inferred that natural resource rent enhances LCF in India. In contrast, Ni, Yang, and Razzaq (2022) relied on the analysis of CS-ARDL to assert that natural resources dampened LCF in highly resource-consuming countries. Interestingly, Guloglu, Caglar, and Pata (2023) remarked a positive influence of natural resource absorption on LCF in OECD countries. Nevertheless, the puzzle became more interesting as Pata and Isik (2021) stressed rather a deleterious effect of resource rents on LCF in China.

Additionally, some extant studies explored the predictive effects of resource rent on other indicators of environmental quality. For instance, Opuala et al. (2023) and Opuala-Charles, Omoke, and

Uche (2022) explain that resource rent contributed to $CO_2$ emissions significantly in West Africa. On the flip side, Nathaniel, Bekun, and Faizulayev (2021) maintained that resource rent dampens environmental quality significantly in BRICS economies. Similarly, Khan, Hou, and Le (2021) reported that resource rent moderates the United States' ecological footprint and $CO_2$ emissions. In contrast, Zhang et al. (2021) maintained that resource rent enhances environmental quality in Pakistan. However, for Zafar et al. (2021) and Ullah et al. (2023), natural resource rent is significantly associated with environmental pollution in Asia and 15 renewable consumption economies, respectively. Byaro, Nkonoki, and Mafwolo (2023) reported that natural resource rent significantly predicts environmental pollution in sub-Saharan African countries. Nathaniel et al. (2021) extended a more puzzling narrative by informing that resource rent hampered environmental quality in the case of ASEAN economies except for Laos PDR and Thailand, where it improves environmental quality significantly. To ascertain the actual effect of resource utilisation on environmental quality, this study hypothesised a negative association between resource rent and LCF in the context of RSA.

### 2.4. Summary of literature gaps

Notably, previous studies failed to probe the effects of the variables considered in this study on load capacity factor in the context of South Africa. Besides, the accounts of extant literature pertaining to the effects of green innovation on load capacity factor remained unclear. We also noted that prior studies relied on weak econometric tools lacking the capacity to provide reliable empirical estimates. This observed gaps and the need for updated insights compelled the current investigation.

## 3. Materials and methods

Based on the objectives of this investigation, the purpose of novelty and policy moderation, we have outlined the data descriptions, model specification and relevant estimation techniques within this section.

### 3.1. Data sources and descriptions

The study relied on secondary sourced annual time-series data spanning 1970–2018 specific to RSA. The choice of the data span is predicted by data availability, particularly data on GFN (2023). The relevant data captured are LCF calculated by the authors following the ratification of Siche et al. (2010). As previously indicated, LCF is obtained by dividing the biocapacity factor by the ecological footprint. Accordingly, the biocapacity factor and ecological footprint data were obtained from GFN. In this respect, green-tech (patent on environmental control technology[*GTech*]) is obtained from the data repository of the Organization for Economic Cooperation and Development (OECD). Energy transition (low-carbon energy – TWh equivalent[*ETran*]) is extracted from Our World in Data (OWID). Resource utilisation (% GDP of total natural resources rents[*NR*]) as well as the control variable (economic growth – Current US$ of GDP per capita[*EGrt*]) were extracted from World Development Indicator (WDI). The inclusion of economic growth (GDP) is informed by its notable influence on environmental quality as narrated in extant literature (Khan, Hou, and Le 2021; Uche and Effiom 2021a). Besides, evaluating the validity of the LCC hypothesis is based on its associated short and long-run effects on LCF.

### 3.2. Model specification

At this stage, the study provides an analytical framework to express the theoretical underpinnings of the ecological load capacity factor and the enlisted predictors. Notably, such a framework is essential in explaining the earlier stated hypotheses. Previous studies have applied many theoretical

frameworks to explain the relevant series of environmental quality. Based on insights from Awosusi et al. (2022), Ni, Yang, and Razzaq (2022) and Alola, Özkan, and Usman (2023), we construct a transformed Cobb–Douglas production function that explores the responses of LCF to the changes in the enlisted predictors. The mathematical interactions of the above association are availed in Equation 1.

$$Lcf_t = f(GTech_t, ETran_t, NR_t, EGrt_t) \tag{1}$$

where $Lcf_t$, $GTech_t$, $ETran_t$, $NR_t$, and $EGrt_t$ depict ecological load capacity factor (dependent variable), green-technology, energy transition, natural resources rents, and economic growth. Equation (1) is further transformed into an econometric scheme, as illustrated in Equation 2.

$$Lcf_t = \varphi_0 + \varphi_1 GTech_t + \varphi_2 ETran_t + \varphi_3 NR_t + \varphi_4 EGrt_t + \varepsilon_t \tag{2}$$

In Equation (2), $t$ and $\varepsilon_t$ depict the time-sets and stochastic error-term, respectively. Meanwhile, $\varphi_1$, $\varphi_2$, $\varphi_3$and $\varphi_4$ are the coefficients of the explanatory variables, $\varphi_0$ is the intercept. Following the earlier stated hypotheses, green-technology, as well as energy transitions, are expected to surge ecological load capacity factor, i.e. $\varphi_1 = \frac{\partial Lcf}{GTech} > 0$, $\varphi_2 = \frac{\partial Lcf}{ETran} > 0$ On the other hand, resources rents is expected to dampen ecological load capacity factor, i.e.$\varphi_3 = \frac{\partial Lcf}{NR} < 0$; likewise, GDP is expected to mitigate ecological load capacity factor, i.e. $\varphi_4 = \frac{\partial Lcf}{EGrt} < 0$

### 3.3. Estimation procedures

Besides several preliminary evaluations, including summary statistics, correlation analysis, variance inflation factor analysis, nonlinearity test, stationarity tests and cointegration test, the empirical estimates of this study emerged from two primary techniques. This includes the conventional ARDL procedure and the newly introduced quantile ARDL procedure. Hence, the relevant information on these estimation procedures is provided herewith.

#### 3.3.1. The autoregressive distributed lag (ARDL) procedure

The ARDL econometric technique, akin to Pesaran and Shin (1999), is adopted as the baseline estimation procedure. The option of the ARDL is premised on its several notable attributes, including the ability to avail reliable estimates both in the short and long terms. Besides, the model is dynamic, flexible and permits the evaluation of series with either uniform or mixed-orders of integration (Pesaran and Shin 1999). In addition, the ARDL technique adopts the bounds-test cointegration process of Pesaran, Shin, and Smith (2001) to verify potential long-run convergence between the explained variable and the explanatory variables. Several studies, including (Akadiri et al. 2022; Opuala-Charles, Omoke, and Uche 2022; Uche 2022) have relied on this technique. Hence, the typical functional scheme of the ARDL technique is provided in Equation 3.

$$\ln \Delta \gamma_t = \quad \varphi_0 + \quad \varphi_1 \gamma_{t-1} + \quad \varphi_2 x_{t-1} + \sum_{i=1}^{n} \phi_1 \Delta \gamma_{t-i} + \sum_{i=0}^{n} \phi_1 \Delta x_{t-i} + {}_{\varepsilon_t} \tag{3}$$

In Equation (3) $\gamma_t$ depicts the predicted variable, while $x_t$ represents all the vectors of the explanatory factors, $\Delta$ connotes the difference operator, and $\varepsilon_t$ represents the error correction term or the speed of adjustment. $\sum_{i=1}^{n} \phi_1 \Delta \gamma_{t-i}$ denotes the short-run outcomes, and $\varphi_1 \gamma_{t-1}$ represents the long-term estimates. Furthermore, Equation (3) is transformed into Equation (4) with the

inclusions of the enlisted series.

$$\Delta Elcf_t = \varphi_0 + \varphi_1 GTech_{t-1} + \varphi_2 ETran_{t-1} + \varphi_3 NR_{t-1} + \varphi_0 EGrt_{t-1} + \sum_{i=1}^{n} \phi_0 \Delta Eclcf_{t-i} + \sum_{i=0}^{n} \phi_1 \Delta GTech_{t-i} + \sum_{i=0}^{n} \phi_2 \Delta ETran_{t-i} + \sum_{i=0}^{n} \phi_3 \Delta NR_{t-i} + \sum_{i=0}^{n} \phi_4 \Delta EGrt_{t-i} + \varepsilon_t \quad (4)$$

The long-term convergence of the series can be obtained from Equation (4) following the specification of the null and alternative hypotheses: $H_o$:$\varphi_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4$; $H_1$:$\varphi_0 \neq \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4$

Hence $H_O$ represents the null hypothesis of no long-run convergence, whereas $H_I$ illustrates the alternative hypothesis of long-term convergence among the series. Implicatively, the study will affirm long-term convergence when there is overwhelming evidence not to accept the null hypothesis.

### 3.3.2. The quantile autoregressive distributed lag (QaRDL) procedure

One factor distinguishing the present study from the rest is the adoption of the QARDL econometrics toolkit to verify the determinants of LCF for RSA. The QARDL procedure extended by Cho, Kim, and Shin (2015) is a unique time-sensitive technique that avails the effects of relevant explanatory variables over the distributions of the predicted series. The model provides reliable empirical evidence over the long and short terms (Cho, Kim, and Shin 2015). The QARDL is superior to most estimation techniques since its outputs are characterised by conditional distributional effects rather than average effects (Omoke and Uche 2021). The model elicits information about potential short- and long-term distributional asymmetries (Hashmi et al. 2022). Besides, the technique is robust to possible serial correlations. On this basis, more policy insights are availed to ensure improvements in A's ecological load capacity factor. Henceforth, the typical functional scheme of the QARDL is depicted in Equation (5).

$$\begin{aligned} Q_{Eclcf} = {} & \phi_0(\tau) + \sum_{i=1}^{n1} \phi_0(\tau)\Delta Elcf_{t-i} + \sum_{i=0}^{n2} \phi_1(\tau)\Delta GTech_{t-i} + \sum_{i=0}^{n3} \phi_2(\tau)\Delta ETran_{t-i} \\ & + \sum_{i=0}^{n4} \phi_3(\tau)\Delta NR_{t-i} + \sum_{i=0}^{n5} \phi_4(\tau)\Delta EGrt_{t-i} \\ & + \varphi_0(\tau)Eclcf_{t-i} + \varphi_1(\tau)GTech_{t-i} + \varphi_2(\tau)ETran_{t-i} + \varphi_3(\tau)NR_{t-i} \\ & + \varphi_4(\tau)EGrt_{t-i} + e_t(\tau) \end{aligned} \quad (5)$$

In Equation 5, ($\tau$) depicts the quantile index, $\phi_0$ is the drift coefficient and n1 – $n5$ are the respective lag orders determined by the specified lag length criterion. $\phi_1 - \phi_4$ are short-run coefficients, whereas $\varphi_1$, $-$ $\varphi_4$ depict long-run coefficients. Based on the estimates of equation (5), the study is able to evaluate the potential distributional asymmetric effects of the enlisted series on LCF. Hence, 11 quantiles: $\tau\{0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95\}$ are identified as the basis of this investigation in alignment with (Hashmi et al. 2022; Uche and Effiom 2021b).

The null hypotheses are provided below:

**Short-run parameter constancy test:**

$$H_0^s{:}\phi_1(0.05) = \phi_1(0.10) = \ldots = \phi_1(0.95);\ H_0^s{:}\phi_2(0.05) = \phi_2(0.10) = \ldots = \phi_2(0.95)$$

$$H_0^s{:}\phi_3(0.05) = \phi_3(0.10) = \ldots = \phi_3(0.95);\ H_0^s{:}\phi_4(0.05) = \phi_4(0.10) = \ldots = \phi_4(0.95)$$

Long-run parameter constancy test:

$$H_0^l{:}\varphi_1(0.05) = \varphi_1(0.10) = \cdots = \varphi_1(0.95);\ H_0^l{:}\varphi_2(0.05) = \varphi_2(0.10) = \cdots = \varphi_2(0.95)$$

$$H_0^l{:}\varphi_3(0.05) = \varphi_3(0.10) = \cdots = \varphi_3(0.95);\ H_0^l{:}\varphi_4(0.05) = \varphi_4(0.10) = \cdots = \varphi_4(0.95)$$

The null hypotheses are provided to critique the eventual parameter constancy effects among the enlisted series. Accordingly, the Wald test, which follows a chi-square distribution asymptotically, is adopted to decide whether to accept or reject the null hypotheses.

## 4. Data analysis and discussions

As earlier stated, the empirical analysis of this study began with relevant pre-evaluation techniques. Hence, this component is dedicated to revealing the summaries of both the pre-estimations, the primary estimations and the post-estimations tests.

The evidence from Table 1 indicates that the expected values of *LCF*, green-technology, energy-transition, resources rents and economic growth in South Africa are 0.418, 9.964, 2.308, 5.491 and 2.308, respectively. Furthermore, the standard deviation indicates a closer spread among series except for *GTech* that is widely dispersed (3.350). *LCF, GTech* and *NR* series have positive tails, whereas *ETran* and *EGrt* have negative tails. All the enlisted series have thinner tails except *NR*, with fatter tail. This made the variable an outlier among other series. The Jarque-Bera statistic also revealed that *NR* deviates from the normal distribution, while other series are normally distributed. An abnormally distributed series eminently suggests the chances of nonlinearity among the series. In this case, the study probed whether the variables are linear or otherwise. Based on the evidence captured in the BDS test (Table 1), it is evident that all the enlisted series are nonlinear. This evidence holds across all the dimensions of the BDS test. Since this is the case, applying rigorous estimation techniques to such datasets is of the essence.

The study also subjected the relevant series to correlation and multicollinearity tests (Table 2). These tests are essential to ascertain the correlation strength between the coefficients of the explanatory and explained variables. The tests are also essential to ascertain the chances of multicollinearity among the predicting series. In this case, *GTech*, and *ETran* are positively and significantly correlated with *LCF*, whereas EGrt is negatively and significantly correlated with *LCF*. On the other hand, *NR* has a positive but insignificant correlation with *LCF*. Table 2 allays the chances of multicollinearity among the explanatory variables since all the VIF coefficients are within the acceptable threshold of 3 (Everitt and Skrondal 2010; Uche, Das, and Bera 2023).

Unarguably, economic series follows a random walk procedure that emanates from economic cycle. Invariably, economic series surfer considerable challenges like structural breaks arising from shocks like the recent COVID-19. On this basis, the enlisted series are subjected to stationarity tests via both linear (ADF) and nonlinear (Zivot-Andrews) unit-root test procedures (Table 3). Accordingly, the ADF tests revealed that while some series (*GTech, ETran* and *EGrt*) are stationary, others (*LCF* and *NR*) are differenced stationary series. However, the nonlinear procedure revealed

**Table 1.** The summary statistics and linearity test.

| Series | Summary statistics | | | | | BDS Linearity test | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Metrics | | | | | Dimensions | | | Remarks |
| Variables | Mean | Std. Div | Skewness | Kutorsis | JB | 2 | 4 | 6 | |
| *LCF* | 0.418 | 0.110 | 0.299 | 2.776 | 0.833 | 0.000 | 0.000 | 0.000 | Nonlinear |
| *GTech* | 9.964 | 3.350 | 0.029 | 2.898 | 0.027 | 0.000 | 0.000 | 0.000 | Nonlinear |
| *ETran* | 2.308 | 1.284 | −0.417 | 1.931 | 3.762 | 0.000 | 0.000 | 0.000 | Nonlinear |
| *NR* | 5.491 | 2.890 | 1.301 | 4.149 | 16.528*** | 0.000 | 0.000 | 0.000 | Nonlinear |
| *EGrt* | 9.249 | 1.583 | −0.283 | 1.786 | 3.662 | 0.000 | 0.000 | 0.000 | Nonlinear |

Note: ***$p < 1\%$; JB implies Jarque-Bara.

**Table 2.** Correlation matrix and variance inflation factors (VIF) test results.

| | Correlation matrix | | | | | VIF test |
|---|---|---|---|---|---|---|
| Series | *LCF* | *GTech* | *ETran* | *NR* | *EGrt* | *VIF coefficient* |
| *LCF* | 1.000 | | | | | - |
| *GTech* | 0.281** | 1.000 | | | | 0.001 |
| *ETran* | 0.786*** | 0.160 | 1.000 | | | 0.004 |
| *NR* | 0.152 | 0.079 | −0.344 | 1.000 | | 0.002 |
| *EGrt* | −0.957*** | 0.225 | 0.642*** | −0.239* | 1.000 | 0.002 |

Note: ***$p < 1\%$; **$p < 5\%$; *$p < 10\%$, VIF connotes variance inflation.

that while *LCF* and *GTech* are level stationary series, *ETran, NR*, and *EGrt* are first differenced stationary series. The table also revealed the influence of structural breaks on all the series over different time ranges. Implicatively, the attributes of these series presuppose the application of the ARDL-related techniques, essentially the time-variant (QARDL) version.

An essential step in the ARDL estimation procedure is the evaluation of the potential long-term coevolution of all selected datasets. For an ARDL procedure, the bounds test cointegration test remains the most acceptable option. The available evidence (Table 4) suggests the rejection of the null hypothesis of no long-run cointegration among the series since the F-statistics (4.282) is greater-than the upper-bounds limits (3.49) at 95% confidence interval. This entails that all the enlisted series share a common long-term trend and therefore cointegrated.

The outcomes of both the ARDL and the QARDL estimates are summarised in Table 5. Accordingly, the upper component elicits the explanatory variables' effects on LCF in South Africa based on ARDL estimates. In contrast, the lower component elicits the outcomes of the QARDL technique. Accordingly, the traditional ARDL technique estimates demonstrate that green (*GTech*) failed to stimulate ecological load capacity in South Africa during the period investigated. The result revealed an insignificant long and short-run negative association between *GTech* and *Lcf*. This implies that such technology has not effectively improved environmental quality in RSA. The observed unimpressive effects of *GTech* on *Lcf* in RSA reflect the embryonic state of such technology in the republic. Such evidence, as explained in prior studies like Rout, Gupta, and Sahoo (2022) and Uche et al. (2023), indicates that South Africa still needs to develop *GTech* capable of improving its ecological load capacity.

Accordingly, the ARDL technique revealed that RSA is currently reaping the benefits of energy transition (*ETran*). The observed long-run significant positive association between *ETran* and *Lcf* demonstrates as follows: Specifically, the load capacity factor improves by 0.024%, given a one-percent increase in renewable energy consumption. Such soothing effect, as illustrated in prior investigations (Samour et al. 2023; Ullah et al. 2023), suggests more commitments from policymakers towards ensuring an unhindered transition to clean energy. Hence this is done, South Africa's LCF would improve and become more sustainable.

Furthermore, the estimates of the ARDL indicate that whereas resource rent is an insignificant positive predictor of LCF, economic growth produced significant mitigating effects in both the long and short run. This outcome indicates that NR utilisation in RSA has failed to improve LCF

**Table 3.** Stationarity test results.

| Variables | ADF | | Zivot-Andrews | | | |
|---|---|---|---|---|---|---|
| | Level | ΔADF | Level | Break Point | ΔZivot-Andres | Break Year |
| *LCF* | −2.149 | −8.792*** | −5.035** | 1993 | - | - |
| *GTech* | −5.967*** | - | −6.392*** | 1983 | −7.385** | 1985 |
| *ETran* | −8.439*** | - | −4.583 | 1984 | −9.493*** | 1990 |
| *NR* | −2.811 | −8.918*** | −3.679 | 1979 | −9.815*** | 1981 |
| *EGrt* | −4.501*** | - | −0.563 | 1980 | −6.620** | 1980 |

Note: ***$p < 1\%$; **$p < 5\%$.

**Table 4.** Bounds test cointegration results.

| Test statistics | Value | Significance | I(0) | I(1) |
|---|---|---|---|---|
| F-statistics | 4.282** | 10% | 2.2 | 3.09 |
| K | 4 | 5% | 2.56 | 3.49 |
| | | 1% | 3.29 | 4.37 |

Note: **$p < 5\%$.

significantly. Moreover, it indicates a situation where clean environment is traded for economic expansions. By corroborating the submissions of Guloglu, Caglar, and Pata (2023), the outcome indicates that a strategically coordinated use of natural resources has the potential to improve environmental quality in South Africa. However, efforts must be exercised to curtail a potential ecological load capacity factor damage given the notable short-term negative effects of natural resource rent.

Following the approach of Narayan & Narayan (2010) and insights from Pata and Isik (2021), we reject the EKC hypothesis in the case of RSA since the long-term elasticity is more harmful than the short-term elasticity. Consistent with this inference, the load capacity curve (LCC) hypothesis does not hold for RSA. Furthermore, in tandem with the submissions of some extant literature (Byaro, Nkonoki, and Mafwolo, 2023), the republic must put lasting control measures pertaining to resource consumption policies if the country is desirious to launch into its expected status by 2030. Most importantly, policymakers must ensure that issues that border on environmental health should be considered alongside economic expansion propagation. Such steps, in line with 'our future make it work' agenda, will make the republic more prosperous and greener.

As earlier stated, the study subjected the relevant series to further evaluation via a nonlinear and time-variant technique (QARDL). Unarguably, the characteristics of the enlisted series informed the choice of such a time-variant model. The QARDL technique produced several interesting outcomes relevant to policy considerations. For instance, the estimates illustrated that in the short term, *GTech* minifies *Lcf* significantly, particularly at the upper quantiles (q0.05 – q0.1), while it produced insignificant and inconsistent effects thereafter. However, there is evidence of long-term ecological load capacity factor improvement. Specifically, *GTech* ensured marginal (0.003%) significant improvements in *Lcf* only at the uppermost quantile (q0.05), whereas it provided largely insignificant positive effects afterwards with the exceptions of (q0.4 – q0.8), where insignificant negative relationships ensued. Based on this outcome, it can be argued that *GTech* is a positive predictor of load capacity factor in RSA. However, it is imperative to underline that the observed soothing effects are still at an embryonic stage. To this end, it is suggested that environmental technologies must be improved. This will enable the republic reap their full benefits. Therefore, the study rejects the null hypothesis to state that *GTech* is a positive predictor of environmental vitality in SA.

Consistent with the ARDL, the estimates of the QARDL procedure revealed that the transition to clean energy is a significant positive predictor of *Lcf* in RSA at all times. In particular, at the upper quantiles (q0.05 - q0.1), *Lcf* improves given a 1% short-term increase in clean energy adoptions. Beyond these quantiles, its effects remained positive but insignificant except at the lower quantiles (q0.7 – q0.95), where its effects became negative yet insignificant. The positive association between *ETran* and *Lcf* is also recorded in the long run, particularly at the middle-quantiles (q0.5 – q0.6). The effect of energy transition remained positive but insignificant at other quantiles except towards the lower quantile (q0.8), where an insignificant negative association was observed.

It is pertinent to highlight that energy-transition improved *Lcf* much more in the short rather than in the long run. Therefore, in line with the earlier submissions, we affirm that energy-transition is a significant positive predictor of *Lcf* in RSA. However, more commitments are required to facilitate unhindered transition and all-inclusive adoption of clean energy in the republic. In particular, the ongoing Energy Performance Certificate (EPC) verification that seeks to verify the commitments of property owners towards the zero-emission building standards by 2030 is a step in the

**Table 5.** ARDL and QARDL estimates.

| Series | $\varphi_1 GTech_{t-1}$ | $\varphi_2 ETran_{t-1}$ | $\varphi_3 NR_{t-1}$ | $\varphi_4 EGrt_{t-1}$ | $\phi_1 \Delta GTech_{t-i}$ | $\phi_2 \Delta ETran_{t-i}$ | $\phi_3 \Delta NR_{t-i}$ | $\phi_4 \Delta EGrt_{t-i}$ | *ECT* |
|---|---|---|---|---|---|---|---|---|---|
| | *Long-run estimates* | | | | *Short-run estimates* | | | | |
| ARDL | −0.003 | 0.024* | 0.002 | −0.075*** | −0.001 | 0.003 | 0.009 | −0.036*** | −0.486*** |
| QARDL | | | | | | | | | |
| Q0.05 | 0.003* | 0.003 | 0.006* | 0.061** | −0.004** | 0.023* | 0.003 | −0.177 | −0.058*** |
| Q0.1 | 0.002 | 0.009 | 0.005** | 0.063*** | −0.003** | 0.023* | 0.002 | −0.071 | −0.066*** |
| Q0.2 | 0.007 | 0.013 | 0.007** | 0.042** | −0.002 | 0.002 | 0.001 | −0.122 | −0.774*** |
| Q0.3 | 0.001 | 0.008 | 0.006** | 0.042*** | −0.001 | 0.002 | −0.001 | −0.083 | −0.734*** |
| Q0.4 | −0.003 | 0.007 | 0.005** | 0.024*** | −0.001 | 0.012 | −0.005 | −0.048 | −0.431*** |
| Q0.5 | −0.001 | 0.005** | 0.003 | 0.028*** | −0.004 | 0.008 | 0.001 | −0.087 | −0.488*** |
| Q0.6 | −0.001 | 0.008** | 0.002 | 0.026** | 0.001 | 0.002 | 0.002 | −0.053 | −0.429*** |
| Q0.7 | −0.001 | −0.001 | 0.001 | 0.029* | −0.003 | −0.001 | 0.001 | −0.037 | −0.417* |
| Q0.8 | −0.005 | 0.002 | −0.009 | 0.017 | −0.001 | −0.005 | 0.001 | −0.070 | −0.264** |
| Q0.9 | 0.001 | 0.014 | −0.002 | 0.007 | 0.001 | −0.003 | 0.001 | 0.130 | −0.195** |
| Q0.95 | 0.002 | 0.021 | 0.005 | 0.006 | 0.001 | −0.007 | −0.002 | −0.174 | −0.235** |

Note: ***$p < 1\%$; **$p < 5\%$; *$p < 10\%$, ECT connotes error-correction term.

right direction. As such, everyone is expected to support the programme to enable the republic realise the objectives of the development plan.

Additionally, available evidence precluded a harmonious and favourable disposition between resources rent and *Lcf* in RSA. Accordingly, resource rent ensured significant improvements in *Lcf*, particularly at the upper quantiles and towards the middle quantiles (q0.05–q0.4). *NR* produced insignificant positive effects thereafter and became unfavourable at the lower quantiles (q0.8–q0.9). The short-term effects also underscored the positive yet insignificant association between NR and *Lcf* except at some upper quantiles (q0.30–q0.40) and lowest quantile (q0.95), where it produced insignificant adverse effects. Considering this outcome, it is essential to comment that the republic has conducted its natural resource utilisation in such a way that it improved the environment at some quantiles.

However, the observed adverse effects over some quantiles suggest that its effects are only partially favourable. In this case, the republic is expected to provide more robust policy guidelines towards natural resources exploration to avoid its unpleasant effects recorded at the upper quantiles. Beyond the guidelines, efficient monitoring mechanisms must be implemented to ensure maximum compliance at all times. In this context, the null hypothesis is rejected in favour of the alternative. It is pertinent to highlight that the submissions of Caglar et al. (2023) and Guloglu, Caglar, and Pata (2023) in the case of G5 and 26 OECD countries resonate with this finding. Therefore, resource utilisation is a significant positive predictor of *Lcf* in South Africa.

Unlike the traditional ARDL procedure, the estimates of the QARDL model demonstrated long-term significant *Lcf* improvements amidst economic growth. In this context, economic growth produced a notable soothing effect across the distributions of *Lcf*. In particular, its favourable effects were more prominent at the upper quantiles (q0.05 – q0.3), less prominent at the middle quantiles (q0.4 – q0.7) and insignificant at the lower quantiles (q80 – q95). On the flip side, its short-term effects are mainly unfavourable and insignificant across all the distributions of *Lcf* except at the 90th quantile (q90), where it produced an insignificant favourable effect. This outcome portrays some favourable turn of events that fizzles out over the distributions. For instance, average elasticity of 0.06% and 0.04% were recorded at the upper and middle quantiles, respectively.

Meanwhile, it produced insignificant positive effects at the lower quantiles. This discovery highlights a potentially unsustainable relationship between growth and *Lcf* in South Africa. This evidence suggests the urgency to ensure that environmental quality is not traded for economic prosperity. Hence such is not adhered to; the republic will invariably bear the negative consequences of a compromised ecosystem.

**Table 6.** Post-estimation/Parameter constancy tests

| Series | *F-statistics* | *Prob.* |
|---|---|---|
| Normality test (Jarque-Bera) | 1.087 | 0.581 |
| Serial correlation test (Breusch-Godfrey) | 1.159 | 0.324 |
| Heteroscedasticity (constant variance) test (ARCH) | 0.692 | 0.409 |
| Specification test (Ramsey RESET) | 0.293 | 0.590 |
| ***Long-term parameter constancy test*** | | |
| $\varphi_1$ | 0.50 | 0.877 |
| $\varphi_2$ | 1.32 | 0.255 |
| $\varphi_3$ | 1.59 | 0.147 |
| $\varphi_4$ | 1.13 | 0.368 |
| ***Short-term parameter constancy test*** | | |
| $\phi_1$ | 0.90 | 0.546 |
| $\phi_2$ | 2.47\ast \ast | 0.022 |
| $\phi_3$ | 0.43 | 0.924 |
| $\phi_4$ | 0.56 | 0.835 |

Note: $^{**}p < 5\%$.

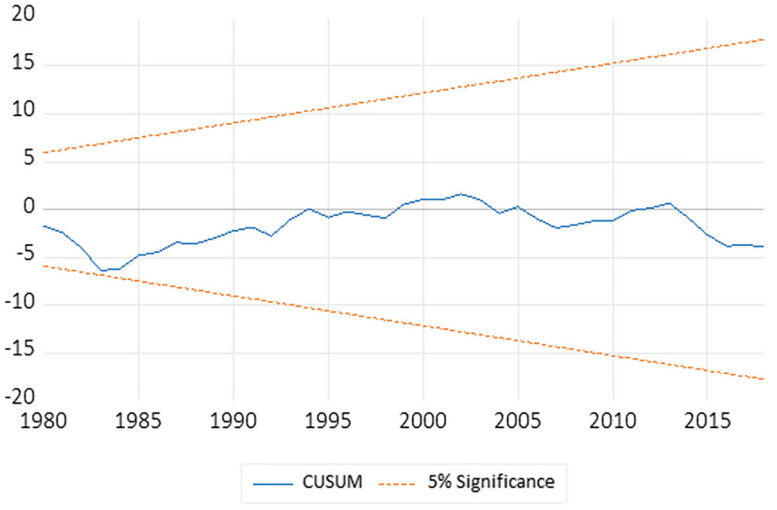



**Figure 3.** Stability graph I (CUSUM).

### *4.1. Post estimation evaluations*

The outcomes of both models, ARDL and QARDL, were subjected to series of post-estimation validity tests. The results of these post-estimation validity tests are summarised in Table 6 and Figures 3 and 4.

The evidence portrayed in the upper panel of Table 6, including the normality test, serial correlation test, constant variance test, and specification test, affirmed the validity of the empirical results. Likewise, the stability tests (Figures 3 and 4) demonstrate that the models are stable over time. In the case of parameter constancy tests, the middle and lower panels of the table revealed that the series is homogeneous over time and across the distributions of the explained variable. An exception to this is the presence of heterogeneity in the case of short-run effects of energy transition ($\phi_2$) on *Lcf*. Given the potential influence of economic cycles and structural breaks,

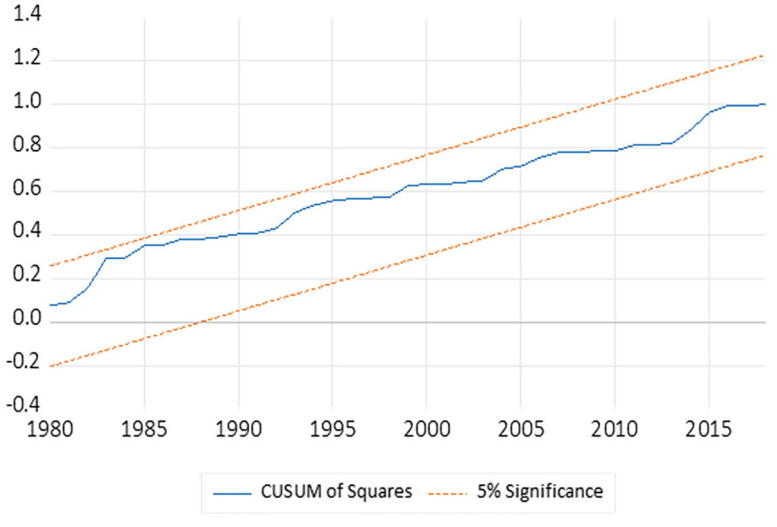



**Figure 4.** Stability graph II (CUSUM of Squares).

this entails the desirability of constant policy monitoring and moderation across the distributions. Forthwith, the empirical estimates and the accompanying policy prescriptions are valid for policy moderation that would ensure improved ecological load capacity factor and ecological balance in RSA.

## 5. Conclusions and policy insights

The RSA is committed to staying on top of everything in the fight against climate change and its associated global warming. In this study, efforts were committed to unravelling the potential influence of green-innovation, energy transition, and resource rent on *Lcf* in the case of RSA. The load capacity factor is a comprehensive environmental quality indicator that unveils the peculiarities of the demand and supply sides of environmental performance. Unfortunately, such essential information does not exist in the context of an important emerging economy like RSA. There are a handful of studies within the context of developing countries and a few emerging economies. Very few considered the BRICS economics but failed to consider load capacity factor.

To put the records straight and update the literature trajectory, this study explored the dimensions of the green-technology, energy-transition and resource rents towards improving *Lcf* in South Africa. For this purpose, the study galvanised annual data sets of these variables, spanning 1970–2018 for empirical evaluation.

In addition, unlike existing studies, we adopted linear (ARDL) and nonlinear (QARDL) estimation procedures for empirical evaluation. Likewise, other essential pre and post-estimation tests were activated to give critical expressions to the veracity of the empirical results. Among the pre-evaluation tests, the bounds test conveyed long-term coevolution among the variables. The empirical estimates of the ARDL exposed that *GTech* failed to improve *Lcf* in RSA, whereas the QARDL informed that *GTech* could improve *Lcf* only at the upper quantile. Likewise, both estimates confirmed the improving effects of energy-transition. However, such a feat was achieved only at the middle quantiles in the case of QARDL.

On the other hand, the ARDL portrayed resource rent as a positive but insignificant predictor of *Lcf*. In contrast, the QARDL demonstrated that resources rest improved *Lcf* significantly, mainly at the upper quantiles. However, resource rent produced harmful effects at the lower quantiles of the distributions. The control variable (GDP) remains a concern for environmental sustainability since it minifies *Lcf* in both the short and long run based on the estimates of the ARDL procedure. However, the estimates of the QARDL revealed that despite its short-term environmental quality-dampening effects, GDP engendered some *Lcf* soothing effects, particularly at the upper and middle quantiles of the distributions. This suggests some potential and possible positive turn up of events.

What is the policy direction given these varied outcomes? It is pertinent to remark that robust and holistic empirical revelation such as this provides far-reaching policy implications than others. In particular, the unimpressive influence of green-technology can be reversed to an all-time appealing effect since it provided a significant but marginal improving effect at the upper quantile. More investments and commitment are essential to activate the improving effects of this unique technology that has ensured improved environments in some other economies. Admittedly, energy transition offered notable soothing effects, yet it could not offer all-time soothing effects in upper and lower quantiles. In this case, the republic must be more committed to realising a full-scale transition to clean energy. RSA should be more emphatic about the switch to electric vehicles (EVs) like other emerging countries such as China. Moreover, there is a need to review, readjust and realign the prevailing energy and environmental taxes. The ongoing energy performance certification (EPC) programme is commendable and should be pushed with more vigour to achieve the expected results.

The relationship between resource rent also demands further strengthening and adjustments towards the realisation of improved *Lcf*. This is because resources rent improved environmental quality only at the upper quantiles while it remained insignificant and harmful at some quantiles

of the distributions. It would not be out of place to invoke more stringent control measures in the utilisation and explorations of natural resources in the republic. This could entail the imposition of higher tax rates on resources explorations. To this end, more investment should be made on advance technologies to ensure cleaner environments. Most importantly, the republic must ensure that the quest for economic expansions does not overshadow the sustainability of its environmental ecosystem at any time. This is particularly important since it produced some notable unimpressive effects on *Lcf* in the case of ARDL and QARDL procedures.

At this point, it is expedient to state that all the steps taken in this study are confined within its stated objectives and focus. Indeed, the study may not have identified some other fundamental determinants of environmental performance. Particularly, the study is confined within the peculiarity of South Africa. On this realisation, we encourage the extension of this study by enlisting other determinants to confirm their effects on *Lcf*. Likewise, other emerging countries should be considered for more empirical insights since only a few were considered in extant studies.

## Note

1. https://www.gov.za/sites/default/files/Executive%20Summary-NDP%202030%20-%20Our%20future%20-%20make%20it%20work.pdf

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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