Environmental sustainability and ecological balance dilemma: accounting for the role of institutional quality

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Abstract
Global warming is a global menace mainly driven by human anthropogenic activities. There is a need for environmental sustainability amidst increased economic growth. To this end, this study draws motivation from the United Nations Sustainable Development Goals (UNSDGs) with special focus on climate change mitigation and ecological balance. Thus, the present study analyses the dynamic relationship between economic growth, conventional energy consumption, access to technological innovation, economic globalisation, and the pertinent role of institutional quality for the case of the Russian Federation. This study employed novel combined Bayer and Hack cointegration test in conjunction with Pesaran’s ARDL bounds testing for robustness. Both tests validate a long-run equilibrium relationship between the outlined variables. Furthermore, empirical results show that increase in economic activities and consumption of energy that stem from a fossil-fuel basis both have deteriorating effect on environmental sustainability for Russia. Additionally, effect of globalisation shows mixed results, such as, in the short run, economic globalisation dampens environmental quality as increase in global integration exacerbates environmental quality, while, in the long term, globalisation improves the quality of the environment. On the contribution of institutional quality, it improves environmental sustainability over the investigated period. Interestingly, renewable is seen as a panacea for environmental sustainability in the Russian Federation given its pertinent effect to improve the environment of Russia. From a policy lens, there is need for a paradigm shift to renewables and clean technologies to mitigate the effect of climate change issues. The concluding section presents more policy strategies.

Keywords Environmental sustainability · Carbon reduction · Ecological balance · Economic growth · Combined Bayer and Hanck cointegration · Russian Federation

Introduction
Despite the numerous challenges faced by the global environment, countries have only sought the expansion of socioeconomic activities. Increased technological innovation, higher energy demand and economic globalisation have only
caused socioeconomic engagements and activity to increase; hence, these are touted as crucial determinants of ecological and environmental quality (Destek and Sarkodie 2019; Alola et al. 2019; Tinta 2021). The resultant effects on the ecology and the environment from the surging different forms of economic activity present the drastic need to transition to responsible and sustainable production methods, through the use of clean energy and technologies, coupled with policy reformations, regulations, and quality institutions (OECD, 2020).

Undeniably, the essence of economic globalisation and industrialisation of nations is to expand trade, drive financial development, and promote economic complexity (Khan et al. 2020). However, these developments also carry over detrimental impacts on the environment, like man-made greenhouse gas and CO₂ emissions, which threaten the climate, degrade, and pollute the environment (Bello et al. 2018; Pata and Caglar 2021). Thus, according to experts, this is the global challenge—to pursue economic development objectives, while maintaining environmental quality and balance between human activities and the natural regenerative resource capacity (Yin et al. 2021). To this end, global partners and international bodies like the UN and UNFCCC have since pushed for the realisation of the sustainable development paradigm (Mehmood and Tariq 2020; Rashid et al. 2018).

The need to formulate and adopt appropriate policy regulations requires quality institutions for accurate impact assessment, of human economic development activity on the environment and its resources (Wandeda et al. 2021). Thus, Tinta (2022) believes that institutional quality is a crucial determinant of environmental quality among several other factors. Beyond this assertion, human activity factors like ecological footprint and CO₂ emissions have also received wide acceptance as environmental indicators (Abbas et al. 2021; Destek and Sarkodie 2019; Fakher 2019; Laurent et al. 2012).

According to the Global Footprint Network, (2012), the concept of ecological footprints “measures the biologically productive area of land and water required by an individual or population to produce all resources it consumes to accommodate urban infrastructure and absorb waste generated in the form of carbon dioxide using prevailing technology and quality management practices.” Ecological footprint is assessed along six perspectives of land use, namely, cropland (area for nutritious food production), pastureland (land for raising livestock), forestland (area for forest product supply), fisheries (fresh and sea water land for fish and sea products), built-up land (land for human infrastructure), and carbon uptake land (forest land needed to consume CO₂) (WWF 2018).

Additional indicators include CO₂ emission and biocapacity, which occur at the supply side. These indicators largely determine the volume of pollution generated from economic engagements and the regenerative capacity of the environment to produce biological materials (Global Footprint Network 2012). For instance, if the ecological footprint exceeds an environment’s biocapacity, then there is an ecological deficit, hence greater pollution. However, where the environment’s biocapacity exceeds the ecological footprint, then an ecological reserve exists, hence lesser pollution (Galli et al. 2016; Torras et al. 2011).

Economic expansion in many newly industrialised countries (NICs) has characterised the rise in negative environmental consequences. For example, Russia measures ecological footprint of 5.48 and a biocapacity of 6.96, compared with other newly industrialised economies like India that shows an ecological footprint per capita of 1.19 and a biocapacity per capita of 0.43 hectares and China showing an ecological footprint of 3.71 hectares per capita and a biocapacity of 0.92 per capita indicating an ecological deficit of −3,435.62, the largest in the world (Wandeda et al. 2021). However, despite the positive signs of ecological reserves growing in Russia, the economic growth pattern of Russia shows an inconsistent impact on environmental quality and degradation. Thus, Russia is among the top five culprits of high carbon emissions (WWF 2018). The ecological footprint report on Russia indicates a 1% change in ecological reserve between 2017 and 2020 (see Fig. 1), while it is yet observed to be a high emission source of carbon dioxide in the world (see Fig. 2). Being among the world’s emerging industrialised economies, Russia has a land size equivalent to 11% of the world’s landmass, and, as such, it is perceived that it will also have a greater demand for energy to facilitate its industrialisation process (IRENA 2018). Russia depends significantly on fossil fuel revenue and has no plans of cutting down on its dependence on these energy sources (Bekun 2022). Thus, given the trend of Russia’s economic growth and expansion, it is likely to continue to produce greater volumes of greenhouse gas and carbon dioxide in the long term that may reduce its ecological reserves per capita and increase greater pollution. This situation amplifies the debate on the consequences of Russia’s economic globalisation goals, technological development, energy consumption, and environmental quality an important one requiring further attention (Rehman et al. 2021).

Whereas some scholars share the view that economic globalisation and other factors, such as technological development, energy consumption, and institutional quality, positively affect environmental degradation across (Ibrahim 2015; Ling et al. 2015; Najan et al. 2007; Rehman et al. 2021; Shahbaz et al. 2015; Shahbaz et al. 2019), others believe that those countries in the process of industrialisation may not experience this positive impact on the environment. Thus, they argue that a weak system and institutions allow economic expansion activities consistent with the pollution
haven framework, and pollution-intensive industrial sectors through the reliance on fossil fuel energy sources deepen environmental degradation in such countries undergoing industrialisation (Lu et al. 2021a, 2021b; Phong 2019; Wang and Dong 2021a, 2021b).

To sustain environmental quality and pursue economic growth, Russia’s strategic goal over the past decade or two has been to transition to a sustainable economy, by gradually moving away from its existing natural resource-based development model and bringing under control the growth of its natural resource-based economy by 2030. This situation has accumulated greater and greater momentum. Thus, it has become more apparent that Russia’s natural resource-exporting model has been outlived; therefore, ensuring quality environments must be at the forefront of its new and emerging developmental models to slow the impact of the unsustainable trends of natural resource depletion.

The aforementioned goal presents evidence imperative to understand how economic development indicators link to ecological footprint and CO2 emissions. Hence, the purpose of this study is to examine the long-run effects and causality between CO2 emissions and ecological footprint and their determinants, including economic globalisation, access to technology, fossil fuel use, renewable energy consumption, and institutional quality over the period 1970 to 2019 in Russia.

This study differs substantially from the existing few studies. First, it combines ecological footprint and CO2 emissions as output variables, while previous studies have mainly examined ecological footprint or CO2 emission separately. The present study builds on the carbon-income function, i.e. the trade-off between environmental degradation (ecological footprint) and economic growth in our study case linear version, while in the energy literature, the cubic form of this intuition on the trade-off between environmental degradation and economic growth is popularised in the literature as the environmental Kuznets curve (EKC) which our study leverages. In addition, it employs robust second-generation panel estimation models such as the ARDL, unit root test, and Bayer-Hanck cointegration testing procedure to ensure greater reliability and validity of findings. Further, at present, very few studies have sought the effect of the determinants of ecological footprint and CO2 emission together in a single assessment and particularly in the Russian context;
no such studies exist to the best of our knowledge. Thus, the evidence of economic globalisation, technology access, renewable energy, fossil fuel consumption, and institutional quality’s impact on ecological footprint and carbon dioxide emission from Russia presents new novelty into the causality direction between these factors for policy and decision-makers in Russia and Europe as a whole.

This remainder of this paper is structured as follows. We provide a review of relevant extant works in the “Literature review” section. Details of the data, model specification, and approach are explained in the “Data and empirical technique” section. The “Result and interpretation” and “Conclusion and policy implications” sections provide details of the empirical estimations, discussions and conclusion, practical implications, and recommendations for policy, respectively.

Literature review

Much evidence exists in the literature on efforts to understand the economic globalisation-energy-consumption-environmental-consequence linkage. Ecological footprint and carbon emissions have been the focus of many of these examinations that have sought to discern this relationship (Bekun 2022; Akadırı et al. 2021; Ansari et al. 2020; Chen et al. 2018; Egbetokun et al. 2020; Ibrahiem 2020; Jebli et al. 2016; Karasoy and Akçay 2019; Liu et al. 2017; Munir and Ameer 2020; Shahbaz et al. 2017).

In a similar vein, other studies have equally investigated economic globalisation, population, renewable and non-renewable (fossil fuels) energy consumption and their link with environmental quality (Dong et al. 2018; Ibrahiem 2018; Islam et al. 2017; Sapkota and Bastola 2017; Zoundi 2017). Specifically, Xu et al. (2018), Haseeb et al. (2019), Phong (2019), and Salahuddin et al. (2019) sought to understand the role of economic globalisation and energy consumption on environmental degradation using CO2 emission as environmental quality determinant. However, it is argued that considering CO2 alone does not provide the complete reflection on the extent of environmental damage perceived from the factors of environmental quality, e.g. technology, renewable and non-renewable (fossil fuel) energy utilisation, and economic globalisation, among others (Aliola and Nwulu 2021; Phong 2019). In that singularly assessing CO2 emissions alone present part of the total environmental consequence from these indicators (Fakher 2019). Hence, ecological footprint presents a significant additional comprehension of the situation (Galli et al. 2016; Uddin et al. 2019). This argument has been behind the rise in studies employing ecological footprint as an antecedent of environmental quality. For instance, Al-Mulali et al. (2015) studied ecological footprint as a determinant of environmental quality by observing the effect of urbanisation, energy consumption, and trade. They found these factors to have negative consequences on environmental quality.

In addition, Ozturk et al. (2016) found energy consumption, urbanisation, and tourism income generation to increase ecological footprints. In a comparative analysis of socio-political indicators and ecological footprint, Charfeddine and Mrabet (2017) confirmed the validity of the EKC hypothesis among selected oil production countries. They observed urbanisation, fertility rate, energy consumption, technological development, and life expectancy rates negatively impact ecological footprint. Charfeddine (2017) also found financial development, demand for electricity, urbanisation, and trade openness (economic globalisation) decreased environmental quality. Some examinations from Asian country contexts suggest that most economic expansion indicators increase ecological footprint (Hassan et al. 2019). For instance, Uddin et al. (2019) found a quadratic relationship between ecological footprint and real income in Malaysia, India, Nepal, and Pakistan, while Hassan et al. (2019) confirmed a negative influence of natural resource use per capita on environmental quality.

It is noteworthy that some existing studies highlight positive and negative links between economic development indicators and environmental quality relative to CO2 emissions. For instance, evidence from high renewable energy-reliant countries suggest that financial development (via market capitalisation) accelerates growth in these countries that have made significant ecological transitions (Cheng et al. 2020). Considering institutional quality, FDI, and demand for energy, Khan et al. (2021) observed a negative effect on environmental quality using a GMM model between 2002 and 2019. Among MENA states, a positive and bidirectional causality is observed between renewable and non-renewable energy and economic expansion (Amri 2017; Kahia et al. 2017), while among European countries in the EU, Balsalobre-Lorente et al. (2018) concluded that renewable energies showed greater positive effect on environmental quality than non-renewable energies (like fossil fuel sources). Shahbaz et al. (2021) examined 34 upper middle income–emerging economies from 1994 to 2015 and pointed out the fact that financial development drives renewable energy consumption, while economic expansion reduces renewable energy consumption.

In retrospect, this finding indicates that reduced renewable energy consumption drives the consumption of unclean energies, which will increase carbon dioxide emissions. Lahiani et al. (2021) studied the role of renewable energy and technological and financial development in the USA and found that, in the short run, only negative effects are observed from financial development and renewable energy, while positive effects are observed in the long run. Renewable energy positively impacts environmental quality.
Recently Alola and Nwulu (2021) sought evidence from Russia on the role of income and economic freedom as environmental quality variables. They conclude that renewable energy sources in Russia have environmental quality benefits. Furthermore, Akadırı et al. (2021) used additional dimensions of economic freedom within the EKC framework to study environmental quality among BRICS bloc of nations, which Russia is a part. The EKC framework was valid in the long run only, and the impact of the blocs energy mix showed undesirable environmental effects.

Despite the existence of these studies indicating the positive impacts of these indicators of environmental quality, other evidence exists in some cases that these indicators increase environmental quality. Sinha et al.’s (Sinha et al. 2018a, 2018b) study on eleven countries showed that economic growth indicators negatively impact environmental degradation. They found that, due to direct investment, inflows and technological growth increased renewable energy and pollution intensified economic growth declines. Aimer (2020) observed a negative association between economic growth and environmental quality. Many other studies (Shittu et al. 2021; Adedoyin et al. 2020, 2021b, 2021c; Ali et al. 2020; Pao and Chen 2019; Sasana and Ghozali 2017) exist with similar conclusions of a negative link between economic development and CO2 emission.

A rare category of studies is also observed in this review, in that these studies are those that present a neutrality result, suggesting no linkage between environmental quality and its indicators. For instance, Adedoyin et al. (2020), Belaid and Youssef (2017), Destek and Aslan (2017), and Taghvaee et al. (2017), from Algeria, twelve developing economies, and Iran, respectively, all found no significant association between renewable energy, economic expansion, and environmental quality. Karhan (2019) examined the causality between economic growth indicators and renewable energy and underlines that the role of renewable energy is unstable.

In conclusion, this literature search presents sufficient evidence of significant studies on the role of environmental quality indicators. However, the plethora of inconsistent findings opens the debate that the role of environmental quality indicators is only nascently explored. This review showed three broad categories of observations. Thus, studies found positive associations, negative, and neutral or insignificant findings.

Therefore, to better discern the actual role of the indicators of environmental quality, it is evident that more explorations into this nexus is required, from different and new contexts, indicators, and approaches for a holistic understanding of the phenomenon (Tinta 2022). Environmental and quality ecological systems are a global challenge. Hence, the current evidence presented in this review only supports the fact that only a nascent portion of its scope has been explored, especially in newly industrialised countries like Russia. Russia’s economic prospects indicate a 2.4% growth in 2022 on the back of a solid oil sector. Its formidable macro-economic stabilisation efforts have supported this steady growth despite the COVID-19 crisis that has reduced its economic lots in certain areas. The negative effects from ongoing travel and trade restrictions, learning losses, and reduced migrant flows because of the global pandemic (COVID-19) require aggressive policy attention. Thus, faster economic recovery from the recent crisis will rely on efforts to promote economic diversification and complexity, attract investment inflows, increase economic governance, and reduce ecological footprint (Caglar et al. 2022).

However, achieving these fiscal objectives only presents greater threats to environmental quality through economic growth. Russia’s carbon intensity, for instance, is twice the global average, and it continues to rely massively on fossil fuel exports, suggesting that greater economic expansion will drive greater carbon intensity. However, Russia is committed to step up cooperation on climate change to improve environmental quality; thus, it is only necessary that experts and researchers alike take pre-emptive steps to facilitate the achievement of the goal of reduced environmental degradation in Russia. This makes this study’s context a best fit for an examination of this kind.

To this end, the current research attempts to contribute to the debate of environmental quality and economic expansion by extending existing works on the economic-indicators-environmental quality nexus from the Russian context. Thus, it examines the impact of technological development (access to technology), renewable energy, economic globalisation, fossil fuel use, institutional quality on ecological footprint, and CO2 emissions.

### Data and empirical technique

#### Data description and model

This study makes use of annual frequency time series data from 1970 to 2020 for the case of the Russian Federation. The outcome variables are CO2 emissions and ecological footprint, which serve as a proxy for environmental quality. To this end, the variables used for this analysis are renewable energy, access to technological innovation (ICT), fossil fuel (non-renewable energy), economic globalisation, and institutional quality on environmental quality (CO2 emissions and ecological footprint). The choice of the variables for the present study is in line with previous empirical literature. However, we distinct by holistically combining the variables which draws motivation from the UNSDGs such an energy variable (SDG-7), economic growth (SDG-8), and climate change mitigation (SDG-13). The definition of these variables, their value, symbol, and sources are in Table 1.
Table 1 Description of studied variables

| Variable                             | Symbol   | Description                                      | Source      |
|--------------------------------------|----------|--------------------------------------------------|-------------|
| CO₂ emission                         | CO₂      | CO₂ emission (metric tons per capita)            | BP          |
| Renewable energy                     | REC      | Renewable energy consumption (% of total final   | BP          |
| Ecological footprint                 | ECF      | Ecological footprint (%)                         | GFN         |
| Access to technological innovation   | ICT      | Access to technological innovation %             | WDI         |
| Fossil fuel                          | NREC     | Renewable energy consumption (% of total final   | BP          |
| Economic globalisation               | EG       | Economic globalisation                           | (Gygli et al. 2019) |
| Institution quality                  | INSQ     | Institution quality                              | WDI         |

Sources: Author’s compilation, 2022. Note GFN Global footprint network

The structure of the framework is for both long- and short-run association between the used variables. The uniqueness to this study is in the context of Russia’s economy as well as adding ICT, which has a huge impact on the ecological quality index to the existing literature (i.e., this differentiates this study from the existing studies). Therefore, the mathematical equation for the baseline models is fitted as shown in Equation (1) based on the previous work of Agboola et al. (2022), Appiah et al. (2022), and Kamel et al. (2022):

\[
\ln I = f (\ln \text{REC}_t, \ln \text{EG}_t, \ln \text{JOH}_t) = -2 \left[ \ln (\rho_{\text{EG}}) + (\rho_{\text{JOH}}) + (\rho_{\text{BO}}) + (\rho_{\text{BDM}}) \right] 
\]  

where \( I \) denotes the two ecological quality (CO₂ emissions and ecological footprint), while the other variables have been defined in Table 1 where all variables except institution quality are transformed to their natural logarithm.

**Econometric method**

The short- and long-term coefficients of the variables under consideration were estimated using the novel ARDL simulation model (Pesaran et al. 2001). This model can estimate their long- and short-term associations. It is necessary to run a stationarity test to determine the order of integration among variables before adopting the novel ARDL simulations approach. Considering this, we use Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) standard unit root tests. After determining the stationarity properties of all variables, we proceeded on to the estimation of linear cointegration. This study uses the Bayer and Hanck (2013) combined cointegration test to analyse long-term cointegration among variables. This technique incorporates several individual tests such as Engle and Granger (1987), Johansen (1991), Boswijk (1995), and Banerjee et al. (1998). The Fisher equation is written as follows:

\[
\text{EG} - \text{JOH} = 2 \left[ \ln (\rho_{\text{EG}}) + (\rho_{\text{JOH}}) \right] 
\]  

\( \rho_{\text{BDM}}, \rho_{\text{BO}}, \rho_{\text{JOH}}, \) and \( \rho_{\text{EG}} \) are the odds of diagnosing individual cointegration tests.

The ARDL bound testing (Pesaran et al. 2001) procedure is considered in this research to assess the robustness of Bayer and Hanck’s (2013) cointegration test. The ARDL bound testing technique can be implemented with the variables at different orders of integration either I(0) or I(1), in contrast to typical cointegration tests. This approach has the advantage of producing effective findings in investigations with small sample sizes. Furthermore, both short- and long-run coefficients can be computed at the same time. To determine ARDL bounds, the following model was created for the two models:

**Model 1**

\[
\Delta (\ln \text{CO}_2)_t = \theta_0 + \sum_{i=1}^{I} \theta_i \Delta \ln \text{CO}_2_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{REC}_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{ICT}_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{INSQ}_{t-i} 
\]  

**Model 2**

\[
\Delta (\ln \text{ECF})_t = \theta_0 + \sum_{i=1}^{I} \theta_i \Delta \ln \text{ECF}_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{REC}_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{ICT}_{t-i} + \sum_{i=1}^{I} \theta_i \Delta \ln \text{INSQ}_{t-i} 
\]
where $t$ denotes the lag length, $t-i$ is the optimal lags derived applying the Akaike information criteria (AIC), $u_t$ signifies the error term, $\Delta$ is the first difference operator, and the long-term association is examined by $\lambda$. In the bound testing strategy, a hypothesis test is necessary to formulate a long-run nexus among the variables under review. The null and alternative hypotheses are no cointegration ($H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$) and evidence of cointegration ($H_{alternative}: \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq 0$), respectively. In this approach, the derived $F$ statistics are compared to the lower and upper bound critical values. When the estimated $F$ statistics are less than the upper bound value, the null hypothesis is not refuted. The rejection of the null hypothesis occurred whenever the estimated $F$ statistics were greater than the upper bound critical value, suggesting that the variables have a long-term relationship (Abbas et al. 2021; Islam et al. 2017; Bekun et al 2021a).

**Result and interpretation**

This section focuses on the discussion of empirical outcomes and begins with a preliminary analysis of summary statistics and correlation coefficient analysis. Table 2 presents the basic measure of central tendency and dispersion of the variables under review, where we observe ICT that shows highest average and ecological footprint with least average over the investigated period. We also observed that there are both positive and negative skewed over the examined period. From the outcome, it is observed that $CO_2$ emission, ecological footprint, non-renewable energy, and institutional quality have positive skewness, while renewable energy, ICT, and economic globalisation have negative skewness. In terms of dataset peaks as reported by Kurtosis, all variables show light tails. The normality analysis test shows that all series are normally distributed, which is desirable as we

**Table 2 Basic statistics and correlation matrix analysis**

|       | CO2  | ECF  | REC  | NREC | ICT  | EG   | INSQ |
|-------|------|------|------|------|------|------|------|
| Mean  | 14.306 | -0.044 | 3.815 | 4.510 | 17.684 | 3.152 | 2.339 |
| Median| 14.299 | -0.100 | 3.871 | 4.509 | 18.622 | 3.214 | 2.380 |
| Maximum| 14.420 | 0.156 | 3.997 | 4.525 | 20.843 | 3.390 | 2.589 |
| Minimum| 14.217 | -0.198 | 3.583 | 4.494 | 11.24  | 2.749 | 2.230 |
| Std. dev. | 0.052 | 0.128 | 0.148 | 0.008 | 3.040  | 0.190 | 0.117 |
| Skewness | 0.370 | 0.396 | -0.375 | 0.391 | -0.620 | -1.014 | 0.667 |
| Kurtosis | 2.499 | 1.552 | 1.515 | 2.477 | 2.068  | 2.773 | 2.545 |
| Jarque-Bera | 0.734 | 2.496 | 2.539 | 0.813 | 2.204  | 3.820 | 1.825 |

**Table 3 Unit root test**

| Variable | ADF test | PP test | KPSS test |
|----------|----------|---------|-----------|
|          | Level    | Difference | Level    | Difference | Level | Difference |
| lnCO2    | -2.780  | -3.998b  | -3.372  | -4.018a  | -0.001 | 14.245a  |
| lnECF    | -1.577  | -4.315b  | -1.575  | -4.315b  | 0.008  | -0.239a  |
| lnREC    | -1.682  | -2.488a  | -1.954  | -2.515b  | -0.011 | 4.048a   |
| lnNREC   | -4.514  | -16.443a | -2.127  | -2.262b  | -0.001 | 4.519a   |
| lnICT    | -0.988  | -4.014a  | -0.988  | -4.025a  | 0.972a | 12.957a  |
| lnEG     | -1.391  | -5.010a  | -1.364  | -5.005a  | 0.060  | 2.970a   |
| INSQ     | -2.683  | -2.265a  | -3.204  | -3.212a  | 0.012  | 2.170a   |

*a, b, and c* represent statistical significance rejection level at 1%, 5%, and 10%, respectively. The critical values and probability of KPSS test are based on Kwiatkowski-Phillips-Schmidt-Shin (1992), where $a=1\%$ $b=5\%$ $c=10\%$ respectively.
fail to reject the Jarque-Bera probability. Subsequently, we seek to explore the pair-wise correlation between the study variables as highlighted at the bottom of Table 2. A strong statistically significant level ($p < 0.01$) is seen between renewable energy and CO$_2$. This suggests that renewable energy helps in improving environmental quality. A positive trend is obtained between the other variables (non-renewable energy, ICT, economic globalisation, and institution quality) and CO$_2$. However, there is a criticism of Pearson correlation analysis; thus, there is a need for more econometrics analysis, which is sorted in the next step of the section of the current study.

Subsequently, the current study advances by exploring the stationarity properties of the study variables by conducting the ADF and PP unit root test and confirmatory non-unit root test of KPSS, as presented in Table 3. Both stationarity tests and confirmatory tests of KPSS agree with stationarity after the first difference is performed. Thus, our study dataset passes the test of I–(1) and not I–(2). Thus, the need to examine long-run properties is crucial. Prior to investigation of cointegration analysis, we explore the lag length criterion to enable the best robust model, i.e. the most parsimonious model for this study is the lag one based on the Akaike information criterion (AIC), which is in line with the study structure as reported in Table 4. For long-run analysis, our study uses the novel Bayer and Hanck (2013) combined cointegration test alongside the ARDL bounds test presented in Tables 5 and 6, respectively, for the two models. Each test confirms the long-run equilibrium relationship between study variables over the investigated period for the two models.

The next step is the baseline regression presented in Table 7 that simultaneously highlighted the short- and long-run dynamics of the relationship between renewable energy, non-renewable energy, ICT, economic globalisation, and institutional quality on the two dependent variables (CO$_2$ emission and ecological footprint) for Russia. The pace of adjustment is captured by the error correction term (ECT). Its calculated value is statistically significant and negative, indicating that the variables under consideration have a long-term association. The ECT-projected value of model 1 is $-0.298$ which indicates $29.8\%$, and that of model 2 is $-0.820$, an indication that $82\%$ of the disequilibrium is rectified in the long run. From the baseline regression, both models 1 and 2 indicate that both renewable energy and economic globalisation have negative impact on the Russian environment for the long-run analysis, while the short run also confirms the same outcome. The only difference

| Lag | LogL | LR | FPE | AIC | SIC | HQ |
|-----|------|----|-----|-----|-----|-----|
| 0   | 212.211 | NA | 7.67e-18 | $-19.543$ | $-19.195$ | $-19.468$ |
| 1   | 355.625 | 177.560c | 1.27e-21c | $-28.535c$ | $-25.750c$ | $-27.931c$ |

Table 5 Results of ARDL bound test

| Level of significance | Lower bound I(0) | Upper bound I(1) | Long-run relationship |
|-----------------------|------------------|------------------|----------------------|
| F-statistics MODEL 1  |                  |                  |                      |
| 4.883                 | 10%              | 2.26             | 3.35                 | Present |
| 5%                    | 2.62             | 3.79             |                      |
| 2.5%                  | 2.96             | 4.18             |                      |
| 1%                    | 3.41             | 4.68             |                      |
| F-statistics MODEL 2  |                  |                  |                      |
| 4.818                 | 10%              | 2.26             | 3.35                 | Present |
| 5%                    | 2.62             | 3.79             |                      |
| 2.5%                  | 2.96             | 4.18             |                      |
| 1%                    | 3.41             | 4.68             |                      |

Table 6 Results of Bayer-Hanck (2013) cointegration test

| Estimated Model 1:  $\ln CO_2 = f(\ln REC, \ln NREC, \ln ICT, \ln EG, \ln SQ)$ |
| Fisher type | Test statistics | CV@1% | CV@5% | CV@10% | Decision |
|-------------|----------------|-------|-------|--------|----------|
| EG-JOH      | 32.866 $^a$    | 14.804| 9.223 | 8.040 | Cointegrated |
| EG-J-BO-BDM | 32.876 $^a$    | 23.025| 14.116| 11.647| Cointegrated |

| Estimated Model 2:  $\ln ECF = f(\ln REC, \ln NREC, \ln ICT, \ln EG, \ln SQ)$ |
| Fisher Type | Test Statistics | CV@1% | CV@5% | CV@10% | Decision |
|-------------|----------------|-------|-------|--------|----------|
| EG-JOH      | 23.806 $^a$    | 12.012| 8.412 | 6.234 | Cointegrated |
| EG-J-BO-BDM | 25.176 $^a$    | 17.567| 11.234| 8.567 | Cointegrated |

$^a$ indicates that the results are significant at the 1% level
between the findings of the two models with regard to renewable energy is the scale of the coefficients. This is in line with the theoretical assertion which posits that renewable energy sources such as wind, solar, and hydro power tend to reduce high emission and favour the environmental performance of any country. This supports the findings by Gyamfi et al. (2021a), Onifade et al. (2021), Agboola et al. (2022), Gyamfi (2022), and Steve et al. (2021). It is well-known that expanding green energy intake is a powerful force for improving the health of the atmosphere, and it is also worth emphasising that economic globalisation is projected to be a significant source of this trend within the uninvestigated Russian economy. Their short-run analysis also reveals that economic globalisation has positive insignificant relation with CO₂ emission, while with ecological footprint shows negative insignificance. For non-renewable energy, the short run presents a positive significance for both models, which is similar for the long-run analysis for the Russian environment as expected by the study based on the existing literature.

Moreover, institution quality has a favourable effect on the environment of Russia as it has positive impact on the environment. The present outcomes of this investigation add to the conclusions of other studies on the potential alleviating influence institution quality on carbon emissions in Russia (Bekun et al. 2021a; Godil et al. 2020; Gyamfi et al. 2021b; Gyamfi et al. 2022a). But the short run reveals that it has negative significance with CO2 emission but is positively insignificant with ecological footprint. In a nutshell, this finding argues for more focus on the critical roles of integrity, responsibility, and the combat against fraud in the government domain in order to achieve a desired and healthy ecology. To move for an ecologically responsible action plan while simultaneously increasing greener income, which can encourage clean energy consumption within the Russian economy, it would be necessary not only for economic globalisation to start happening, but also for a greater standard of institutional quality to be achieved.

Furthermore, there is a negatively significant connection between ICT and CO₂ emission. This implies that ICT is not only a source of environmental deterioration but also a significant contributor to pollution. Therefore, it is essential to mitigate its negative impact on the environment by promoting greener alternatives and ensuring better management of ICT use.

### Table 7: Findings of ARDL model

| Variables     | MODEL 1 | MODEL 2 |
|---------------|---------|---------|
| Cons.         | -7.242<sup>a</sup> | -0.813<sup>a</sup> |
| lnREC         | -0.883<sup>b</sup> | -0.555<sup>c</sup> |
| ΔlnREC        | -1.174<sup>b</sup> | -0.105<sup>c</sup> |
| lnNREC        | 3.931<sup>b</sup>  | 0.614<sup>c</sup> |
| ΔlnNREC       | 1.172    | 0.504<sup>c</sup> |
| lnICT         | -0.126<sup>a</sup> | 0.019<sup>c</sup> |
| ΔlnICT        | 0.087<sup>b</sup>  | 0.015<sup>c</sup> |
| lnEG          | -0.414<sup>a</sup> | -0.169<sup>a</sup> |
| ΔlnEG         | 0.113    | -0.040  |
| INSQ          | 0.229<sup>a</sup>  | 0.136<sup>a</sup> |
| ΔINSQ         | -0.068<sup>a</sup> | 0.111   |
| ECT(-1)       | -0.298<sup>b</sup> | -0.820<sup>b</sup> |

<sup>a</sup>, <sup>b</sup>, and <sup>c</sup> denote significance at 1%, 5%, and 10% level, respectively

### Table 8: Findings of FMOLS

| Variables     | MODEL 1 | MODEL 2 |
|---------------|---------|---------|
| lnREC         | -0.534<sup>b</sup> | -0.445<sup>c</sup> |
| lnNREC        | 0.746<sup>b</sup>  | 0.524<sup>c</sup> |
| lnICT         | -0.456<sup>a</sup> | 0.317<sup>c</sup> |
| lnEG          | -0.618<sup>a</sup> | -0.460<sup>a</sup> |
| INSQ          | 0.227<sup>a</sup>  | 0.331<sup>c</sup> |
| R²            | 0.667    | 0.38    |
| Adjusted R²   | 0.646    | 0.629   |

### Table 9: Residual diagnostic test

| Diagnostic test | Chi-square (P-value) | Findings                  |
|-----------------|----------------------|---------------------------|
| MODEL 1         |                      |                           |
| Breusch-Godfrey Serial Correlation LM | 0.429 | No serial correlations |
| Breusch-Pagan-Godfrey | 0.429 | No heteroscedasticity |
| ARCH test       | 0.296                | No heteroscedasticity    |
| Ramsey RESET test | 0.406 | Model correctly specified |
| MODEL 2         |                      |                           |
| Breusch-Godfrey Serial Correlation LM | 0.521 | No correlations          |
| Breusch-Pagan-Godfrey | 0.427 | No heteroscedasticity |
| ARCH test       | 0.493                | No heteroscedasticity    |
| Ramsey RESET test | 0.614 | Model correctly specified |
vital in decreasing environmental degradation for Russia with respect to CO₂ emission and is in line with Gyamfi et al. (2022b), Bekun et al. (2021b), Al-mulali et al. (2015), and Nguyen et al. (2020). This result suggests that, as duration progresses and the usage of mobile customers in Russia increases, the atmospheric integrity (CO₂) in this nation is deteriorating. As Zhang and Liu (2015) argue, a continual rise in the expansion of the ICT industry is favourably associated with the higher energy usage, which, in turn, results in increased carbon pollution. On the other hand, for model 2, it is observed that there is a positive connection regarding ICT and ecological footprint. This assumption can be supported by an understanding of the positive role played by the supply curve, which is strongly connected to the operations of cutting emissions, demobilisation, and digitalisation, among other things. The significant improvement in ICT in the Russian Federation increases in the operations of inherent commodities, such as e-banking, electronic mail, e-books, e-commerce, and mutually beneficial gatherings (conferences); decreases energy intake; and, as a result,
lessens air degradation. Initially, the positive alternative impact of reducing ecological footprint outweighed the impending negative impact of the expense and intake impact of reducing ecological footprint. Many academicians agree with this finding, recommending that the ICT-based displacement impact reduces pollution levels considerably by boosting energy savings and effectiveness, as well as stimulating technical growth and resource competency in their respective manufacturing industries (Apergis 2016; Dogan and Seker 2016; Özokcu and Özdemir 2017). However, the short-run connection reveals that both models have a positive connection with emissions.

Moreover, by utilizing fully modified ordinal least square (FMOLS) as robustness check in Table 8. It was observed that all the outcome are in line with the already ARDL technique used indication that, a percentage change in non-renewable energy and institutional quality positively increases both ecological footprint and CO₂ emission whereas renewable energy, ICT and economic globalization decreases both dependent variables in the long run.

Table 9 outlines the study diagnostic tests where all test satisfactorily pass all model tests, such as serial correlation, heteroscedasticity, and ARCH test and Ramsey model specification test. The stability of the fitted model is presented by the CUSUM and CUSUMsq plots that satisfactorily pass the 5% boundary, suggesting that the model is stable and fit for policy crafting (Figs. 3 and 4).

**Conclusion and policy implications**

The perpetual need for economic growth driven by energy consumption driven from fossil fuel has its implication on environment. This study focuses on the mitigating role of renewables and institutional quality for the case of the Russian Federation in a carbon-income environment with two fitted models on two key pollutants, namely carbon dioxide emission and ecological footprint. The current study leverages on novel combined Bayer and Hanck and Pesaran ARDL bound testing approach to explore the dynamic relationship between economic growth, economic globalisation, access to technological innovation, and the pertinent role of institutional quality. Empirical evidence traces equilibrium relationship between the study’s investigated variables, suggesting a long-run bond between the highlighted variables. Key findings from the study include the validation of the economic growth energy-induced emission for the Russian Federation. This suggest that energy mix in Russia stems from fossil fuel which is a root cause of emission levels, while increased anthropogenic human economic activities that are not green worsen environmental quality, as revealed by our study. To this end, from a policy perspective, there is urgent need for decision-makers in Russia to intensify policy strategies that decouple economic growth from emission increase. Strategies such as adoption of clean technologies will help achieve this position and the need for shift to cleaner energy alternatives for cleaner ecological and blue skies of Russia. Investments in renewable energy infrastructure and research and development (R&D) will foster sustainable economic growth without compromise for the quality of the environment. Feedback from interaction of access to technological innovation and institutional apparatus shows strong strength to improve the quality of the environment. Thus, government administrators are encouraged to tighten institutional apparatus in terms of environmental regulations to attain the adverse effect of weak institutional laws and strategies.

Authorities and environmentalists should use a phase-by-phase approach to solve their problems. As a starting point, the centralised government must make it simple for small- and medium-sized industrial enterprises to obtain financial resources, with the goal of encouraging them to use ICT-based outlines in their readily available production methods. At this time, the borrowing costs on funds loaned will vary depending on the amount of borrowed capital and the level of environmental damage caused by the economic firm. Organisations with high levels of ecological pollution will be compelled to pay a high rate of credit, while enterprises with low levels of carbon pollution will be obliged to pay a lower rate of return. As a result, this strategy approach will encourage cleaner and more contemporary businesses to expand their new innovative possibilities, while simultaneously discouraging polluting institutions from consuming non-renewable energy inputs.

The present study is limited by scope for the Russian Federation; thus, there is a need to explore the variables highlighted in this study for other economies using disaggregated data to either refute or agree with the current findings.

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**Data availability** The data for this present study are sourced from World Development Indicators (WDI) available at www.data.worldbank.org.
Declarations

Ethical approval The authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and gave consent for submission and subsequent publication of the manuscript.

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