The Nexus between sustainable energy and ecological footprint: evidence from Algeria

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ABSTRACT
Despite the considerable attention that has been spent studying the connections between energy and sustainable development, the most salient issues have only become conspicuous in the last few decades. Interest in these issues is now unavoidable with significant effort being devoted to achieving sustainable development goals. The present study attempts to highlight the role of sustainable energy in protecting the environment using the ecological footprint (EF) in Algeria. We use the unit root test, co-integration, Granger causality, and dynamic ordinary least squares (DOLS) and the results reveal a long-term equilibrium relationship between renewable energy consumption (REC), carbon-dioxide (CO2) emissions (CE), primary energy intensity (PEI), and the ecological footprint. The regression relationship reveals a positive and significant relationship from REC, CE, and PEI to EF. It also demonstrates the existence of bidirectional causality between REC and EF at 1% level and four unidirectional causal relationships where two relationships start from CE to EF at 1% and two start from PEI to REC, CE at 1% (i.e., PEI affects both REC and CE). These results indicate that decision makers should enhance investment in renewable energy as well as control the exploitation of fossil energy, which leads to reducing emissions and preserving the environment.

ARTICLE HISTORY
Received 12 October 2020
Accepted 17 June 2021

KEYWORDS
Sustainable energy; ecological footprint; dynamic ordinary least square method; Algeria

Introduction
Working toward sustainable development has become an urgent necessity as a result of growing disappointment with the current economic system and acceleration of the accompanying climate, environmental, and development crises. Sustainable development takes into account the pursuit of economic objectives by protecting the environment and improving human welfare and social equity.

Energy is an essential element for meeting human needs, as it plays an important role in achieving the goals of sustainable development. In the 1970s, concerns about energy use mainly focused on the relationship between energy and economics. An institutional structure emerged in following years in many countries to deal with visible and objectionable environmental problems. As environmental concerns, such as pollution, stratospheric ozone depletion, and global climate change became major issues in the 1980s, interest in the link between energy utilization and the environment became more pronounced (especially in the late 1980s and early 1990s). Efforts to increase the efficiency of energy-resource utilization and to substitute more environmentally benign energy resources for damaging ones have been prevalent ways to reduce the environmental impact of energy use (Dincør and Zamfirescu 2011).

The trend toward sustainable energy requires finding appropriate ways to achieve the sustainable development goals (SDGs). The seventeen SDGs were announced in September 2015, with SDG 7 defining targets to “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations Economic Commission for Europe (UNECE) n.d). This sustainable energy contributes to reducing dependence on fossil resources, diversifying the energy mix, and reducing emissions. The adoption of an energy mix consisting of renewable and fossil energy requires improving energy efficiency, which enables reductions in the environmental, economic, and social costs associated with energy production and consumption and ultimately reduces the ecological footprint and is consistent with the aims of sustainable development.
In the present study, we focus on the case of Algeria. The country is a member of the Organization of Petroleum Exporting Countries (OPEC) and is an important hydrocarbon producer in the region as well as an exporter of natural gas to Europe. Algeria is strongly reliant on fossil fuels and these energy sources represent 95% of its exports and 60% of its national budget. The country has US$75 billion in foreign currency reserves though these funds have dropped significantly since 2014 due to declining oil and natural gas prices (Africa Oil and Power 2020). Moreover, oil and natural gas account for almost all of Algeria’s total primary energy consumption, and so far, only 3.39% of installed energy capacity is from renewable energy resources, hydropower and solar. The government aims to diversify the energy mix and to bring the share of electricity generation from renewable energy resources to 27% by 2030 (RCREEE 2020). Therefore, it launched a national program for “a renewable energy and energy efficiency development plan (2011–2030)” in 2011 and then in 2015 adopted an update to this plan.

The updated version of the program aimed to install 4,500 megawatts (MW) of new projects prior to 2020 and to build overall capacity of 22,000 MW by 2030 (IEA 2016). This program leans on a strategy focused on developing the use of renewable resources such as solar energy in order to diversify the country’s energy sources and to prepare for the future (Rahmane, Bentafat, and Sellami 2019). Since 2011, Algeria has installed only 22 solar power plants, representing a cumulative capacity of 400 MW because a series of obstacles hampered the implementation of the projects, including funding, insufficient local technical expertise, and lack of effective coordination between the various actors in the sector (Feukeng 2019).

This article seeks to shed light on the role of sustainable energy in protecting the environment using the ecological footprint as an indicator. Accordingly, we attempt to clarify the importance of an energy transition in Algeria, relying on sustainable energy based on boosting both renewable energy and energy efficiency, rather than shifting directly to renewable energy. The current study strives to contribute to the literature on the relationship between energy use and sustainability. First, to the best of our knowledge there have been no prior studies of Algeria using the ecological footprint as an indicator of the connection between energy, environment, and sustainable development. Second, in contrast to previous work, our research focuses on the energy sector using sustainable energy as an independent variable that affects sustainable development measured by the ecological footprint. Third, rather than deploying gross domestic product (GDP) and fossil-energy consumption to assess the direct impact of economic and social activity on the environment, we used carbon dioxide (CO2) emissions as an indicator. Finally, our study relied on the method of dynamic ordinary least squares (DOLS), a powerful method for handling small samples such as the one assembled for this project, which comprised only 27 observations. This method estimates the long-term equilibrium relationship after ensuring the existence of a co-integration relationship. We also diagnosed the direction of influence to analyze the causality between the variables. The latter is a preferred approach in identifying the nature of economic relations compared to the methods of correlation and regression.

We divide the present article into several sections. First, in the introduction above, we discussed the issues related to sustainable energy and environment especially in Algeria. Then we move on to review the literature in the following section. After that, we explain the methodology used in this article and in the fourth section discuss the results of the study. Finally, we offer some closing observations in the conclusion.

**Literature review**

Before describing several previous studies that have treated the nexus between energy and environment, we provide brief definitions of the two variables. Conceived in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, the ecological footprint launched the broader footprint movement, including the carbon footprint, and the methodology is now widely used by scientists, businesses, governments, individuals, and institutions working to monitor ecological resources use and enhance sustainable development (GFN 2020). According to Wackernagel and Rees (1996), the ecological footprint represents the land area necessary to sustain current levels of resource consumption and waste discharge by that population.

Concerning sustainable energy, there is no universally accepted definition of what it means, but in general, the concept focuses on achieving a supply of energy that is sustainable over long periods of time with manageable or no negative environmental impacts (Reader 2018). Moreover, Jefferson et al. (2012) assert that sustainable energy is a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and the preservation of the Earth for future generations. Furthermore, Owen and Garniati (2016) argue that sustainable energy requires a balanced composition between energy security, economic
development, and environmental protection. It encompasses energy systems based on three core dimensions: energy security, social equity, and environmental impact mitigation. A large component of this would be the incorporation of renewable energy into the existing energy mix, but it does not eliminate the efficient use of conventional sources to ensure sustainable energy security.

A considerable number of studies have tackled the relationship between energy and sustainable development but many of them have used CO2 emissions as an indicator of environmental degradation. Recently, the use of CO2 emissions to proxy for environmental quality has encountered criticism alleging that it is not all encompassing since the individual effect on the environment is not considered (i.e., the other negative effects of human activities except those limited to the atmosphere). Therefore, attention among researchers has shifted to the ecological footprint as a better proxy (Nathaniel, Anyanwu, et al. 2020).

In brief, we can divide previous studies that have explored the connection between energy and the environment into two groups. The first group has relied on CO2 emissions as an environmental indicator and most of these studies have investigated the hypothesis of the environmental Kuznets’ curve (EKC). The second group has used the ecological footprint that offers a much broader measure than CO2 emissions.

Especially worth noting here is the study of Altıntaş and Yacouba (2020) and the work of Mrabet and Mouyad (2016) which examined the extent to which the environmental Kuznets curve (EKC) in Europe and Qatar is associated with CO2 emissions or the ecological footprint. They concluded that the latter approximates the EKC unlike the CO2 emissions. (For details see Altıntaş and Yacouba (2020) and Mrabet and Mouyad (2016)).

These two studies concluded that the EKC is achieved when using the ecological footprint and is not achieved when using the CO2 emissions. We referred to these studies to guide us in using the ecological footprint as an expression of environmental degradation or as a dependent variable in the study.

Concerning the studies that used the ecological footprint, we mention, for instance, the study of Al-Mulali et al. (2015) that examined the extent to which its findings were consistent with the Kuznets hypothesis by using the ecological footprint as an indicator of environmental degradation on two groups of high-income and low-income countries. The study concluded that the EKC is realized in high-income countries because it achieves high levels of sustainable energy (energy efficiency, energy saving and renewable energy) which low-income countries cannot access due to its high cost (Al-Mulali et al. 2015).

Likewise, Destek and Samuel (2019) investigated the Kuznets hypothesis for the ecological footprint. They examined the relationship between economic growth, energy consumption, financial development, and the ecological footprint during the period 1977–2013 in eleven newly industrialized countries. Their study employed both an augmented mean group (AMG) estimator and the heterogeneous panel causality method, which are suitable for dependent and heterogeneous panels. The results of the estimator showed that there is an inverted U-shaped relationship between economic growth and the ecological footprint. According to the causality test results, there is a bi-directional causality between economic growth and the ecological footprint.

In addition, Nathaniel (2020) explored the effect of energy use, urbanization, trade, and economic growth on the environment as captured by the ecological footprint in Indonesia. He concluded that urbanization, economic growth, and energy consumption increase environmental degradation while trade deteriorates it in the long run. Trade reduces environmental quality in the short run while economic growth, energy use, and urbanization show consistent results with their long-run outcomes.

Nathaniel, Anyanwu, et al. (2020) also discussed the impact of both renewable and nonrenewable energy use, urbanization, and financial development on the environment in the Middle East and North Africa (MENA) countries during the period 1990–2016. They found that the consumption of renewable energy does not enhance environmental quality in about 84% of the study sample while the consumption of nonrenewable energy contributes to the deterioration of the environment by 17% of the countries in the region.

Moreover, Nathaniel, Anyanwu, et al. (2020) studied the relationship between renewable energy, urbanization, and the ecological footprint in CIVETS countries (Colombia, Indonesia, Vietnam, Egypt, Turkey, and South Africa). They found that renewable energy improves environmental quality and that trade is not particularly harmful to the environment whereas nonrenewable energy consumption and urbanization damage the environment. Similarly, Nathaniel and Khan (2020) examined almost the same relationship in member countries of the Association of Southeast Asian Nations (ASEAN). The study concluded that renewable energy is an important enhancer of environmental quality in the region in addition to growth.
and trade that contributes alarmingly to environmental degradation.

Furthermore, Adedoyin, Nathaniel, and Adeleye (2021) investigated the long-run relationship between energy consumption, tourists’ arrivals, economic policy uncertainty, and ecological footprint in the top ten earning countries from international tourism over the period 1995–2015. They used the fully modified ordinary least squares and dynamic ordinary least squares estimation techniques and the Dumitrescu and Hurlin causality tests. They found that economic policy uncertainties, tourism, and energy consumption lead to environmental degradation while economic policy uncertainties significantly moderate the contribution of energy consumption to ecological footprint.

Ulucak, Danish, and Burcu (2020) analyzed the impact of energy and natural resources consumption on environmental sustainability using the following indicators: CO2 emissions, ecological footprint, and carbon footprint in member countries of the Organization for Economic Co-operation and Development (OECD). They found that nonrenewable energy has a harmful effect on the environment while renewable energy reduces environmental degradation in terms of the ecological footprint and the carbon footprint. The extraction of natural resources also contributes to increased CO2 emissions while its role is not statistically significant in the ecological and carbon footprints (Ulucak, Danish, and Burcu 2020). Finally, the study of Kassouri and Altıntaş examined the existence of a tradeoff or complementarity between achieving well-being through the human development index and protecting the environment using the ecological footprint index in MENA countries. The study concluded that procedures to preserve the quality of the environment lead to a deterioration and loss of human well-being; therefore, policies aimed at increasing human development do not comply with policies aimed at enhancing environmental quality (Kassouri and Altıntaş 2020).

From the literature mentioned above, no study to date has assessed the relationship between sustainable energy and CO2 emissions that resulted from economic activity with the environment by looking at an entire country dependent on fossil energy (more than 99% of total energy). Therefore, this article studies the environmental impacts of energy use and the volume of economic and social activity represented by the amount of CO2 emissions in Algeria. It analyzes long-term estimates and the causal relationship between sustainable energy’s variables, CO2 emissions, and the ecological footprint.

To sum up, in light of the scarcity of previous studies dealing with the relationship between sustainable energy and the environment, the present study provides a vision about the environmental impact of energy transition in countries rich in energy resources, such as Algeria. Thus, we find that most of the work that has dealt with the problem of environmental degradation from the perspective of the Kuznets hypothesis through the relationship between economic growth and the environment are similar to the studies of Destek and Samuel (2019), Adedoyin, Nathaniel, and Adeleye (2021), Altıntaş and Yacouba (2020), and Mrabet and Mouyad (2016). They focused on the use of renewable and nonrenewable energy variables but neglected an important variable, energy efficiency, which could have a dual impact on both economic growth and the environment. In addition, several of these previous studies tended to use CO2 as an indicator of environmental degradation (a dependent variable).

Our contribution derives from the perspective of the relationship between sustainable energy and the environment. We assess environmental impact using the ecological footprint as the best indicator, so far, of environmental degradation as in the studies of Nathaniel, Anyanwu, et al. (2020), Altıntaş and Yacouba (2020), and Mrabet and Mouyad (2016). We use known sustainable energy indicators such as energy intensity (which provides a picture of the pattern of fossil-energy use), renewable energy (which provides a picture of the shift toward clean energy), and CO2 emissions (which provides a measure of activity volume through fossil-energy consumption).

Data and methodology

Data presentation

The methodological basis of this study rests on the analysis of the behavior and characteristics of time-series data for sustainable energy and environmental variables in Algeria according to an econometric model that includes the impact of primary energy intensity, renewable energy consumption, and CO2 emissions on the ecological footprint during the period 1990–2017. We selected the following independent variables: renewable energy consumption (REC) (measured in terms of millions of tons of oil equivalent), CO2 emissions (measured in terms of millions of ton of CO2), and primary energy intensity (PEI) (millions of tons of oil equivalent per US$1,000 in constant values for 2010). We obtained the data for these variables from the International Energy Agency (IEA) (IEA 2017) and expressed the environmental dimension using the ecological footprint (EF) (measured in terms of global hectares) (GFN 2019).
Study methodology

Study of time series stability (unit root test)
Before estimating the model, we checked whether the previously mentioned series are stable or not in order to avoid the emergence of spurious regressions (Cadoret et al. 2004). This term refers to a regression with good results in terms of (t, F) test and $R^2$ value, but it does not give a real meaning to the results, nor does it provide a meaningful economic explanation. This means that resorting to the ordinary least squares (OLS) method gives false results in case of instability of chains, so a unit root test is required to test the stationarity of time series for the study variables of the model in terms of the unitary root.

Testing the time-series stationarity of the model variables on the unitary root requires use of the Dickey-Fuller unit root test (DF), the Augmented Dickey-Fuller test (ADF) (Dickey and Fuller 1981), and the Philips-Perron test (PP) (Phillips and Perron 1988). The latter is based on a non-parameter correction of the simple Dickey-Fuller test statistics to address the problem of correlation and/or biases resulting from the special characteristics of random oscillations. This test has the same finite distributions for the ADF and DF.

Determining the optimum delay degree
Before performing the testing and evaluation process, the optimum delay degree was determined based on two criteria: (1) the Akaike Information Criterion (Nakkar and Al-Awwad 2012) and (2) Schwarz’s Bayesian Information Criterion (Lardi and Mignon 2002).

Co-Integration test
The study uses the Johanes-Juselius method to perform the co-integration test (Johansen and Juselius 2009). To determine the number of integration vectors, we used two statistical tests based on the Likelihood Ratio Test (LR): the trace test ($\lambda_{\text{trace}}$) and the maximum eigenvalues test ($\lambda_{\text{max}}$). The impact test is:

$$\lambda_{\text{trace}}(r) = -T \sum_{i=r+1}^{n} \ln (\hat{\lambda}_i)$$

Accordingly, we tested the null hypothesis with the number of co-integrated vectors being $r \leq q$ against the alternative hypothesis with the number of co-integrated vectors being $r = q$.

The maximum characteristic test is:

$$\lambda_{\text{max}}(r, r+1) = -T \ln (1 - \hat{\lambda}_{r+1})$$

when we tested the null hypothesis with the number of co-integration vectors being $r$ against the alternative hypothesis with the number of simultaneous integration vectors being $r + 1$. In light of the stability test, it became clear that, separately, each variable is a first-class integral, meaning that it is not static in the level but static in the first difference.

Causality test
Causality analysis between variables and their measurement is sometimes an important way to identify the relationship between economic phenomena compared to the method of correlation and regression. The causal test determines the relationship between variables then ascertains the direction of the causal relationship between them. The Granger contribution is the most prominent among the rest of the studies that deals with the issue of causation (Arbash and Naker 2011).

Model estimation using dynamic ordinary least squares method
After establishing the time-series stationarity and that long-term co-integration relationships among the studied variables exist following the Johansen-Juselius method, we estimated the proposed model using the dynamic ordinary least squares (DOLS) method which is a parameterized method and one of the most recent and powerful methods due to its performance in small-sized samples. It is used to estimate the long-term balance relationship of a system that contains integrated variables of different degrees, but is still jointly integrated (Kanaan and Al-Jouburi 2012).

To test the relationship between renewable energy, CO$_2$, energy intensity, and the ecological footprint in Algeria, the model used in this study takes the following form:

$$EF = (REC, CE, PEE, u_t)$$

Therefore, the model takes the mathematical form after entering the natural logarithm to correct the heterogeneity in the variables and becomes as follows:

$$\ln EF_t = \alpha_0 + \alpha_1 \ln REC_t + \alpha_2 \ln CE_t + \alpha_3 \ln PEE_t + \mu_t$$

where:

- $T$: represents the time (1990–2017)
- $\ln EF$: logarithm of the ecological footprint indicator/unit (in global hectares)
- $\ln REC_t$: logarithm of renewable energy consumption/unit (in millions of tons of oil equivalent)
- $\ln CE_t$: logarithm of CO$_2$ emissions/unit (in millions of tons of CO$_2$)
- $\ln PEE_t$: logarithm of primary energy intensity/unit: tons of oil equivalent per US$1,000 in 2010 prices
- $\alpha_0, \alpha_1, \alpha_2, \alpha_3$: model parameters
- $\mu_t$: random error
The time series is stationary in the first difference. We conclude that the variables reached the stage of staticity and stability at 1%, 5%, and 10% significant levels, after taking their first stationary form. Each variable is an integral of the first degree, meaning that it is not static in the level but static in the first difference (see Table 3).

**Determining the optimal degree of delay**

Before performing the testing and assessment process, the optimal degree of delay must be determined. We followed the Akaike and Schwarz’ criteria with the help of the statistical program Eviews.10.

We note from Table 2 that the optimum delay degree suitable to the minimum value is \( p = 1 \).

**Co-integration test**

In light of the stability test it became clear that, separately, each variable is an integral of the first degree, meaning that it is not static in the level but static in the first difference (see Table 3).

The results of the test shown in Table 3 lead us to accept the alternative hypothesis because the calculated value of the trace statistic is greater than its scheduled value at a level of significance of 5% (there is a co-integration relationship and the number of co-integration vectors is one vector).

The results of the Eigen-Max statistical test also support the results of the effect test, which means the rejection of the null hypothesis and acceptance of the alternative hypothesis (there is a co-integration relationship and the number of co-integration vectors is one vector). This result confirms the existence of a long-term equilibrium relationship between these variables, which means that they do not diverge from each other so much and that they exhibit a similar behavior, as highlighted in the study of Adedoyin, Nathaniel, and Adeleye (2021).

**Causality test**

To determine the direction of the causal relationship between the study variables, we employed the Granger test. Table 4 shows the direction of the causal relationship between the variables.

Through Table 4, we note that, overall, the variables cause the ecological footprint as \( p = .0001 < .01 \). There is a two-way causal relationship between the variables.
renewable energy consumption variable \((p = .0215 < .05)\) and the ecological footprint \((p = .0092 < .01)\). That is to say, there is a mutual influence between the two variables. This indicates that renewable energy has an important role in reducing environmental degradation caused by fossil energy. This result corresponds with the studies of Nathaniel, Anyanwu, et al. (2020) and Nathaniel and Khan (2020).

There is a causal relationship moving from \(\text{CO}_2\) emissions to both of the ecological footprint variables \((p = .0018 < .01)\) and renewable energy consumption \((p = .0816 < .10)\). In other words, \(\text{CO}_2\) emissions stimulate the consumption of renewable energy and cause the deterioration of the environment by increasing the ecological footprint.

The existence of a unidirectional causal relationship from the intensity of primary energy to renewable energy consumption \((p = .0037 < .01)\) and \(\text{CO}_2\) emissions \((p = .0669 < .10)\). This means that changes in the intensity of primary energy cause changes in the consumption of renewable energy. In addition, the increase in intensity causes a rise in \(\text{CO}_2\) emissions and thus is a driver of environmental degradation.

### Model estimation using the DOLS method

The results of the test in Table 5 indicate that the coefficients of the following explanatory variables – the variable of primary energy intensity, the variable of renewable energy consumption, and the variable of \(\text{CO}_2\) emissions – were significant at the level of 5%. Therefore, the regression equation is as follows:

\[
\text{LnEF}_t = 0.125057 \ln \text{REC}_t + 0.781831 \ln \text{CE}_t + 0.948192 \ln \text{PEE}_t + 1.553085, 
\]

The mean dependent variable is the empirical mean of the endogenous variable

\[
\bar{y} = \frac{\sum y_i}{n} 
\]

The standard deviation of the dependent variable is

\[
\sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}} = \sqrt{\frac{\text{SCT}}{n-1}} 
\]

The sum squared residual is

\[
\text{SCR} = \bar{e}^2 = \sum e_i^2 
\]

We conclude the results of the estimated parameter values as follows: The value of the parameter estimated for the constant indicates that when the values of the independent variables are null, the ecological footprint index is at the range of 1.553, which is not significant.

The value of the estimated parameter of the renewable energy-consumption factor is positive and significant (at the level of 5%) because \((p < .05)\). The value of this parameter reached (0.125), which means that if renewable energy consumption increases by 1%, it will lead to an increase of the ecological footprint of 0.125%. The signal of the correlation coefficient came up against the logic of economic theory. This is contrary to what was stated in the studies of Destek and Samuel (2019) and Ulucak, Danish, and Burcu (2020) where expansion

### Table 3. Results of the co-integration test according to the Johansen-Juselius method.

| Hypothesized No. of CE(s) | Eigenvale | Trace | 0.05 | Statistic | 0.05 | Critical Value | Prob.** |
|--------------------------|-----------|-------|------|-----------|------|----------------|---------|
| None*                    | 0.697213  | 56.99096 | 47.85613 | 0.0055 |
| At most 1                | 0.456526  | 25.92806 | 29.79707 | 0.1309 |
| At most 2                | 0.315677  | 10.07393 | 15.49471 | 0.2751 |
| At most 3                | 0.008101  | 0.211488 | 3.841466 | 0.6456 |

### Table 4. Granger block exogeneity results.

| Excluded | Chi-sq | Df | Prob. |
|----------|--------|----|-------|
| Dependent variable: LnEF | 0.1553085 | 0.936522 | 1.658354 | 0.1231 |
| LnREC | 0.781831 | 0.131205 | 5.953866 | 0.0001** |
| LnPEE | 0.948192 | 0.402634 | 2.354973 | 0.0364** |
| C | 1.553085 | 0.936522 | 1.658354 | 0.1231 |

### Table 5. Model estimation using the (DOLS) method.

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|----------|-------------|------------|-------------|-------|
| LnREC | 0.125057 | 0.043894 | 2.849048 | 0.0146** |
| LnCE | 0.781831 | 0.131205 | 5.953866 | 0.0001** |
| LnPEE | 0.948192 | 0.402634 | 2.354973 | 0.0364** |
| C | 1.553085 | 0.936522 | 1.658354 | 0.1231 |

Significant at *0.10 and **0.05 levels, respectively.
in the consumption of renewable energy helps to limit environmental degradation, and thus to reduce the ecological footprint. The reason for the ineffectiveness of renewable energy in Algeria in mitigating environmental degradation is due to the relatively low use of renewable energy sources which is still below the required level (see also Nathaniel, Anyanwu, et al. (2020)).

Moreover, the value of the estimated parameter indicates a positive and significant CO₂ emission factor (at the 1% level) because \( p < .01 \), where the value of this parameter was 0.781. That means that if CO₂ emissions increased by 1%, it would lead to an increase in the ecological footprint indicator by 0.718%. This is in line with the logic of economic literature, wherein the cause of the increase in emissions is the expansion of economic activity driven by the growth in consumption of nonrenewable energy, which is an essential element of production in all sectors of the national economy (Amri 2017). Adding to this situation is both the lack and ineffectiveness of programs that support using alternative and clean energy to limit emissions and, thus, reduce the ecological footprint.

Despite Algeria’s commitment to international agreements such as the Paris Accord in which the country pledged to reduce its emissions by 7% by 2030 (Bouznit and Pablo-Romero 2016), the volume of releases is still out of control. The steady increase in emissions in Algeria resulting from the expansion in nonrenewable energy consumption has a clear impact on economic growth because of the prominent role of fossil-energy production (the energy sector represents about 60% of GDP and 98% of total exports). Consequently, planners and public policy makers in Algeria must balance between the goals of economic growth and preserving the environment by reducing emissions.

The value of the estimated parameter of the primary energy-intensity coefficient is positive and significant (at the level of 5%) because \( p < .05 \), where the value of this parameter was 0.948. In other words, if the primary energy intensity increases by 1%, this will lead to an increase in the ecological footprint indicator by 0.948%. This result is also consistent with the logic of economic theory, as an increase in primary energy intensity (an indicator of energy efficiency, which summarizes information on energy consumed per unit of GDP) leads to the loss of a significant amount of energy that could be saved. This results in an increase in the ecological footprint as achieved in the study of Al-Mulali et al. (2015) for low-income countries. As mentioned previously, the energy-efficiency program launched by Algeria in 2011 did not contribute to improving energy use, which lead to negative impacts on the environment through the high ecological footprint indicator. What boosts confidence in these results is Figure 2.
that the value of the coefficient of determination is $R^2 = 0.994$. This ratio reflects the explanatory power of the model, and it shows the effect of independent variables and their contribution to identifying and explaining the changes in the ecological footprint indicator. In other words, this model has the ability to explain that 99.4% is due to the independent variables, and the remaining 0.6% refers back to other factors such as other variables that were not included in the model or to the random variable ($u_t$).

For enhanced accuracy in estimations, we compared real values with the estimated values using the model in Figure 1.

We notice that the estimated values converge to the real values, indicating the quality of the estimated model. Thus, it is reliable in the interpretation of the results.

Finally, we checked the normal distribution condition of residues by using the Jarque-Bera goodness of fit test and the test result was not significant. This finding supports the validity of assuming the remainder of the normal distribution model through the value of $JB = 1.29$ less than $X^2_{0.95} = 5.99$ as Figure 2 demonstrates.

**Conclusion**

This study aimed to reveal the extent of the correlation and existence of a long-term equilibrium relationship, as well as to know the direction of the causal association between sustainable energy variables and the ecological footprint in Algeria during the period 1990–2017 by using the following tests: unit root, co-integration, Granger causality, and DOLS. We reached a number of conclusions that are summarized below.

First, the existence of a strong statistically significant relationship between the variables means that one independent variable does not work in isolation from other independent variables. In other words, there is a strong relationship between the independent variables and the ecological footprint indicator.

Second, all the unit root test results showed that the study variables contain the unit root, meaning that they are unstable at the non-stationary in the level and stable at the stationary in the first difference. This means that they are integrated in the first order CI ~ (1).

Third, the results of the co-integration test suggest acceptance of the alternative hypothesis because the computed value of the trace statistic is greater than its scheduled value at a significance level of 5% (there is a co-integration relationship, and the number of co-integration vectors is one vector). The results of the Eigen-Max statistic test also supported the results of the effect test, which means rejection of the null hypothesis and acceptance of the alternative hypothesis (there is a co-integration relationship and the number of co-integration vectors is one vector). This result confirms the existence of a long-term equilibrium relationship between these variables, which means that they do not diverge from each other very much and they exhibit similar behavior.

Fourth, the results of the Granger causality test showed a two-way causal relationship between renewable energy and the ecological footprint. In other words, interest in renewable energy projects would have a very important impact on enhancing the quality of the environment in Algeria. In addition, a causal relationship moving from CO$_2$ emissions to consuming renewable energy and the ecological footprint, i.e., reducing emissions will stimulate renewable energy and reduce environmental degradation.

Finally, a causal relationship moving from primary energy intensity to consuming renewable energy and CO$_2$ emissions – for example through energy-efficiency projects – will stimulate the transition to renewable energy in addition to reducing CO$_2$ emissions. Therefore, Algeria’s move toward sustainable energy projects (energy transition) will enable it to achieve environmental sustainability.

In conclusion, energy policy makers in Algeria should make additional efforts with regard to energy efficiency. Moreover, they should work to achieve a gradual reduction in energy subsidies to reach efficient prices in allocating resources. This will enhance the growth of renewable energy by expanding investments in this field, and at least the 2030 horizon may be the start of a new era of clean energy exploitation that meets the increasing demand for energy associated with economic growth and reduce CO$_2$ emissions.

The present study provides neither an absolute nor a definitive view on the relationship between sustainable energy and the environment. Future research can address this relationship through several aspects using other variables and future time dimensions, especially since the applied results remain dependent on the coming period. Therefore, this relationship can be analyzed in the context of a group of countries such as the European Union or the G20 that have achieved significant levels of sustainable energy. The EKC can also be tested in this context by using sustainable energy indicators as independent variables.

**Disclosure statement**

No potential conflict of interest was reported by the authors.
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