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The Role of Sustainable Energy in Reducing Environmental Degradation in Algeria: An ARDL Bounds Testing Approach

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Abstract: Most of the framework agreements on climate change call for reducing the use of fossil fuels. This constitutes a significant challenge for energy-exporting countries in a manner that minimises the burden on their economies, which puts them before the inevitability of transitioning to sustainable energy solutions. The present study explores the long-term equilibrium relationship between sustainable energy (renewable energy and energy efficiency) and the ecological footprint. It also assesses the role of natural resource rents and energy subsidies as enhancers of environmental degradation and technological innovation as an enhancer of ecological quality. This is achieved by advancing sustainable energy solutions in Algeria using the Autoregressive Distributed Lag Model

(ARDL) from 1990 to 2020. Next, the experimental results indicate that despite the weak impact of renewable energies, their development can enhance environmental quality in Algeria in the long and short term. The generalised energy subsidies applied in Algeria have contributed significantly to environmental degradation in the long and short terms. In addition, technological innovation has yet to contribute to reducing environmental degradation or advancing sustainable energy solutions. Moreover, rents from natural resources and energy intensity positively impacted the ecological footprint in the short term. Finally, these results confirm that to ensure environmental sustainability, policymakers in Algeria must move towards sustainable energy projects based on green technology and cancel generalised energy subsidies to meet the increasing demand for energy related to development needs.

Keywords: Sustainable energy, environmental degradation, technological innovation, ARDL, Algeria.

Introduction

The world faces multiple challenges in the energy sector, including climate change, environmental degradation, and the depletion of fossil fuel resources. Consequently, there is an urgent need to transition towards sustainable energy development (Arulkumar et al., 2023). Sustainable energy development centres on fulfilling the current generation's energy needs without undermining future generations' ability to meet their own energy requirements. Global forecasts regarding energy consumption indicate a growing demand for energy, with fossil fuels projected to dominate the structure of energy demand until 2040 (OECD, 2014).

Human impact on the environment will increase and persist, alongside the risk of depleting energy reserves and the potential for accelerating climate change. Concerns regarding the continuity of the current energy policy have prompted a growing interest in sustainable development, as stable access to energy, particularly electricity, is deemed one of the foundational factors in establishing civilisations (Goldemberg & Lucon, 2009). However, it remains challenging to establish a clear and precise definition of developing a strategy for enhancing the energy sector within the sustainable development framework through documents, studies, and research. This issue is typically summarised in two aspects: developing renewable energy sources and implementing energy efficiency (Lemaire, 2004). Consequently, renewable energy and energy efficiency represent the “dual pillars” of sustainable energy policy according to the following equation (Oyedepo, 2012):

$$\text{Sustainable Energy (SE)} = \text{Renewable Energy (RE)} + \text{Energy Efficiency (EF)} \quad (1)$$

Additionally, this study focuses on testing the role of sustainable energy through the duality of renewable energies and energy efficiency in reconciling the requirements of economic growth and environmental preservation. There are important reasons for choosing Algeria as a case study. First, it is an energy country par excellence (single-income). One of its characteristics is the increasing rate of fossil energy consumption, not to mention the heavy reliance on fuel exports to achieve development. Next, it is the third-largest oil-producing African country and the 17th-largest oil producer globally. Thus, the volume of energy exports may significantly impact that country's environment in terms of ecological footprint¹. Furthermore, it is among the 25 countries globally that subsidise energy. Energy export revenues have been crucial in generating resources to finance growth and development. The country's exports from this sector represent about 90% of its total exports, about 30% of the total GDP, and about 60% of budget revenues.

With these facts in mind, Algeria has gradually included the environmental dimension in its economic development process. In 2011, it developed an ambitious program for developing renewable

¹The International Energy Agency (IEA). <https://www.iea.org>

energy and energy efficiency. The program will generate electricity for the national market in two phases.

Since Algeria is a rentier country (oil rents represent more than 10% of GDP, and more than 90% of total exports are energy exports), and it has high levels of fossil energy consumption due to population growth, our study is based on the hypothesis that rents from natural resources and energy subsidies increase energy consumption. The latter has a double impact: positive on growth and negative on the environment. The adverse effects on the environment will negatively affect growth, at least in the long term; thus, we enter a vicious circle. Sustainable energy policy must be adopted in parallel with technological innovation to break this cycle.

The sustainable energy variable was expressed by the consumption of renewable energy and fossil energy efficiency, and other variables were used, such as technological innovation, because of its positive impact on both renewable energy and energy efficiency. We used the variables of natural resource rent and fossil energy subsidy to know the actual effect of the use of fossil energy in Algeria on the environment, compared to the impact of technological innovation, renewable energies, and fossil energy efficiency.

Research Problem

Many studies on energy, environment, and resource economics have addressed the problem of exploitation, production, and distribution of natural resources and their effects on the environment in various regions of the world, regardless of their economic, geographical, or demographic characteristics. However, they have neglected limiting the analysis of the effects of sustainable energy on the environment using renewable energy without addressing the energy efficiency variable. This variable is essential to the sustainable energy equation (Oyedepo, 2012).

Therefore, compared to existing studies, our contribution is an attempt to analyse the role of factors causing environmental degradation in exploiting natural resources, especially in resource-rich developing countries, in light of adopting energy projects. Based on the variable of technological innovation, sustainable energy (renewable energy and energy efficiency) will lead to the development and modernisation of public policies to efficiently allocate resources. Notably, this is the first study to simultaneously measure the role of sustainable energy, natural resource rents, energy subsidies, and technological innovation on the ecological footprint in Algeria. Therefore, this study can contribute to directing future policies to achieve the goals of the United Nations for sustainable development represented by the seventh and thirteenth resolutions related to reducing climate change and clean energy. This aims to reduce emissions related to fossil fuel consumption, promote renewable energy use, and generalise measures to improve energy efficiency.

Research Aim and Research Questions

In this regard, testing the relationship between sustainable energy, economic growth, and the environment in Algeria represents a unique opportunity to determine how much the Renewable Energy and Energy Efficiency Programs of 2030 can achieve their set goals and clarify the importance of energy transition in Algeria by relying on sustainable energy.

Research Focus

In light of the above considerations, the study's primary interest is assessing and analysing the impact of sustainable energy on reducing environmental degradation in Algeria during 1990–2020. Additionally, it focuses on how much the technological innovation variable resolves the conflict between the negative impact of natural resource rents and energy subsidies on the environment. Consequently, the central questions of this study are:

1. Does sustainable energy reduce environmental degradation in Algeria by consuming renewable energies and adopting fossil energy efficiency measures?

2. How does technological innovation enhance environmental quality through the sustainable energy channel in Algeria?
3. What is the impact of natural resource rents and energy subsidies on the environment in Algeria?
4. Given the variables presented, what policies can be developed to enhance environmental quality in Algeria?

Literature Review

In this part of the study, we include studies that examine the relationships between sustainable energy, technological innovation, natural resource rents, and energy subsidies. We also include studies related to economic growth and the environment.

Renewable Energy and Environment

Renewable energy represents the focus of the sustainable development process in light of the Transforming Our World initiative (The 2030 Agenda for Sustainable Development) through a significant increase in the share of renewable energy in global energy sources by 2030². From this standpoint, adopting renewable energies has become an essential part of achieving sustainability (economic, social, and environmental) (Bei & Wang, 2023; Xie et al., 2023).

Among the studies that addressed the relationship of renewable energies to the environment within the framework of the growth hypothesis is Sulaiman et al. (2013). It examines the potential of renewable energy sources in reducing the impact of carbon emissions in Malaysia using the environmental Kuznets curve hypothesis (EKC) conducted during 1980–2009. It concluded that electricity production from renewable sources to CO₂ emissions has a unidirectional negative causality. In comparison, the findings of Suki et al. (2022) achieved the same results while using the ecological footprint. Next, Khan et al. (2020) indicated that renewable energy consumption improved environmental quality in the Nordic countries during 2001–2018. The same result was obtained in 31 transitioning economies (Omri & Belaïd, 2021).

Baek (2016) concluded that renewable energy consumption improved the environment's quality in the short term in the United States of America during 1960–2010. In contrast, Boudiaf (2023) found a long-term relationship between renewable energy consumption and the reduction of emissions in a group of high-income European countries during 1990–2020. Conversely, the effect of consuming renewable energies on reducing emissions is weak due to the weak use of renewable energies, as shown in the study by Chen and Lei (2018). Additionally, according to Saidi and Omri (2020), there is a bidirectional causal relationship between renewable energy and emissions in the short term in the 15 largest renewable-energy-consuming countries. Besides, institutional and economic factors significantly influence the development of renewable energies, unlike environmental factors, whose impact is weak Filimonova et al. (2021).

In recent years, the use of CO₂ emissions as a variable of environmental quality has been criticised for being incomprehensive because it did not consider the individual impact on the environment. Therefore, attention shifted to the ecological footprint as a better variable. In the study of Javed et al. (2023) in Italy during 1994–2019, renewable energy enhances environmental quality by reducing the ecological footprint. Similarly, Saqib et al. (2023b) concluded that integrating innovative technology and renewable energy reduces the environmental footprint in emerging economies and OECD countries. Conversely, for Appiah et al. (2023), improving the rate of renewable energy usage can mitigate harmful environmental impacts in the long term by reducing military spending in 15 countries participating in the (RCEP) agreement (Chang et al., 2023). Additionally, Saqib et al. (2023a) confirm the long-term

² United Nations Sustainable Development – <https://www.un.org/sustainabledevelopment>

balance of the relationship between renewable energies and the ecological footprint in the United States under the Kuznets curve hypothesis between 2005 and 2020.

Regarding Algeria, few studies have addressed the nature of the relationship between renewable energy and the environment at the national, regional, or continental level. Notably, most of these studies used CO₂ emissions as an environmental quality variable, and only a few studies applied the ecological footprint as an environmental indicator (Chekouri et al., 2023).

Most studies that dealt with this relationship in Algeria agreed that using renewable energies has a limited role in reducing environmental degradation because their exploitation has not yet reached the degree of economic and commercial use. Similarly, Elbadri et al. (2023) concluded that there is a hypothesis of conservatism between renewable energy and the environment. This is because using renewable energy has yet to reach a point where it can cause significant CO₂ emissions, which is also what Hassoun et al. (2018) found. In addition, Amri (2017) concluded that renewable energy has a negligible impact on improving the environment. Additionally, as Bélaïd and Youssef (2017) indicated, renewable electricity consumption can enhance environmental quality in Algeria. Nevertheless, so far, renewable electricity generation has not reached a level that allows a significant contribution to the goal of reducing CO₂ emissions. Notably, all recent studies have used emissions as an environmental indicator.

Among the studies that used the ecological footprint in Algeria to test the relationship between renewable energy and the environment (Adekoya et al., 2022). This study concluded that consuming renewable energies is vital for the environment in energy-importing countries rather than energy-exporting ones, where the environmental impact is weak due to the limited use of renewable energies and the widespread use of fossil fuels. Among the studies that dealt with the ecological footprint as an indicator of environmental degradation in Algeria, we mention the study of Rahmane et al. (2021). The study reveals a positive and significant regression relationship between renewable energy consumption and the ecological footprint. It also demonstrates the existence of a two-way causality from renewable energy consumption to the environmental footprint.

In short, the reviewed literature revealed that the results obtained regarding the relationship between renewable energy and the environment show variation in results and impacts depending on the economic, geographical, and institutional characteristics of the country under study. The main takeaway from these studies is that energy-exporting countries have yet to benefit from the interactions of this relationship, unlike energy-importing and high-income countries, which have made significant strides in using renewable energies within their energy mix.

Energy Efficiency and Environment

Improving energy efficiency generally refers to using less energy to produce the same amount of services or outputs. Since the global oil crisis in 1973, most countries have begun integrating energy efficiency policies into their energy strategy (Ang, 2006). Using energy efficiently is crucial to achieving sustainability (Madaleno & Nogueira, 2023). Energy efficiency can neutralise about 40% of the world's greenhouse gases by mitigating the effects of climate change while maintaining economic growth, a major global challenge (Chen et al., 2024). In recent years, most researchers and academics have recognised the importance of energy efficiency among the determinants of environmental performance (Singh et al., 2023).

The following are studies that addressed the impact of energy efficiency on growth and the environment. Ning et al. (2022) showed that bank financing through green bonds for energy efficiency projects enhances economic growth. Next, using the ARDL methodology, Balcilar et al. (2023) concluded that, in Turkey, there is a positive long and short-term relationship between energy intensity and investment in public-private partnerships in energy. In a recent study addressing 12 countries with the best energy security during 1990–2019, Alola et al. (2023) found that the increase in energy efficiency

(energy intensity), economic growth, and spending on research and development on renewable energy sources significantly contribute to the development of renewable energy.

Furthermore, Wenlong et al. (2022) studied 12 Asian economies to study the impact of energy efficiency, technological innovations, trade openness, and institutional quality on the environment. He found that both trade openness and institutional quality are harmful, while energy efficiency and technological innovations positively affect environmental quality. In addition, Liu et al. (2023) chose the case of southern European countries during 1990–2018. They used the AMG and CCEMG methodology to investigate the effects of energy productivity, growth, and globalisation on emissions. The results showed that energy productivity reduces CO₂ emissions while GDP and globalisation increase CO₂ emissions. Furthermore, any reductions in energy productivity will positively impact emissions.

Nikbakht et al. (2022) addressed TOBIT regression in Persian Gulf countries during 2000–2014 concerning the environmental and economic impact of energy efficiency in oil-producing countries. The results revealed that the GDP per capita, oil prices, degree of industrialisation, and population size had a direct relationship with energy efficiency. In contrast, the paper citation rate (as an indicator of science, technology, and innovation) and foreign direct investment had an inverse relationship with energy efficiency. Besides, the United Arab Emirates and Qatar recorded the best environmental performance through energy efficiency.

Regarding Algeria, its experience in adopting energy efficiency within its energy policy is small. The National Energy Efficiency Program was launched in 2011, aiming to save about 40% of energy by 2030. Therefore, it is early to discuss the economic and environmental role of energy efficiency policy in Algeria. Despite that, some studies dealt with this topic, such as Rahmane et al. (2021), which tried to determine the environmental impact of sustainable energy in Algeria from 1990 to 2017 using the ecological footprint and the DOLS methodology. The results showed the presence of unilateral causality from primary energy intensity towards the environmental footprint. In Traich and Rahmane (2023), the LMDI methodology was applied to deconstruct the factors driving the change in emissions in Algeria during 2000–2019. The results revealed that the energy intensity factor did not contribute to reducing emissions.

Technological Innovation and Environment

Regarding the relationship between technological innovation and the environment, the new growth theory reveals that technological change is essential to reduce environmental degradation, especially air pollution and climate change (Weitzman, 2017). Many studies have focused on this relationship by showing various reasons that enable us to understand the role of technological innovation in reducing environmental degradation. Namely, more energy-efficient production techniques and technology are used to control the use of renewable energies (De Bruyn, 1997). Moreover, Gyamfi et al. (2022) addressed BRICS countries from 1990 to 2019. He used AMG and CCEMG methodology to reveal the nature of the relationship between industrialisation, total reserves, foreign direct investment flows, technological innovation, renewable and natural resources, and CO₂ emissions. It was concluded that technological innovation and renewable energy reduce CO₂ emissions while industrial-added value, natural resources, foreign direct investment, and total reserves contribute to environmental degradation. Likewise, Doğan et al. (2022) found that ecological innovation supports environmental quality in the G7 countries. A study by Destek and Manga (2021) focused on this relationship in the framework of the environmental footprint. It examined the effects of technological and financial development and renewable and non-renewable energy consumption on the ecological footprint. It focused on emerging markets countries (BEM economies) from 1995 to 2016. The results indicate that technological innovation effectively reduces CO₂ emissions but has little impact on the ecological footprint.

In addition, the findings of Hamhami et al. (2020) showed that the intensity of regulation, technological policy, and market forces explains the variation in industrial pollution in Algeria. In

addition, the collected data showed that the technologies necessary for green growth in Algeria are mastered in 53% of cases in which technology transfer, research, and development have an essential role. In 75% of cases, regulatory incentives related to integrating technological change and environmental innovations are one of the main drivers for reducing ecological problems. Next, Bouarioua and Mohand (2023) showed the impact of technological development on the management of Algerian companies and its role in enhancing administrative practices. The research showed that Algerian companies have a very profound technological deficiency and that the Algerian environment does not meet the conditions necessary for a technological breakthrough.

In contrast, a recent study by Bergougui and Aldawsari (2024) aimed to understand the impact of patents related to green technology on the ecological footprint using economic growth and energy consumption. It had positive results on the crucial role of clean technologies in mitigating environmental damage in Algeria during 1990–2022.

Rent of Natural Resources and Environment

Natural resource rent includes all revenues from hard currency from nature, such as minerals, coal, natural gas, oil, and forests. It is calculated based on the difference between “the cost of producing the resource and the price of the resource in the global market” (Hussain et al., 2020). Exploiting and extracting natural materials is an energy-intensive process that can lead to significant energy consumption and chemical residues in the air, land, and water (Kwakwa et al., 2020). It results in considerable pressure on the environment, primarily if this activity represents a sole source of income. Therefore, countries’ dependence on natural resources as an essential source of income can negatively affect the environment. This effect happens because the depletion of natural resources, their extraction, processing, and mining leads to environmental degradation. It affects ecosystems by reducing environmental quality, causing air, water, and land pollution, desertification, soil destabilisation, landscape degradation, and climate change (Agboola et al., 2021). This is confirmed by Amer et al. (2022). Otherwise, natural resources can reduce the ecological footprint of a diversified high-income country, which was confirmed by Zafar et al. (2019) in the United States of America during 1970–2015. In addition, other results showed an inverted U-shaped EKC behaviour in ASEAN countries, thus, a negative relationship between tourism and natural resources with the ecological footprint. This indicates that tourism and natural resources help improve the quality of the environment in ASEAN countries (Kongbuamai et al., 2020). The same conclusion was drawn by Nathaniel and Adedoyin (2022) and Sun et al. (2022).

Regarding Algeria, some studies have addressed the nature of the relationship between natural resource rents and the environment, such as Aladejare (2022) and Chekouri et al. (2023). They unanimously agreed that the continuous depletion of natural resources significantly contributes to environmental degradation in Algeria.

Energy Subsidies and Environment

The energy subsidy policy of many countries has often failed to achieve its stated goal of driving the economic, social, and technological progress Hosan et al. (2023). It also discourages investment in renewable energies (Stiglitz et al., 2017). In most previous studies, energy subsidies were addressed concerning their relationship to energy transition and research, development, and innovation in energy technology, such as Solarin (2020) and Zhang and Chiu (2023).

Some findings also addressed the impact of energy subsidies on growth and the environment. For example, Gelan (2018) in Kuwait conducted an experiment simulating the application of a 30% reduction in subsidies to the electricity sector. The results revealed positive effects on GDP growth and a noticeable decrease in emission volume. Likewise, Al Iriani and Trabelsi (2016), who examined the impact of gradually reducing energy consumption subsidies in the Gulf Cooperation Council countries, found positive results on growth by urging investment in energy efficiency measures. In addition,

investment in energy efficiency technologies leads to a reduction in emissions. Besides, adopting a competitive pricing policy for energy products by removing price ceilings would redirect industries towards increased electricity use and capital and labour intensity.

Algeria's researchers have not studied the impact of energy subsidies on growth and the environment. Nevertheless, some studies have examined the impact of energy subsidies on investment in renewable energies, such as Matallah et al. (2023). The main findings confirmed that phasing out inefficient fossil fuel subsidies could significantly boost renewable energy development in Algeria in the short and long term.

Materials and Methods

Theoretical Model

The study focuses on the relationship between sustainable energy and the ecological footprint. Through its two basic components, energy efficiency and renewable energies, sustainable energy can have an important role in environmental quality because energy efficiency reduces environmental degradation (Chen et al., 2024; Singh et al., 2023). Renewable energies also improve environmental performance (Khan et al., 2020).

The literature mentioned above reveals that sustainable energy improves environmental quality and confirms the hypothesis that “sustainable energy reduces the ecological footprint.”

The energy subsidy variable largely contributes to environmental degradation via its direct and accelerating effect on the demand for fossil fuel energy (Gelan, 2018). This confirms the hypothesis that “energy subsidies increase environmental pollution.” Furthermore, the energy subsidy variable considerably contributes to environmental degradation via its direct and accelerating effect on the demand for fossil fuel energy. This verifies the hypothesis that “energy subsidies increase environmental pollution.”

There is a global consensus that creativity and technological development improve environmental quality (Wenlong et al., 2022). Sustainable energy depends primarily on creativity and technological development, which creates efficient technologies and devices (Alola et al., 2023) and develops technologies for renewable energies by reducing exploitation costs (Saqib et al., 2023a). In this case, it is possible to confirm the hypothesis that “creativity technology improves the quality of the environment.”

Countries rich in natural resources, especially energy-exporting countries (rentier or unilateral), depend on the returns from these resources to achieve economic growth (Yu, 2023). The continued depletion of these natural resources to meet their development needs may negatively impact the environment. Hence, the hypothesis can be put forward that “natural resource rent promotes environmental degradation.”

In light of the above experimental specifications, we can write the following equation to analyse the relationship between the study variables:

$$EF = f(REC, NRR, ITEC, ES, EI) \quad (2)$$

After taking the logarithm of the equation (2), we obtained the following model as shown in equation (3).

$$\ln ef_t = a_0 + \theta_1 \ln REC_t + \theta_2 NRR_t + \theta_3 \ln ES_t + \theta_4 \ln ITEC_t + \theta_5 \ln EI_t + \varepsilon \quad (3)$$

The various variables of the model are explained in Table 1.

The Autoregressive Distributed Lag (ARDL) Model

In this study, we use the annual time series data from 1990 to 2020 in Algeria, which is dictated by data availability. A summary of the variables used in the study is presented in Table 1, along with

information about their measurement and sources. This study uses the Ecological Footprint (EF) to express the environmental performance. The individual's ecological footprint was described using the global hectares footprint of each individual (GHA) as a unit and taken from the Global Footprint Network (GFN)³. In addition, our data set includes other variables that affect environmental quality, such as energy subsidies (ES) in billion dollars, which are calculated through the gap in local and global energy prices. Furthermore, we obtained data from the Algerian company for marketing energy products⁴, the Algerian Electricity and Gas Company⁵, the Platts platform for energy reference prices⁶, natural resource rents (NRR) (a percentage of GDP), and technological innovation (ITEC). These were expressed as the number of patents for residents and non-residents. Additionally, from the World Development Indicators (WDI)⁷, we acquired information for those variables and the energy intensity (EI) variable, expressed as energy consumption per 1,000 dollars of GDP at the current prices for 2015. Moreover, from the International Energy Agency, we took the renewable energy consumption variable (REC) in million tons of oil equivalent.

The empirical equation of the ARDL model for this study can be expressed as follows by equation (4):

$$\Delta \text{Ln } EF_t = a_0 + \theta_0 \text{Ln } EF_{t-1} + \theta_1 \text{Ln } REC_{t-1} + \theta_2 \text{NRR}_{t-1} + \theta_3 \text{Ln } ES_{t-1} + \theta_4 \text{Ln } ITEC_{t-1} + \theta_5 \text{Ln } EI_{t-1} + \sum_{i=1}^p \beta_0 \Delta \text{Ln } EF_{t-1} + \sum_{j=0}^{q_1} \beta_1 \Delta \text{Ln } REC_{t-j} + \sum_{j=0}^{q_2} \beta_2 \Delta \text{NRR}_{t-j} + \sum_{j=0}^{q_3} \beta_3 \Delta \text{Ln } ES_{t-j} + \sum_{j=0}^{q_4} \beta_4 \Delta \text{Ln } ITEC_{t-j} + \sum_{j=0}^{q_5} \beta_5 \Delta \text{Ln } EI_{t-j} + e_t \quad (4)$$

The model shows that the ecological footprint can be explained by its lagged values and the lagged values of the independent variables. The ARDL methodology relies mainly on testing the existence of cointegration. This depends on testing the following hypotheses:

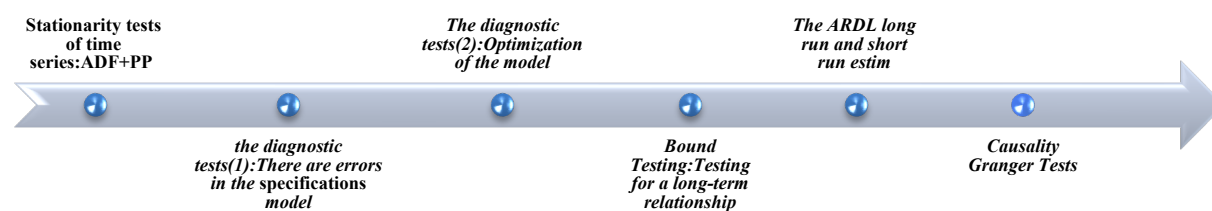
$$\left\{ \begin{array}{l} H_0 : \theta_0 = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0 \\ H_1 : \theta_0 \neq \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq 0 \end{array} \right. \quad (5)$$

Where Δ is a difference operator; a_0 is the constant term; $\theta_0, \theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ are the long-run coefficients; $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the short-run coefficients; e_t is the error term; and EF, REC, NRR, ES, ITEC, and EI are the variables defined previously.

The steps of this methodology are summarised in Figure 3 as follows:

Figure 3

Steps of the Study's Methodological Approach



Data Analysis

In this study, we use the annual time series data from 1990 to 2020 in Algeria, which is dictated by data availability. A summary of the variables used in the study is presented in Table 1, along with information about their measurement and sources. This study uses the Ecological Footprint (EF) to

³ Global Footprint Network – <https://www.footprintnetwork.org/>

⁴ Naftal – <https://www.naftal.dz/fr>

⁵ Sonelgaz – <https://www.sonelgaz.dz/fr>

⁶ Platts Price Benchmarks – <https://commodityinsights.spglobal.com/pricebenchmarks>

⁷ World Development Indicators – <https://databank.worldbank.org/source/world-development-indicators>

express the environmental performance. The individual's ecological footprint was described using the global hectares footprint of each individual (GHA) as a unit and taken from the (GFN, 2023). In addition, our data set includes other variables that affect environmental quality, such as energy subsidies (ES) in billion dollars, which are calculated through the gap in local and global energy prices. Furthermore, we obtained data from the Algerian company for marketing energy products (Naftal, 2023), the Algerian Electricity and Gas Company, the PLLATS platform for energy reference prices, natural resource rents (NRR) (a percentage of GDP), and technological innovation (ITEC). These were expressed as the number of patents for residents and non-residents. Additionally, from the World Development Indicators (WDI), we acquired information for those variables and the energy intensity (EI) variable, expressed as energy consumption per 1,000 dollars of GDP at the current prices for 2015. Moreover, from the International Energy Agency, we took the renewable energy consumption variable (REC) in million tons of oil equivalent.

Table 1

Variable Descriptions

Variables	Symbol	Description	Source
Environmental Quality	EF	An indicator of the extent of human impact on natural resources and land and water ecosystems, measured in global hectares per person.	GFN
Energy Subsidies	ES	Any government action that lowers the cost of energy production is calculated by measuring the gap between the local and reference prices for each energy product. It is billions of US dollars.	NAFTAL, PLLATS
Technological Innovation	ITEC	Number of Patents applications (resident + nonresident)	WDI
Renewable Energy Consumption	REC	Renewable energy consumption (% of total final energy)	WDI
Total Natural Resources Rents	NRR	The sum of oil rents, natural gas rents, coal rents, mineral rents, and forest rents as a percentage of GDP	WDI
Energy Intensity	EI	The amount of energy required per unit of production or activity. Measured by: MTOE (Final Energy) per 1000\$ (constant 2015 \$)	IEA, WDI

Note. GFN: Global Footprint Network, WDI: World Development Indicators, IEA: International Energy Agency, NAFTAL: Algerian Energy Products Marketing Company, PLATTS: Energy Reference Price Platform.

Source: Author's searching.

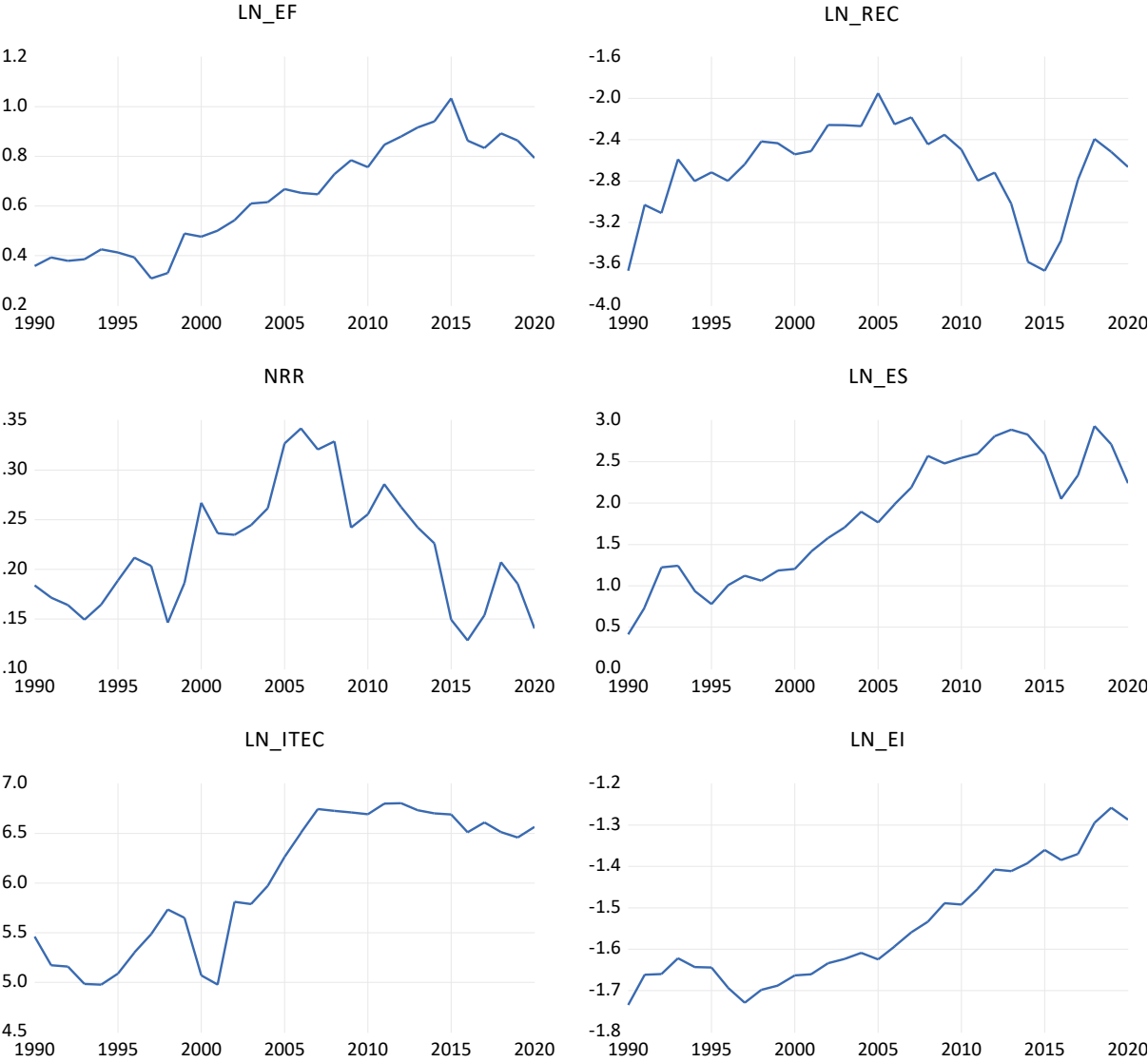
Figure 2 shows the evolution of the behaviour of both sustainable energy variables (renewable energy consumption and energy intensity) and the environmental performance variable, expressed as the ecological footprint, during 1990–2020. We notice a steady increase in energy intensity starting in 1990 from 0.17 million tons of oil equivalent per 1000 dollars to levels exceeding 0.27 million tons of oil equivalent per 1000 dollars, indicating a significant deterioration in fossil fuel energy use. In addition, we note the weakness of using renewable energy because it reached a maximum value in 2005 at 0.14 million tons of oil equivalent, equivalent to 0.18% of the final total energy consumption. This will put tremendous pressure on the environment, especially in light of Algeria's heavy reliance on fossil fuel energy, as the per capita ecological footprint increased from 1.43 in 1990 to 2.21 in 2020.

Contrarily, the number of patents for residents and non-residents defined the technological innovation variable. The figure displayed a remarkable development in 2007, reaching 849 patents after 200 and less than 500 during 1990–2006, an essential indicator of Algeria's interest in scientific research. Additionally, Algeria occupies advanced ranks among the countries that provide significant

fossil fuel energy subsidies, as the subsidy increased from \$1.51 billion in 1990 to \$18.53 billion in 2018, then decreased to \$9 billion in 2020. This will encourage a steady increase in fuel energy consumption. Moreover, environmental pressures may be driven by natural resource rents. Given that Algeria relies primarily on exploiting its energy resources to finance the wheel of development, it reached 48% of output in 1990, then decreased to 27% in 2020. This decline is due to the fluctuations and shocks the energy market experienced over the study period.

Figure 2

Graphical Representations of the Main Variables



Results

Stationarity Tests of Time Series

The tests were carried out both at the level and first differences. Table 2 displays the outcomes of the ADF (Augmented Dickey-Fuller test) and PP (Phillips and Perron test) unit root tests (Dickey & Fuller, 1979; Phillips & Perron, 1988). The findings in Table 2 suggest that based on the ADF and PP unit root tests, the variables (Ln EF, NRR, Ln REC, Ln ES, Ln EI, and Ln-ITEC) exhibit non-stationarity at the levels but become stationary after the first difference.

Table 2*Unit Root Tests*

Variables	Dickey and Fuller (PP)		Phillips and Perron (ADF)	
	At level	At first difference	At level	At first difference
Ln EF	-1.62	-5.36*	-1.66	-4.53*
Ln NRR	-1.13	-7.63*	-1.34	-4.18**
Ln REC	-2.76	-5.20*	-2.07	-5.14*
Ln ES	-1.95	-3.87**	-0.90	-6.05*
Ln EI	-1.52	-5.80*	-1.91	-3.95**
Ln ITEC	-2.07	-4.78**	-1.88	-4.23*

Note. * and ** show significance at the 1%, 5% level respectively.

The Diagnostic Tests**Table 3***Results of the Diagnostic Tests*

Breusch-Godfrey LM	lags(p)	Prob	Description
	1	0.3791	No problem with serial correlations
	2	0.6559	No problem with serial correlations
Skewness/kurtosis tests for normality		0.4102	Residuals are normally distributed
Ramsey RESET test		0.0477	There are errors in the specifications model
ARCH LM test		0.8195	There is no problem with heteroskedasticity

The results of the diagnostic tests for the estimated ARDL model are shown in Table 5. The Breusch-Godfrey LM and ARCH-LM tests indicate the absence of serial correlation problems and heteroscedasticity, respectively. The normal distribution tests in Table 3 reveal that the residuals follow a normal distribution, which is not reassuring, given the values of skewness and kurtosis, which are slightly away from (0 and 3), respectively. The natural law is characterised by symmetry concerning the average and low probability of outliers, which may be attributed to the presence of outliers (Gujarati & Porter, 2009).

Next, the Ramsey RESET test indicates the possibility of an error in describing the model, as the F-statistic is significant at (0.05). These are not all the reasons leading to errors in the study model's description; however, the residuals concern us most. We had expressed our discomfort with the result that proved that the residuals follow a normal distribution because the study sample is not very large, in addition to the relative abundance of relationships between the dependent variable and the rest of the variables. Considering these data and results and the importance of the residuals as a significant diagnostic tool, they are used to discover standard problems and model specification errors. If there is one of these errors, the histogram of the residuals will have a specific pattern (Gujarati & Porter, 2009), which is what Figure 4 shows. From the figure, significant changes occurred in the data during (2009–2012) that the model could not capture, which can be confirmed because of the deviation of the two curves from each other in the same period. This situation suggests the possibility of the presence of anomalous points. The remaining box plot in Figure 5 shows that it contains anomalous points, which may be due to a structural change in the data initially caused by a shock in one year.

Figure 4

Graph of Residues

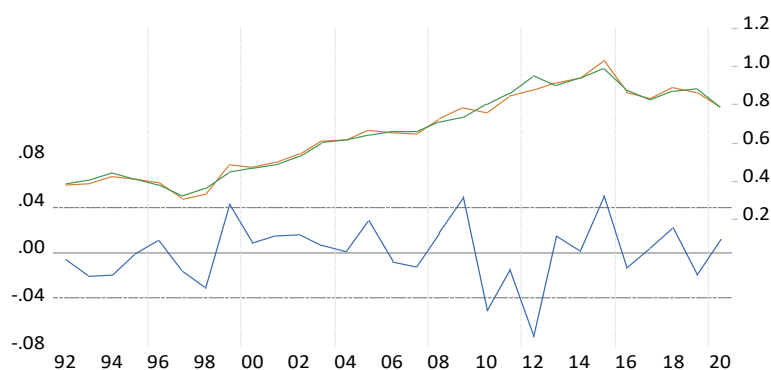
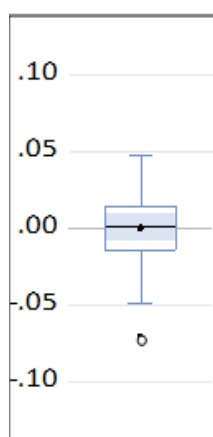


Figure 5

Box-Plox of Residues



We will now process the information until we obtain a model that can understand the behaviour of structural changes, including the ability to capture the impact resulting from the shock so as not to lose its information. We will resort to adding explanatory variables, which are dummy variables. Among the conditions for including the explanatory variable is their significance within the estimated model, and their addition contributes to improving the estimated model. From the estimation results, it is clear that there are two significant variables: D_{2009} , D_{2012} , as in Table 4.

Table 4

Results of the Dummy Variables

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
D_{2009}	0.119721**	0.048431	2.471996	0.033
D_{2010}	-0.095241***	0.047915	-1.987704	0.0702
D_{2011}	-0.022887	0.050184	-0.45606	0.6565
D_{2012}	-0.197629*	0.04103	-4.816687	0.0005

Note. *, **, and *** show significance at the 1%, 5% and 10% level respectively.

When only (D_{2009} and D_{2012}), (D_{2012}) were added to the model, the model cannot be improved. In the first case, the Breusch-Godfrey LM test showed the presence of a serial correlation problem, as ($LM=6.5115$ and $P = 0.0386$). However, in the second case, the residuals did not follow the normal distribution ($JB = 6.53$ and $P = 0.038$), while the model improved in general and was firm when adding the variable D_{2009} . Only the diagnostic results of the new model showed the absence of model characterisation error, which was present before treatment, as shown in Table 3. The suitability of the variable D_{2009} to the model is consistent with two essential elements. The first is the international

events in 2009 when oil prices fell from 147 to 30 between 2008 and 2009 (Khan, 2017). The second is the nature and characteristics of the Algerian economy, which is considered a rentier economy that depends absolutely on oil revenues. Consequently, these external changes affected internal balances, which led to a shock that led to a structural change in the Algerian economy in general and in the study data in particular in 2009.

Table 5

Results of the Diagnostic Tests

Breusch-Godfrey LM	lags(p)	Prob	Description
	1	0.4536	No problem with serial correlations
	2	0.6365	No problem with serial correlations
Skewness/kurtosis tests for normality		0.6524	Residuals are normally distributed
Ramsey RESET test		0.5515	The Model has no omitted variables
ARCH LM test		0.8281	There is no problem with heteroskedasticity

Bound Testing

Bound Testing was used to examine the existence of a long-term equilibrium relationship between variables (Pesaran et al., 2001). Conducting this test with dummy variables only depends on the F-statistic. The test results showed that the calculated value is greater than the lower limits of the critical values, which suggests a long-term equilibrium relationship, according to Table 6.

Table 6

Bounds Test

Null hypothesis:	No levels relationship					
	10%		5%		1%	
F-statistic	5.021799					
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Sample Size						
Asymptotic	2.407	3.517	2.91	4.193	4.134	5.761
n= 30	2.080	3.000	2.390	3.380	3.060	4.150

Note. I(0) is the lower band critical values; I(1) is the upper band critical values.

Results

The results of the bounds test are shown in Table 6. Fisher's statistic indicates the rejection of the null hypothesis at all levels, confirming long-term relationships between the ecological footprint and the explanatory variables. Table 7 shows the long-run and short-run estimates of the ARDL model. The error correction model, which shows the short-run model estimation results, was estimated based on the Akaike criterion to determine the optimal delays. The estimated error correction coefficient $(ECT)_{t-1}$ appears negative and statistically significant at the 1%. Its value (-0.444379) indicates that the speed of adjustment to restore long-run equilibrium will be corrected by 45% in one year. . Therefore, the return to equilibrium position requires two years and three months. In addition, Figure 6 reveals that both the CUSUM and off-squares CUSUM tests are within the critical limits at the 5% significance level. This level confirms that the long-run relationships are reliable and that the estimated coefficients of the error correction model are stable over the studied period. Accordingly, the model, in general, explains environmental performance. All variables had a significant impact in the short term, and both renewable energy consumption and energy subsidies had a substantial effect of 10% in the long term.

Table 7

Results of Long-Run and Short-Run Estimates

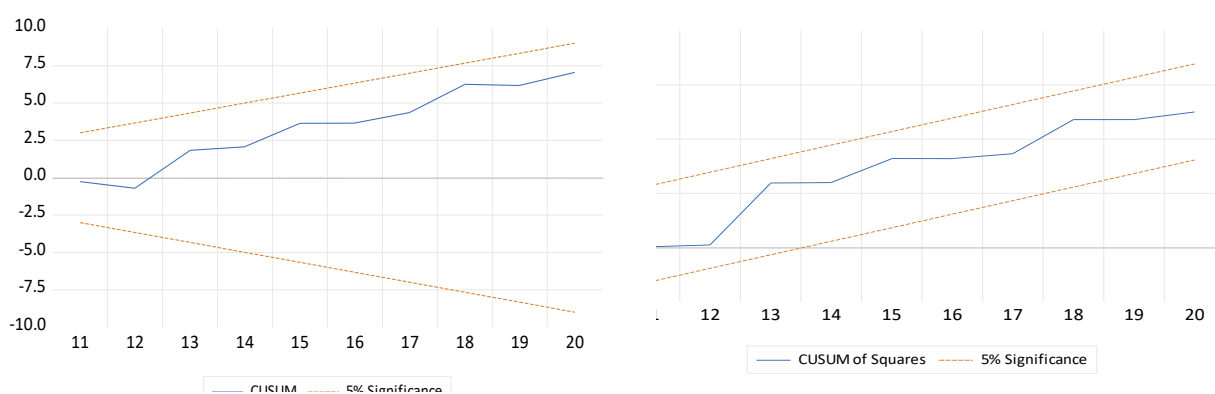
Model	$EF = f(REC, NRR, ES, ITEC, EI)$	
	Coef	S.E.
Long-run estimates		
Ln REC _{t-1}	-0.139328***	0.077401
NRR _{t-1}	-2.430726	2.402597
Ln ES _{t-1}	0.765747***	0.414226
Ln ITEC _{t-1}	-0.127048	0.138099
Ln EI _{t-1}	-2.127697	1.891536
Short-run estimates		
Ln EF _{t-1}	-0.452224*	0.117236
Ln REC	-0.083234*	0.021532
Ln REC _{t-1}	-0.073322*	0.023414
NRR	0.542220**	0.187786
NRR _{t-1}	0.902789*	0.201570
Ln ES	0.137299*	0.029144
Ln ES _{t-1}	-0.155898*	0.035827
Ln ITEC	0.070590*	0.023775
Ln ITEC _{t-1}	0.104428*	0.023729
Ln EI	0.585536**	0.212623
Ln EI _{t-1}	1.902381*	0.281294
ECT _{t-1}	-0.444379	0.055333

ARDL Model (2 ;2 ;2 ;2 ;2)

Note. *, **, and *** show significance at the 1%, 5% and 10% level respectively.

Figure 6

CUSUM and CUSUM of Squares Test.



Results of Causality Granger Tests

Table 8

Granger Results

Direction of causality	Prob.	F-Statistic
ES→EF	0.0057	9.02514*
REC→EF	0.0121	7.23352**
REC→NRR	0.0022	11.4304*
ES→REC	0.0396	4.67857**
EI→REC	0.0764	3.39499***
NRR→ES	0.0932	3.02889***
NRR→ITEC	0.0452	4.41166**
ITEC→ES	0.0085	8.06896*
ITEC→EI	0.0238	5.73515**

Note. *, **, and *** represent 10%, 5%, and 1% significance level, respectively.

The ARDL-associated testing technique results showed a long-term equilibrium relationship between the ecological footprint, renewable energy consumption, and energy subsidies. However, unidirectional causality is also required when applying the ARDL model, although it is not evident in band testing (Shahid et al., 2024). The numerical results of the Granger causality analysis show that at the significance levels of 10%, 5%, and 1%, respectively, both energy subsidies and renewable energy consumption cause an ecological footprint. Therefore, there is a unidirectional causality between the variables, which complies with the results of the requirements for using the ARDL model. It is worth noting that there is a unidirectional causal relationship between technological innovation energy intensity and energy subsidy. This confirms that technology causes efficient energy use in Algeria, which will impact the ecological footprint.

Discussion

The estimation results indicate that renewable energy consumption (REC) negatively and weakly affects the ecological footprint (EF) in Algeria, which confirms what was reported by Ansari et al. (2021) and Bozatli and Akca (2023). A 1% increase in renewable energy consumption one year later leads to a decrease in ecological footprint by 0.13% on average in the long-term and by 0.07% on average in the short-term. To explain, the continuous investment and expansion in renewable energy projects in Algeria encourage the reduction of excessive consumption of fossil fuels. Consequently, toxic emissions that cause climate change are decreased, and the use of depleted energy resources is decreased by reducing local demand and directing it to export to benefit hard currency revenues reinvested in sustainable energy projects. Therefore, renewable energy can effectively reduce environmental degradation in Algeria in the long and short term.

Additionally, these outcomes explain that the weak relationship between renewable energy and the ecological footprint is caused by Algeria's short experience in exploiting renewable energy, as it has not reached the commercial scale yet. Moreover, according to the National Renewable Energy Program, during its first phase, 2015–2020, it was expected to achieve an installed capacity of 4525 megawatts of renewable electrical energy. However, what was achieved in this phase was 686 megawatts. It is also possible that the weak effect of renewable energies in reducing the ecological footprint in Algeria is due to the absence of the impact of the technological innovation variable in influencing the development of renewable energies. Previous experimental results have proven that the effect of green technological innovation on renewable energy production is significantly positive (Solarin et al., 2022).

In contrast, the results of estimating the model in the short term indicate that technological innovation directly affects the ecological footprint. When technological innovation increases by 1%, it leads to environmental degradation by raising the ecological footprint by 0.1044% on average. This result was in line with the findings of Kihombo et al. (2021).

However, the result contradicted the findings of Raza et al. (2023), which indicate a long-term balanced relationship between renewable energy and technological innovation on the ecological footprint with a negative impact. This result can be explained by saying that the variable of technological innovation in Algeria has not yet developed green energy technologies to advance sustainable energy solutions, such as solar panel technology, energy storage technologies, smart grid technology, and transportation electrification. Spending on research and development in 2017 in Algeria reached 0.53% of output. It is five times far from the global average of 2.31%. The number of research published globally in applied and basic sciences in 2020 reached 5689, equivalent to 0.19% of research published globally, which is a very weak percentage. This is also reflected in the weakness of high-tech exports, which amounted to 0.96. % of the total goods exported in 2017 is \$9 million.

In the short term, the ecological footprint variable is directly affected by the energy intensity variable in Algeria. A 1% increase in energy intensity leads to an increase in the ecological footprint by 1.9% on average in the short term in Algeria, which confirms that the deterioration of energy efficiency negatively affects the environment through an increase in its intensity index. Algeria's high energy intensity index can explain this outcome due to the increasing demand for the local consumption of fossil fuel energy compared to the low economic growth rate. The production of one unit of output requires the consumption of additional energy from year to year, which increases emissions. This may directly affect the reduction of environmental quality. Therefore, energy efficiency is essential in enhancing the ecological footprint, as Khan et al. (2022) concluded. In addition, the energy efficiency program launched by Algeria in 2011 did not give tangible results in reducing CO₂ emissions driven by the increase in fossil fuel energy consumption. The effect of energy intensity contributed to 18.6 million tons of CO₂ emissions, or 24.8% of the total change in emissions between 2000 and 2019 (Traich & Rahmane, 2023).

Previous experimental studies also indicate that improving energy efficiency negatively influences the ecological footprint and improves environmental quality (Deka et al., 2023). The deterioration of energy efficiency can be attributed to technological innovation. Improving energy efficiency depends primarily on research and development through energy-saving devices and smart home systems significantly reducing electricity use. This reduction leads to saving costs and reducing the ecological footprint, which Yao et al. (2021) reached. Moreover, although technological innovations work to improve energy efficiency and reduce the environmental footprint, we find that technological innovation did not contribute to the positive impact of energy efficiency on the ecological footprint in Algeria. The results of the causality test in Table 8 confirm this.

The model estimation results in the short-term explain that natural resource rents directly affect the ecological footprint. A 1% increase in the rent of natural resources leads to an average increase in the environmental footprint by 0.9%. To explain, the rent of natural resources significantly contributes to financing development and moving sectors outside of hydrocarbons in Algeria, as it is primarily a rentier state, and the source of the rent is fossil energy. It is possible to obtain more rents driven by the pressures of financing development, leading to more depletion of these natural resources and more emissions that cause climate change. This negatively impacts air, water, and ecological diversity. This result is in line with the studies of Ahmad et al. (2020) and Ullah et al. (2021), who concluded that rising natural resource rents led to an increase in the ecological footprint. However, it contradicts the findings of Li et al. (2023), who indicate that natural resource rents improve the environmental quality of the USA and high and middle-income countries.

Energy subsidies (ES) have a significant positive impact on the ecological footprint (EF) in Algeria, validating the report of Iyke-Ofoedu et al. (2023). Increasing energy subsidies in Algeria by 1% raises the environmental footprint by 0.76% on average in the long term and 0.13% on average in the short term. To clarify, continuing inefficient fossil fuel subsidies encourages excessive fossil fuel consumption. Traich and Rahmane (2024) verified this and discovered that subsidising fossil fuels caused an increase in energy consumption by 3.72 million tons of oil equivalent in the residential sector in Algeria from 2000-2020. Therefore, subsidising fossil fuels is essential in increasing the ecological footprint and environmental degradation in Algeria in the long and short terms.

Overall, the previous results confirm the importance of sustainable energy in reducing environmental degradation in Algeria, mainly if the technological innovation variable drives it. This is due to its vital impact in advancing sustainable energy solutions through developing new technologies for generating energy from renewable sources, improving energy use efficiency, developing technologies for storing them and managing intelligent networks for distribution. However, there is a weak environment for scientific research and technological development in Algeria, a weak budget for scientific research, and a lack of coordination and cooperation between research centres, universities, and the economic and social institutions of the state. This weakness has been reflected in the meagre scientific outcome of Algeria at the global level, such as the lack of scientific publications and patents registered by researchers, besides their quality, through the small number of citations. Hence, the Algerian state's interest in sustainable energy has reduced environmental degradation but has had a weak impact.

2011, Algeria launched a very ambitious program for renewable energies and energy efficiency. It was expected to generate 22,000 megawatts by 2030 and 4525 megawatts of renewable electrical energy in 2015–2020. Contrarily, only 686 megawatts were achieved, which is about 15%. Additionally, the energy efficiency program did not reduce environmental degradation in Algeria, as evidenced by the variable of energy intensity, which directly impacted the ecological footprint. The program's goal was to provide 63 million tons of oil equivalent from fossil fuel energy by 2030, and the results obtained by evaluating the energy policy in Algeria from 2000–2019 confirmed this. Energy intensity increased fossil fuel energy consumption by 14.61%. A value of 12.83 million tons of oil was wasted, equivalent to 40% of the wasted energy that could have been saved if energy intensity had remained constant at the values of the base year 2000. Concerning the rents of natural resources and their negative impact on the environment in Algeria, they constitute the primary source of revenues and represent more than 90% of total exports.

The main challenge currently when exploiting natural resources in Algeria is reconciling development needs without compromising the quality of the environment. Another challenge is the continuous depletion of these resources, mainly because they are characterised by depletion to meet the increasing domestic demand. This continuity will reduce their export revenues, leading to pressures on financing development. By comparison, increasing the rate of their depletion will lead to mortgaging the rights of subsequent generations in addition to environmental pressures. Furthermore, most researchers, such as Matallah et al. (2023), have agreed that ineffective subsidy for fossil fuel energy in Algeria weakens the transition towards environmentally friendly energy. It encourages wasteful consumption of fossil fuels, attracts companies to industries based on fossil fuels, and makes renewable energy projects uncompetitive.

Limitations of the Study

The study on the role of sustainable energy in reducing environmental degradation in Algeria, using an ARDL approach, faces several limitations that impact its generalizability and practical relevance. Data constraints, such as a limited time frame, potential gaps in data availability, and reliance on aggregated national-level data, may obscure critical regional or sectoral variations. Methodological limitations include the assumptions of the ARDL model, potential endogeneity issues, and the exclusion

of key variables like political stability, urbanisation, and international trade, which can significantly influence environmental outcomes. Contextual challenges stem from Algeria's unique economic and political environment, its limited experience with renewable energy, and persistent obstacles in policy implementation and technological innovation. These factors, coupled with the gap between the country's ambitious renewable energy targets and actual achievements—often due to bureaucratic inefficiencies, funding shortages, and insufficient political will—further limit the applicability of the findings to other contexts. To address these limitations, future research should incorporate a broader range of variables, extend the temporal scope for longitudinal analyses, and explore regional or sectoral dimensions. Comparative studies across countries with diverse energy policies and technological capabilities could also provide deeper insights into the interplay between sustainable energy, innovation, and environmental degradation, enhancing the robustness and applicability of the findings.

Conclusions and Implications

Countries that rely on rents from natural resources to finance their development needs and provide ineffective energy subsidies, which often suffer from pressures and adverse environmental effects. Promoting sustainable energy based on technological innovation is among the effective solutions for reducing environmental degradation. The continuous negative pressures left by the depletion of natural resources and generalised energy subsidies on the environment through greater consumption of fossil fuels result in more emissions. These emissions enhance climate change, which leads to the erosion and deterioration of environmental and biological diversity systems. The adverse effects of these factors on the environment can be reduced by adopting renewable energy and energy efficiency based on technological innovation.

Using an autoregressive distributed lag model (ARDL), this study analysed the long-term effects of sustainable energy variables (renewable energy and energy efficiency) on reducing environmental degradation in Algeria from 1990 to 2020. Simultaneously, it evaluated the roles of natural resource rents and energy subsidies as factors promoting environmental degradation and technological innovation as an enhancer of environmental quality by advancing sustainable energy solutions.

The results support long-term relationships between renewable energy-reducing environmental degradation and energy subsidies promoting ecological degradation. The energy intensity variable promoted environmental degradation in the short term, while the technological innovation variable also enhanced the environmental degradation variable in the short term. These results confirm that technological innovation has not been able to advance sustainable energy solutions in Algeria. Therefore, reducing the ecological footprint decreases environmental degradation and ensures environmental security and sustainability in Algeria. This will require considerable investments in advancing sustainable energy solutions based on research, development, and technological innovation.

Consequently, this study recommends that policymakers establish an urgent timetable for gradually reducing general energy subsidies. The purpose is to reach targeted and effective subsidies, gradually transfer local energy through the export of fossil fuels, and direct an essential percentage of its revenues to investment in green energy technology. This would slowly shift local energy consumption from fossil fuels to green energy, especially since Algeria has enormous potential from clean energy sources. Moreover, this would achieve several advantages by reducing fossil fuel consumption, preserving environmental quality, and achieving significant growth rates by investing fossil fuel revenues in green energy technology.

Additionally, to avoid the negative impact of fossil fuel consumption on the environment, we recommend generalising the use of liquefied petroleum gas (GPL) as a means of transportation, pending the gradual shift towards electrification of the transportation sector. We also recommend importing electricity instead of generating it locally to reduce emissions from generating stations after studying the economic feasibility of such projects. We suggest working to emit green hydrogen energy and integrate it into the energy mix and working to diversify sources of income by creating productive links

between the energy sector and the rest of the sectors (industry, agriculture, and services). Finally, we recommend becoming stringent in implementing the National Program for Renewable Energies and Energy Efficiency measures, Horizons 2030.

Suggestions for Future Research

This study does not provide an absolute or final vision of the studied phenomenon. It can be examined through several aspects within the framework of different variables and with future time dimensions since the applied results remain dependent on the coming period. Therefore, this relationship can be studied within the framework of an international group or an economic or political bloc. Furthermore, future research can focus on the role of technological innovation through variables such as spending on research and development or green technology. They can resolve the conflict between the impact of fossil energy consumption and sustainable energy on environmental quality using other variables, such as green finance or green jobs. Finally, they can model the determinants and the factors that resolve the conflict between growth and environmental quality in high, low, and middle-income countries.

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Conflict of Interest

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References

- Adekoya, O. B., Oliyide, J. A., & Fasanya, I. O. (2022). Renewable and non-renewable energy consumption – Ecological footprint nexus in net-oil exporting and net-oil importing countries: Policy implications for a sustainable environment. *Renewable Energy*, 189, 524–534. <https://doi.org/10.1016/j.renene.2022.03.036>
- Agboola, M. O., Bekun, F. V., & Joshua, U. (2021). Pathway to environmental sustainability: Nexus between economic growth, energy consumption, CO2 emission, oil rent and total natural resources rent in Saudi Arabia. *Resources Policy*, 74, Article 102380. <https://doi.org/10.1016/j.resourpol.2021.102380>
- Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., & Muhammad, S. (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. *Resources Policy*, 69, Article 101817. <https://doi.org/10.1016/j.resourpol.2020.101817>
- Al Iriani, M. A., & Trabelsi, M. (2016). The economic impact of phasing out energy consumption subsidies in GCC countries. *Journal of Economics and Business*, 87, 35–49. <https://doi.org/10.1016/j.jeconbus.2016.04.004>
- Aladejare, S. A. (2022). Natural resource rents, globalisation and environmental degradation: New insight from 5 richest African economies. *Resources Policy*, 78, Article 102909. <https://doi.org/10.1016/j.resourpol.2022.102909>
- Alola, A. A., Olanipekun, I. O., & Shah, M. I. (2023). Examining the drivers of alternative energy in leading energy sustainable economies: The trilemma of energy efficiency, energy intensity and renewables expenses. *Renewable Energy*, 202, 1190–1197. <https://doi.org/10.1016/j.renene.2022.11.045>

- Amer, E. A. A. A., Meyad, E. M. A., Gao, Y., Niu, X., Chen, N., Xu, H., & Zhang, D. (2022). Exploring the link between natural resources, urbanization, human capital, and ecological footprint: A case of GCC countries. *Ecological Indicators*, 144, Article 109556. <https://doi.org/10.1016/j.ecolind.2022.109556>
- Amri, F. (2017). Carbon dioxide emissions, output, and energy consumption categories in Algeria. *Environmental Science and Pollution Research*, 24(17), 14567–14578. <https://doi.org/10.1007/s11356-017-8984-7>
- Ang, B. W. (2006). Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index. *Energy Policy*, 34(5), 574–582. <https://doi.org/10.1016/j.enpol.2005.11.011>
- Ansari, M. A., Haider, S., & Masood, T. (2021). Do renewable energy and globalization enhance ecological footprint: An analysis of top renewable energy countries?. *Environmental Science and Pollution Research*, 28(6), 6719–6732. <https://doi.org/10.1007/s11356-020-10786-0>
- Appiah, M., Li, M., Naeem, M. A., & Karim, S. (2023). Greening the globe: Uncovering the impact of environmental policy, renewable energy, and innovation on ecological footprint. *Technological Forecasting and Social Change*, 192, Article 122561. <https://doi.org/10.1016/j.techfore.2023.122561>
- Arulkumar, C., Manikandan, C., Dheena Dayalan, M., Sanjai, R., & Ravikumar, G. (2023). Sustainable energy development: Transitioning towards a cleaner future. *International Journal for Research in Applied Science and Engineering Technology*, 11(5), 6265–6274. <https://doi.org/10.22214/ijraset.2023.53171>
- Baek, J. (2016). Do nuclear and renewable energy improve the environment? Empirical evidence from the United States. *Ecological Indicators*, 66, 352–356. <https://doi.org/10.1016/j.ecolind.2016.01.059>
- Balcilar, M., Uzuner, G., Nwani, C., & Bekun, F. V. (2023). Boosting energy efficiency in Turkey: The role of public–private partnership investment. *Sustainability*, 15(3), Article 2273. <https://doi.org/10.3390/su15032273>
- Bei, J., & Wang, C. (2023). Renewable energy resources and sustainable development goals: Evidence based on green finance, clean energy and environmentally friendly investment. *Resources Policy*, 80, Article 103194. <https://doi.org/10.1016/j.resourpol.2022.103194>
- Bélaïd, F., & Youssef, M. (2017). Environmental degradation, renewable and non-renewable electricity consumption, and economic growth: Assessing the evidence from Algeria. *Energy Policy*, 102, 277–287. <https://doi.org/10.1016/j.enpol.2016.12.012>
- Bergougui, B., & Aldawsari, M. I. (2024). Asymmetric impact of patents on green technologies on Algeria's ecological future. *Journal of Environmental Management*, 355, Article 120426. <https://doi.org/10.1016/j.jenvman.2024.120426>
- Bouarioua, R., & Mohand, M. S. (2023). The impact of technological development and innovation on corporate management and governance in Algerian companies. *Management & Economics Research Journal*, 5(3). <https://asjp.cerist.dz/en/article/231470>
- Boudiaf, H. (2023). Renewable energy, environment and GDP in high-income countries: Evidence from Europe. *Economics and Business*, 37(1), 119–134. <https://doi.org/10.2478/eb-2023-0008>
- Bozatli, O., & Akca, H. (2023). The effects of environmental taxes, renewable energy consumption and environmental technology on the ecological footprint: Evidence from advanced panel data analysis. *Journal of Environmental Management*, 345, Article 118857. <https://doi.org/10.1016/j.jenvman.2023.118857>

- Chang, S., Chen, B., & Song, Y. (2023). Militarization, renewable energy utilization, and ecological footprints: Evidence from RCEP economies. *Journal of Cleaner Production*, 391, Article 136298. <https://doi.org/10.1016/j.jclepro.2023.136298>
- Chekouri, S. M., Chibi, A., & Benbouziane, M. (2023). The impact of natural resource abundance on ecological footprint: Evidence from Algeria. *Environmental Science and Pollution Research*, 30(26), 69289–69306. <https://doi.org/10.1007/s11356-023-26720-z>
- Chen, W., Alharthi, M., Zhang, J., & Khan, I. (2024). The need for energy efficiency and economic prosperity in a sustainable environment. *Gondwana Research*, 127, 22–35. <https://doi.org/10.1016/j.gr.2023.03.025>
- Chen, W., & Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. *Renewable Energy*, 123, 1–14. <https://doi.org/10.1016/j.renene.2018.02.026>
- De Bruyn, S. M. (1997). Explaining the environmental Kuznets curve: Structural change and international agreements in reducing sulphur emissions. *Environment and Development Economics*, 2(4), 485–503. <https://doi.org/10.1017/S1355770X97000260>
- Deka, A., Bako, S. Y., Ozdeser, H., & Seraj, M. (2023). The impact of energy efficiency in reducing environmental degradation: Does renewable energy and forest resources matter? *Environmental Science and Pollution Research*, 30(37), 86957–86972. <https://doi.org/10.1007/s11356-023-28434-8>
- Destek, M. A., & Manga, M. (2021). Technological innovation, financialization, and ecological footprint: Evidence from BEM economies. *Environmental Science and Pollution Research*, 28(17), 21991–22001. <https://doi.org/10.1007/s11356-020-11845-2>
- Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, 74(366a), 427–431. <https://doi.org/10.1080/01621459.1979.10482531>
- Doğan, B., Ghosh, S., Hoang, D. P., & Chu, L. K. (2022). Are economic complexity and eco-innovation mutually exclusive to control energy demand and environmental quality in E7 and G7 countries? *Technology in Society*, 68, Article 101867. <https://doi.org/10.1016/j.techsoc.2022.101867>
- Elbadri, M., Bsikre, S., Alamari, O., & Balcilar, M. (2023). Nexus between renewable energy consumption, economic growth, and CO2 emissions in Algeria: New evidence from the Fourier-Bootstrap ARDL approach. *Natural Resources Forum*, 47(3), 393–412. <https://doi.org/10.1111/1477-8947.12292>
- Filimonova, I. V., Nemov, V. Y., Komarova, A. V., Mishenin, M. V., & Kozhevnikov, V. D. (2021). Relationship of renewable energy consumption to economic, environmental and institutional factors in Europe. *Energy Reports*, 7, 358–365. <https://doi.org/10.1016/j.egyr.2021.07.115>
- Gelan, A. (2018). Economic and environmental impacts of electricity subsidy reform in Kuwait: A general equilibrium analysis. *Energy Policy*, 112, 381–398. <https://doi.org/10.1016/j.enpol.2017.10.032>
- Goldemberg, J., & Lucon, O. (2009). *Energy, environment and development* (2nd ed.). Routledge. <https://doi.org/10.4324/9781849774468>
- Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics*. McGraw-Hill.
- Gyamfi, B. A., Agozie, D. Q., & Bekun, F. V. (2022). Can technological innovation, foreign direct investment and natural resources ease some burden for the BRICS economies within current industrial era?. *Technology in Society*, 70, Article 102037. <https://doi.org/10.1016/j.techsoc.2022.102037>
- Hamhami, A., Amrani, A. K., & Smahi, A. (2020). Environmental economics in Algeria: Empirical investigation into the relationship between technological policy, regulation intensity, market

- forces, and industrial pollution of Algerian firms. *Environmental Science and Pollution Research*, 27(36), 45419–45434. <https://doi.org/10.1007/s11356-020-10411-0>
- Hassoun, S. E. S., Mékidiche, M., & Guellil, M. S. (2018). Examining the connection amongst renewable energy, economic growth and carbon dioxide emissions in Algeria. *Ekoist: Journal of Econometrics and Statistics*, 14(29), 199–223. <https://doi.org/10.26650/ekoist.2018.14.29.0013>
- Hosan, S., Rahman, M. M., Karmaker, S. C., & Saha, B. B. (2023). Energy subsidies and energy technology innovation: Policies for polygeneration systems diffusion. *Energy*, 267, Article 126601. <https://doi.org/10.1016/j.energy.2022.126601>
- Hussain, J., Khan, A., & Zhou, K. (2020). The impact of natural resource depletion on energy use and CO₂ emission in Belt & Road Initiative countries: A cross-country analysis. *Energy*, 199, Article 117409. <https://doi.org/10.1016/j.energy.2020.117409>
- Iyke-Ofoedu, M. I., Nwonye, N. G., Abner, I. P., Ezeaku, H. C., & Ubani, O. (2023). Impact of the carbon footprint of bank loans and fossil fuel subsidies on the ecological footprint in Tunisia: A contingency and asymmetric analysis. *Journal of Cleaner Production*, 426, Article 139026. <https://doi.org/10.1016/j.jclepro.2023.139026>
- Javed, A., Rapposelli, A., Khan, F., & Javed, A. (2023). The impact of green technology innovation, environmental taxes, and renewable energy consumption on ecological footprint in Italy: Fresh evidence from novel dynamic ARDL simulations. *Technological Forecasting and Social Change*, 191, Article 122534. <https://doi.org/10.1016/j.techfore.2023.122534>
- Khan, M. I. (2017). Falling oil prices: Causes, consequences and policy implications. *Journal of Petroleum Science and Engineering*, 149, 409–427. <https://doi.org/10.1016/j.petrol.2016.10.048>
- Khan, I., Hou, F., Zakari, A., Irfan, M., & Ahmad, M. (2022). Links among energy intensity, non-linear financial development, and environmental sustainability: New evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, 330, Article 129747. <https://doi.org/10.1016/j.jclepro.2021.129747>
- Khan, S. A. R., Yu, Z., Belhadi, A., & Mardani, A. (2020). Investigating the effects of renewable energy on international trade and environmental quality. *Journal of Environmental Management*, 272, Article 111089. <https://doi.org/10.1016/j.jenvman.2020.111089>
- Kihombo, S., Ahmed, Z., Chen, S., Adebayo, T. S., & Kirikkaleli, D. (2021). Linking financial development, economic growth, and ecological footprint: What is the role of technological innovation? *Environmental Science and Pollution Research*, 28(43), 61235–61245. <https://doi.org/10.1007/s11356-021-14993-1>
- Kongbuamai, N., Bui, Q., Yousaf, H. M. A. U., & Liu, Y. (2020). The impact of tourism and natural resources on the ecological footprint: A case study of ASEAN countries. *Environmental Science and Pollution Research*, 27(16), 19251–19264. <https://doi.org/10.1007/s11356-020-08582-x>
- Kwakwa, P. A., Alhassan, H., & Adu, G. (2020). Effect of natural resources extraction on energy consumption and carbon dioxide emission in Ghana. *International Journal of Energy Sector Management*, 14(1), 20–39. <https://doi.org/10.1108/IJESM-09-2018-0003>
- Lemaire, X. (2004). Glossary of terms in sustainable energy regulation. In *Renewable Energy and Efficiency Partnership* (pp. 7–11).
- Li, R., Wang, Q., Li, L., & Hu, S. (2023). Do natural resource rent and corruption governance reshape the environmental Kuznets curve for ecological footprint? Evidence from 158 countries. *Resources Policy*, 85, Article 103890. <https://doi.org/10.1016/j.resourpol.2023.103890>

- Liu, M., Chen, Z., Sowah Jr, J. K., Ahmed, Z., & Kirikkaleli, D. (2023). The dynamic impact of energy productivity and economic growth on environmental sustainability in South European countries. *Gondwana Research*, 115, 116–127. <https://doi.org/10.1016/j.gr.2022.11.012>
- Madaleno, M., & Nogueira, M. C. (2023). How renewable energy and CO2 emissions contribute to economic growth, and sustainability—An extensive analysis. *Sustainability*, 15(5), Article 4089. <https://doi.org/10.3390/su15054089>
- Matallah, S., Boudaoud, S., Matallah, A., & Ferhaoui, M. (2023). The role of fossil fuel subsidies in preventing a jump-start on the transition to renewable energy: Empirical evidence from Algeria. *Resources Policy*, 86, Article 104276. <https://doi.org/10.1016/j.resourpol.2023.104276>
- Nathaniel, S. P., & Adedoyin, F. F. (2022). Tourism development, natural resource abundance, and environmental sustainability: Another look at the ten most visited destinations. *Journal of Public Affairs*, 22(3), Article e2553. <https://doi.org/10.1002/pa.2553>
- Nikbakht, M., Hajiani, P., & Ghorbanpur, A. (2022). Assessment of the total-factor energy efficiency and environmental performance of Persian Gulf countries: A two-stage analytical approach. *Environmental Science and Pollution Research*, 30(4), 10560–10598. <https://doi.org/10.1007/s11356-022-22344-x>
- Ning, Y., Cherian, J., Sial, M. S., Álvarez-Otero, S., Comite, U., & Zia-Ud-Din, M. (2022). Green bond as a new determinant of sustainable green financing, energy efficiency investment, and economic growth: A global perspective. *Environmental Science and Pollution Research*, 30(22), 61324–61339. <https://doi.org/10.1007/s11356-021-18454-7>
- OECD. (2014). *World energy outlook 2014*. Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/energy/world-energy-outlook-2014_weo-2014-en
- Omri, A., & Belaïd, F. (2021). Does renewable energy modulate the negative effect of environmental issues on the socio-economic welfare?. *Journal of Environmental Management*, 278, Article 111483. <https://doi.org/10.1016/j.jenvman.2020.111483>
- Oyedepo, S. O. (2012). On energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews*, 16(5), 2583–2598. <https://doi.org/10.1016/j.rser.2012.02.010>
- Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289–326. <https://doi.org/10.1002/jae.616>
- Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, 75(2), 335–346. <https://doi.org/10.1093/biomet/75.2.335>
- Rahmane, A., Benelbar, M., & Traich, M. (2021). The nexus between sustainable energy and ecological footprint: Evidence from Algeria. *Sustainability: Science, Practice and Policy*, 17(1), 323–333. <https://doi.org/10.1080/15487733.2021.1946298>
- Raza, A., Habib, Y., & Hashmi, S. H. (2023). Impact of technological innovation and renewable energy on ecological footprint in G20 countries: The moderating role of institutional quality. *Environmental Science and Pollution Research*, 30(42), 95376–95393. <https://doi.org/10.1007/s11356-023-29011-9>
- Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environmental Research*, 186, Article 109567. <https://doi.org/10.1016/j.envres.2020.109567>
- Saqib, N., Duran, I. A., & Ozturk, I. (2023a). Unraveling the interrelationship of digitalization, renewable energy, and ecological footprints within the EKC framework: Empirical insights from the United States. *Sustainability*, 15(13), Article 10663. <https://doi.org/10.3390/su151310663>

- Saqib, N., Ozturk, I., & Usman, M. (2023b). Investigating the implications of technological innovations, financial inclusion, and renewable energy in diminishing ecological footprints levels in emerging economies. *Geoscience Frontiers*, 14(6), Article 101667. <https://doi.org/10.1016/j.gsf.2023.101667>
- Shahid, R., Shahid, H., Shijie, L., & Jian, G. (2024). Developing nexus between economic opening-up, environmental regulations, rent of natural resources, green innovation, and environmental upgrading of China-empirical analysis using ARDL bound-testing approach. *Innovation and Green Development*, 3(1), Article 100088. <https://doi.org/10.1016/j.igd.2023.100088>
- Singh, A. K., Raza, S. A., Nakonieczny, J., & Shahzad, U. (2023). Role of financial inclusion, green innovation, and energy efficiency for environmental performance? Evidence from developed and emerging economies in the lens of sustainable development. *Structural Change and Economic Dynamics*, 64, 213–224. <https://doi.org/10.1016/j.strueco.2022.12.008>
- Solarin, S. A. (2020). An environmental impact assessment of fossil fuel subsidies in emerging and developing economies. *Environmental Impact Assessment Review*, 85, Article 106443. <https://doi.org/10.1016/j.eiar.2020.106443>
- Solarin, S. A., Bello, M. O., & Tiwari, A. K. (2022). The impact of technological innovation on renewable energy production: Accounting for the roles of economic and environmental factors using a method of moments quantile regression. *Heliyon*, 8(7), Article e09913. <https://doi.org/10.1016/j.heliyon.2022.e09913>
- Stiglitz, J. E., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G. M., La Rovere, E. L., Morris, A., Moyer, E., Pangestu, M., Shukla, P. R., Sokona, Y., & Winkler, H. (2017). *Report of the High-Level Commission on Carbon Prices*. International Bank for Reconstruction and Development and International Development Association/The World Bank <https://doi.org/10.7916/D8-W2NC-4103>
- Sulaiman, J., Azman, A., & Saboori, B. (2013). The potential of renewable energy: Using the environmental Kuznets curve model. *American Journal of Environmental Sciences*, 9(2), 103. <https://doi.org/10.3844/ajessp.2013.103.112>
- Suki, N. M., Suki, N. M., Sharif, A., Afshan, S., & Jermsittiparsert, K. (2022). The role of technology innovation and renewable energy in reducing environmental degradation in Malaysia: A step towards sustainable environment. *Renewable Energy*, 182, 245–253. <https://doi.org/10.1016/j.renene.2021.10.007>
- Sun, Y., Guan, W., Mehmood, U., & Yang, X. (2022). Asymmetric impacts of natural resources on ecological footprints: Exploring the role of economic growth, FDI and renewable energy in G-11 countries. *Resources Policy*, 79, Article 103026. <https://doi.org/10.1016/j.resourpol.2022.103026>
- Traich, M., & Rahmane, A. (2023). LMDI decomposition analysis of CO₂ emissions in Algeria during 2000–2019 and the role of energy policy in reducing emissions. *Economics and Policy of Energy and the Environment*, 2022(2), 83–106. <https://doi.org/10.3280/EFE2022-002005>
- Traich, M., & Rahmane, A. (2024). A decomposition analysis of Algeria's residential energy consumption change: (2000–2020). *Strategic Planning for Energy and the Environment*, 43(01), 151–176. <https://doi.org/10.13052/spee1048-5236.4317>
- Ullah, A., Ahmed, M., Raza, S. A., & Ali, S. (2021). A threshold approach to sustainable development: Nonlinear relationship between renewable energy consumption, natural resource rent, and ecological footprint. *Journal of Environmental Management*, 295, Article 113073. <https://doi.org/10.1016/j.jenvman.2021.113073>

- Weitzman, M. L. (2017). Sustainability and technical progress. In J. C. V. Pezzey & M. A. Toman (Eds.), *The economics of sustainability* (pp. 329–341). London: Routledge. <https://www.taylorfrancis.com/chapters/edit/10.4324/9781315240084-21>
- Wenlong, Z., Tien, N. H., Sibghatullah, A., Asih, D., Soelton, M., & Ramli, Y. (2022). Impact of energy efficiency, technology innovation, institutional quality, and trade openness on greenhouse gas emissions in ten Asian economies. *Environmental Science and Pollution Research*, 30(15), 43024–43039. <https://doi.org/10.1007/s11356-022-20079-3>
- Xie, P., Zhu, Z., Hu, G., & Huang, J. (2023). Renewable energy and economic growth hypothesis: Evidence from N-11 countries. *Economic Research-Ekonomska Istraživanja*, 36(1), Article 2121741. <https://hrcak.srce.hr/file/442409>
- Yao, X., Yasmeen, R., Hussain, J., & Shah, W. U. H. (2021). The repercussions of financial development and corruption on energy efficiency and ecological footprint: Evidence from BRICS and Next 11 countries. *Energy*, 223, Article 120063. <https://doi.org/10.1016/j.energy.2021.120063>
- Yu, Y. (2023). Role of natural resources rent on economic growth: Fresh empirical insight from selected developing economies. *Resources Policy*, 81, Article 103326. <https://doi.org/10.1016/j.resourpol.2023.103326>
- Zafar, M. W., Zaidi, S. A. H., Khan, N. R., Mirza, F. M., Hou, F., & Kirmani, S. A. A. (2019). The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: The case of the United States. *Resources Policy*, 63, Article 101428. <https://doi.org/10.1016/j.resourpol.2019.101428>
- Zhang, W., & Chiu, Y.-B. (2023). Country risks, government subsidies, and Chinese renewable energy firm performance: New evidence from a quantile regression. *Energy Economics*, 119, Article 106540. <https://doi.org/10.1016/j.eneco.2023.106540>