Assessment of the total-factor energy efficiency and environmental performance of Persian Gulf countries: a two-stage analytical approach

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Abstract
In recent decades, achieving sustainable economic growth and development through energy efficiency has been a key challenge for Persian Gulf countries. This study presents a two-stage analysis of the energy efficiency and environmental performance of Persian Gulf countries in 2000–2014 using data envelopment analysis and Tobit regression. The hypothesis of this study is that energy efficiency is low in the Persian Gulf countries and these countries have the potential to reduce greenhouse gas emissions. At first, using data envelopment analysis, total-factor energy efficiency and environmental efficiency of the Persian Gulf countries were measured. Then, using Tobit regression, the effects of GDP per capita, oil price, industrialization degree, population size, paper citation rate, foreign direct investment, and the degree of commercial openness on energy efficiency were investigated. The results of the first stage measurements show that Saudi Arabia and the United Arab Emirates had the highest and second highest total-factor energy efficiency, respectively, while Oman and Iran had the lowest, and second lowest, respectively. In terms of environmental performance, the UAE and Qatar proved to have the best and second best performance, respectively, while Iran and Iraq showed the weakest and second weakest performance, respectively. The results of Tobit regression revealed that GDP per capita, oil prices, industrialization degree, and population size had a direct relationship with energy efficiency while the paper citation rate (as an index of science, technology, and innovation) and foreign direct investment had an inverse relationship with energy efficiency. This study shows that the Persian Gulf countries could potentially reduce their energy consumption by up to 18%. Finally, a number of environmentally friendly economic policies and several environmental projects are proposed and it is emphasized that more innovative green technologies should be used to increase energy efficiency and optimize the energy structure to combat climate change.

Keywords Total-factor energy efficiency · Data envelopment analysis · Tobit regression · Persian Gulf countries · GCC · Sustainable development

Introduction
One of the most important issues faced by governments and policymakers across the world is global warming (Rogelj et al. 2018; Destek and Sarkodie, 2019; Khattak et al. 2020). The earth’s average surface temperature needed a hundred years (1880–1994) to increase by 0.5 °C (from 0.19 to 0.31 °C), but surprisingly, it increased up to 0.9 °C in 2017, that is, in only 20 years. The main reason behind such rapid rise of temperature is the emission of greenhouse gasses especially carbon dioxide (CO2) which occurs due to overutilization of fossil fuels in the form of gas, coal, and oil and acts as an energy source for economic activities (Gokmenoglu and Taspinar, 2018; Sarkodie, 2018; Rafindadi and Usman, 2019 and Noshaba et al. 2020). CO2 emissions in
In recent decades, many countries have tried to improve their energy efficiency while attempting to obtain sustainable economic development. The quick development of global economy and industrialization of countries have made for an increase in the global consumption of energy and the emissions of various pollutants. The low energy efficiency causes not only the waste of energy, but also a great amount of environmental pollution. This is why many academic experts are paying attention to the issue of energy efficiency and are trying to propose modern, reliable, and environment-friendly ideas for improving policy energies in different countries (Adedoyin et al. 2020a; Adedoyin et al. 2020b; Borozan, 2018; Cho, et al. 2019; Jebali et al. 2017; Marzi et al. 2019; Ouyang & Yang, 2019; Ouyang & Yang, 2020; Trotta, 2020; Verma et al. 2018; Liu et al. 2020).

According to the World Energy Council report in 2018, energy intensity continuously decreased in most parts of the world, but it was increasing in the Persian Gulf countries, where energy consumption increased more rapidly than the region’s gross domestic product, which is due to the development of their energy-intensive industries, especially for producing oil and gas, as well as the low price of energy in those countries. The Persian Gulf region is made up of eight countries of Iran, Iraq, Kuwait, Saudi Arabia, Qatar, Bahrain, United Arab Emirates, and Oman, whose main income source is oil exportation. Due to their access to cheap energy sources and energy subsidies, these countries are among the largest consumers of energy in the world and are in no suitable conditions in terms of energy intensity and efficiency. The World Bank’s statistics concerning the trend of energy consumption in 2016 show that all the Persian Gulf countries on average experienced a 55% increase in their consumption of energy. On the other hand, due to oil production and refinement as well the production of oil products and high energy consumption levels, the environment in these countries was highly affected by oil-based economic growth so much so that in recent years these countries have been among the largest producers of greenhouse gasses, including carbon dioxide. The World Bank’s 2016 statistics on the trend of carbon dioxide emissions in the Persian Gulf region reveal that on average there was a 52% increase in the countries’ emissions in 2014 compared to 2000. Moreover, statistics show that the carbon dioxide emissions per capita of the Persian Gulf countries were very high in 2019, so much so that eight of these countries were among the eleven countries with the highest emission. The emission amounts of these countries, in metric tons, were 39.57 for Qatar, 23.15 for Kuwait, 22.15 for Bahrain, 21.98 for the United Arab Emirates, 17.47 for Oman, 17.38 for Saudi Arabia, 8.28 for Iran, and 5.01 for Iraq (Crippa et al. 2021).

Significant development in oil and gas industries, which has led to increase in energy consumption and low energy...
efficiency, as well as subsidized oil and gas products has made it highly important for these countries to improve their productivity and energy efficiency and reduce energy consumption. Relatively little attention has been paid to the environmental sustainability of this region even though the countries are important sources of global energy supply (Salahuddin & Gow, 2014; Jammazi & Aloui, 2015; Salahuddin et al. 2015; Magazzino & Elliott, 2016).

Numerous studies have explored the interactions between energy consumption, economic growth, and environment, but the relationship between energy efficiency and environmental quality has never been considered using a combined analytical approach in the economic literature on the Persian Gulf countries. This paper, therefore, will contribute to the existing literature by focusing on Persian Gulf countries in terms of their environmental efficiency and total-factor energy efficiency (TFEE).

This article can contribute to the existing knowledge in different ways. This article provides the first study of all the Persian Gulf countries in terms of their TFEE and environmental efficiency. Also, both desirable (GDP) and undesirable (CO2) output variables have been used at the same time in the data envelopment analysis (DEA) model to evaluate the efficiency of these countries. Moreover, this is the first article to study the elements affecting the TFEE of these countries using a Tobit model.

Thus, this study seeks to answer the following question: what is the level of TFEE in these countries, and what is the effect of each economic and social element on energy efficiency in them?

This paper is presented in five parts. After the introduction, the theoretical background and a review of the literature will be provided. In the third part, the methodology will be explained. The fourth part of this article will present the empirical results and discussion, and the fifth part includes the conclusion and policy implications.

**Theoretical background and review of literature**

**Energy efficiency**

The International Energy Agency (IEA) considers energy efficiency as a method of managing and controlling the growth of energy consumption. Energy is called efficient when more services are provided using less energy input. Economists define energy efficiency as the ratio of a monetary variable to energy input (Huntington, 1996). In general, energy efficiency means using less energy to produce the same product or to provide the same amount of service, compared to the previous situation.

**Total-factor energy efficiency**

The concept of total-factor energy efficiency (TFEE) was first proposed by Hu and Wang (2006). The index of TFEE is used to assess the amount of energy consumed for a certain GDP value based on a few input indexes (Xiali et al., 2013). This index is a good replacement for the traditional indexes of energy efficiency and can involve all three factors of production (labor force, capital, and energy) as inputs to measure the total efficiency (Honma and Hu, 2009).

**Environmental efficiency**

Environmental efficiency is estimated as the ratio of minimum feasible to observed use of the environmentally detrimental input (Reinhard et al., 1999). In fact, this efficiency is an indicator of the level of pollution created by production inputs. Environmental efficiency is also an aspect of technical energy efficiency which focuses on the inputs in terms of their negative impacts on the environment (Graham, 2004). Environmental efficiency, in fact, means producing products and providing services using less energy and raw materials, which leads to less waste, pollution, and environmental damage. Total-factor undesirable output efficiency is measured for some undesirable products such as carbon dioxide. Indeed, this kind of efficiency denotes the total-factor efficiency of the input factor; that is, the real undesirable output should be more than, or equal to, the intended undesirable output while the total surplus of the undesirable output should be higher than, or equal to, zero (Fathi et al., 2015).

**Energy consumption, energy efficiency, and the environment**

Based on the literature, the purpose of improving energy efficiency is not only to achieve environmental goals, such as reducing carbon dioxide emissions, but also to achieve commercial development, industrial competitiveness and energy security. On the other hand, an improvement in energy intensity (the ratio of energy consumption to GDP), as an indicator of energy efficiency, reveals an enhancement in technology and energy consumption. A high level of energy intensity, in general, can have detrimental impacts on the environment. The correlation between the emission of greenhouse gasses and energy intensity is positive because these gasses result from the combustion of fossil fuels, which are created by producing and consuming energy. Many researches have been carried out to propose solutions to the problems of environmental pollution. For example, according to the environmental Kuznets curve, an increase in the income and GDP ultimately leads to an improvement in environmental indicators. Soytas et al. (2007), however, believe that income growth does not in itself lead to solving...
environmental issues and that a reduction in energy consumption is needed to achieve that purpose. It is also possible to view the environmental crisis in another way: efficient use of energy can both prevent energy waste and help enhance the environment through reducing greenhouse gas emissions.

**Review of experimental literature**

Many researches have been carried out on the relationship between energy consumption and the environment. Sharekian and Lotfalipour (2015) studied the effects of energy intensity, population size, wealth, and energy consumption on greenhouse gas emissions. Their results showed that all these variables had a significant positive effect on carbon dioxide emissions. The results of Kafaie and Aqayyan’s study (2015), entitled “Identifying the Factors Affecting Energy Efficiency in Iranian Economy,” showed that foreign direct investment and relative energy prices have a positive effect while added value and the ratio of capital to labor has a negative effect on energy efficiency. Yang and Wei’s study (2018), “The Measurement and Influences of China’s Urban Total-Factor Energy Efficiency Under Environmental Polusion: Based on the Game Cross-Efficiency DEA. Journal of Cleaner Production,” showed that no energy efficiency was achieved during the course of their research. They also found that economic development and city size had a positive effect whereas governmental expenditure, industrial structure, foreign investment, research investment, and production had a negative effect on the urban energy efficiency.

The paper shows that GDP per capita had a negative effect on environmental efficiency during the period. Their study showed that the number of cities below the average environmental efficiency increased from 70 (53.4%) to 83 (63.4%) in that period.

Ervural et al. (2018) carried out a study entitled “A Two-Stage Analytical Approach to Assess Sustainable Energy Efficiency” in Turkey which revealed that GDP per capita, population size, and the amount of energy produced from renewable energy sources had a direct positive effect on energy efficiency. Sağlam (2018), in “A Two-stage Performance Assessment of Utility-Scale Wind Farms in Texas Using Data Envelopment Analysis and Tobit Models,” showed that the elevation, rotor diameter, hub height, and brand of turbine had significant contributions to the wind farms’ efficiency while the turbine age had a negative impact on that efficiency. Borozan (2018), in “Technical and Total-factor Energy Efficiency of European Regions: A Two-Stage Approach,” argued that there were considerable differences in technical and energy efficiency across EU regions with most regions being technically and energy inefficient. Their results also showed that the more developed EU regions were more technically and energy efficient. Their Tobit regression analysis revealed that human capital and innovation were extremely important for efficiency improvement. In “Energy Efficiency and Influencing Factors Analysis on Beijing Industrial Sectors,” Wang et al. (2017), using a bootstrap-DEA and Tobit regression, studied the factors affecting energy efficiency. The results of their research showed that property right structure, market concentration, technological progress, foreign direct investment, enterprise scale, and energy consumption structure affected energy efficiency. Li and Lin (2015), in “The Improvement Gap in Energy Intensity: Analysis of China’s Thirty Provincial Regions Using the Improved DEA (Data Envelopment Analysis) Model,” argued that GDP, industrialized structure, transportation, and fuel prices exerted an effect on energy efficiency.

In “Research on the impact of green finance on energy efficiency in different regions of China based on the DEA-Tobit model,” Wang and Wang (2022) used a DEA to evaluate China’s regional energy efficiency and the Tobit model to analyze the impact of green finance on energy efficiency. They concluded that energy consumption structure had negative relationships with energy efficiency in all regions, energy prices had a positive effect in the central and western regions, but no significant effect on the whole country.

In an article entitled “Evaluation for water resource system efficiency and influencing factors in western China: A two-stage network DEA-Tobit model,” Dong et al. (2021) measured the overall efficiency of water resource systems, water use (WU) efficiency, and wastewater treatment (WT) efficiency of 11 provinces in western China during 2008–2017. They used a panel Tobit regression model to analyze the factors influencing the overall efficiency, WU efficiency, and WT efficiency. Further related studies are summarized in Table 12 in the Appendix.

**Methodology**

The statistical population of this research consisted of the countries of the Persian Gulf region, namely, Iran, Iraq, Saudi Arabia, Qatar, the United Arab Emirates, Bahrain, Oman, and Kuwait in the period 2000–2014 (Fig. 1). The relevant data was acquired from the websites of the World Bank, OPEC, and International Energy Agency. This research was carried out using the following conceptual model (Fig. 2).

**Data envelopment analysis**

Data envelopment analysis is a mathematical planning method which uses linear programming to optimize the target function. In this non-parametric method, efficiency is calculated by dividing the total output value by the total input value. In other words, the efficiency of each
A decision-making unit (DMU) consists of the maximum of ratio of weighted outputs to weighted inputs subject to certain conditions (Charnes et al. 1978). When the goal is to study the efficiency of a number of DMUs (with each unit having $m$ inputs and $n$ outputs), the efficiency of each unit is calculated using the following equation:

$$
\text{Efficiency of } j\text{th DMU} = \frac{\sum_{r=1}^{s} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}}
$$

where $Y_{rj}$ and $X_{ij}$ are the $r$th output and $i$th input of the $j$th DMU, and $V_i$ and $U_r$ are the vectors of the input and output weights. The efficiency value calculated in this method concerns figures less than, or equal to, 1 (Wang et al., 2007). Since the secondary models of DEA are more capable of differentiating between efficient and inefficient units than the primary ones, this study draws on the latter models. The model used in this research has five variables, of which the total number of labor force, gross capital stock (at the constant price of 2010 US dollar), and primary energy...
consumption in kilograms of oil equivalent were the model inputs while the real GDP was the desirable output, and carbon dioxide emissions (in kilo tons) was the undesirable output. Owing to the fact that energy is considered as an input, we have used the input orientation to assess energy efficiency in order to minimize the production factors at a certain level of outputs, assuming variable returns to scale and using a multi-stage linear planning model for each DMU. The following model was used for calculating energy efficiency:

\[ \text{Min} \ Y_{it} = \theta \]  

(2)

\[ \begin{align*}
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot \text{GDP}_{ij} & \geq \text{GDP}_{it} \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot \text{CO}_2 & \geq \text{CO}_2 \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot K_j & \leq \theta K_j \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot L_j & \leq \theta L_j \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot E_j & \leq \theta E_j \\
\sum_{j=1}^{n} \lambda_j & = 1
\end{align*} \]

where \( Y_{it} \) indicates the target function which seeks to minimize the inputs of the Persian Gulf countries as the DMU (\( i \)) at time (\( t \)). Also, \( \lambda, \text{GDP}, \theta, \) and \( \text{CO}_2 \), respectively, indicate the minimum input, real GDP, DMUs’ efficiency, and undesirable output (in the sense of possible reduction in greenhouse gas emissions by decreasing the level of production), that is, carbon dioxide emissions. Moreover, \( K, L, E, \) and \( j \) represent the capital, labor force, energy consumption, and the reference unit with the highest efficiency.

The limitations on the outputs (i.e., the first two limitations) indicate that the studied output of the reference country (the DMU with the highest efficiency) should be equal to, or more than, the same output in the studied country. If the studied output in the studied country is equal to that of the reference country, the studied country is considered as completely efficient in terms of that output, and if it is less than that, the \( i \)th country is considered less efficient than the reference country. The conditions of the inputs reveal that the inputs of the reference country are less than, or equal to, those of the studied country. The condition \( \lambda_j \geq 0 \) indicates the positive parameters of the variables. The condition \( \sum_{j=1}^{n} \lambda_j = 1 \) creates the assumption of a variable returns to scale of the model. In measuring environmental efficiency, the inverse index of carbon dioxide emission is added to the model as the output in order to use the carbon-dioxide-output-oriented model to maximize the outputs, assuming a variable return to scale. Environmental efficiency was calculated using the following model:

\[ \text{Max} Y_{it} = \theta \]  

(3)

\[ \begin{align*}
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot \text{GDP}_{ij} & \geq \theta \text{GDP}_{it} \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot \text{CO}_2 & \geq \theta \text{CO}_2 \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot K_j & \leq K_j \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot L_j & \leq L_j \\
\sum_{j=1}^{n} \sum_{m=1}^{m} \lambda_j \cdot E_j & \leq E_j \\
\sum_{j=1}^{n} \lambda_j & = 1
\end{align*} \]

\[ i = 1, 2, \ldots, 8, j = 1.2, \ldots, n, t = 1, 2, \ldots, m \]

In this model, the target function aims at maximizing the outputs, and \( \theta \) corresponds to this maximization. Here, too, \( \theta \) is a coefficient with a value of less than 1 which causes the outputs of the studied DMUs to be less than, or equal to, the output of the reference unit. If \( \theta = 1 \), the output of the studied unit will be equal to that of the reference unit. This model was used to calculate the ideal values of the outputs and inputs. Then, the total-factor energy and environmental efficiency values of the studied country were obtained using the model provided by Hu and Wang (2006). The total-factor energy and environmental efficiency values were calculated for each DMU using Eqs. (2) and (3), respectively:

\[ TFEE^E_{it} = \frac{\text{ideal energy consumption}}{\text{real energy consumption}} \]  

(4)

\[ TFEE^{CO2}_{it} = \frac{\text{real carbon dioxide emission}}{\text{ideal carbon dioxide emission}} \]  

(5)

**Tobit regression**

Tobit regression is a model proposed by James Tobit in 1958. It describes the relationship between dependent and independent variables. The model treats the data of the dependent variable on the basis that it consists of two parts, and each part of it takes a specific distribution function. Tobit regression is utilized when there are many zero dependent variables whose range is restricted by different conditions. In other words, this model is used to study the effect of variables on efficiency where the variables can be seen in a limited range (Wang et al., 2017). Since energy efficiency ranges between 0 and 1 (a minimum of 0 and maximum of 1) where the variable is restricted at both the upper and lower limits, parametric estimation using ordinary least squares (OLS) will be biased and inconsistent. If the efficiency value is considered as the dependent variable, the OLS general estimation will lead to wrong and unrealistic results.
The use of OLS estimation for a censored sample with limited dependent variables leads to biased and inconsistent estimates, which is due to the basic assumptions of the OLS method. In this part, maximum likelihood estimation was used to estimate the regression coefficients in a censored model. In various regression methods, the analyzed data may be continuous or discrete, but there is a combination of both types of data in Tobit regression: limited observations \((y=0)\) and non-limited observation \((y>0)\). In other words, in this model, the dependent variable indicates two groups or conditions which are either zero or positive values.

\[
y^*_it = \alpha + \beta X_it + \mu_i, \mu_i \sim N(0, \delta^2), i = 1 \cdots n \tag{6}
\]

In the panel Tobit model, the process of producing data is as follows:

\[
y^*_it, y^*_it > 0
\]

\[
y^*_it \leq 0
\]

In the above equations, \(y_{it}\) is a dependent variable (energy efficiency) and \(y^*_it\) is a random unobservable or hidden variable. \(X_it\) is the vector of exogenous variables in which \(K \times 1, \beta\) is a \(K \times 1\) of unknown parameters, \(\alpha\) is the intercept and \(\mu_i\) is the random error (residual), which has a normal distribution with an average of zero and constant variance of \(\delta^2\). In the panel Tobit model, the probability density function for the dependent variable \(y\) is as follows (Amemiya, 1974):

\[
f(y_{it}|X_it, \theta) = \begin{cases} 0 & \text{if } y_{it} < 0 \\ \phi\left(-y_{it}/\sigma_i\right) & \text{if } y_{it} = 0 \\ \varphi\left(y_{it}-y^*_it/\sigma_i\right) & \text{if } y_{it} > 0 \end{cases} \tag{8}
\]

where \(\phi\) and \(\varphi\) are the cumulative distribution and normal probability density functions. Some researchers such as Li and Shi (2018) have used a Tobit censored model while others such as Wijesiri et al. (2015) have used a truncated regression. Simar and Wilson argued that the Tobit censored model leads to contradictory and wrong estimates of the regression results of the factors affecting efficiency estimated by DEA. They believed that the shortened regression would be a better tool for these studies. The shortened regression model, however, may miss some observations and reduce the sample size. The Tobit censored regression model is as follows:

\[
y_{it} = \begin{cases} y^*_{it} & 0 \leq y^*_{it} \leq 1 \\ 0 & y^*_{it} < 0 \\ 1 & y^*_{it} > 1 \end{cases}
\]

\[
y_{it}^* = x_{it}\beta + u_i + \epsilon_{it}
\]

where \(y_{it}^*\) is the unobservable random variable, \(y_{it}\) is the dependent variable, \(x_{it}\) is an explanatory variable, \(u_i\) is the individual effect, and \(\epsilon_{it} \sim N(0, \delta^2)\). The shortened regression model is in the form of the following equation:

\[
y_{it} = \begin{cases} y^*_{it} & 0 \leq y^*_{it} \leq 1 \\ 0 & 0 \leq w \end{cases} \tag{10}
\]

Before estimating based on the static and cointegration tests, autocorrelation and recognition tests were carried out. After fitting the Tobit regression model, the optimum models were analyzed using a leaps-and-bounds algorithm, Bayesian information criterion (BIC), Akaike’s information criterion (AIC), Akaike’s corrected information criterion, and adjusted \(R^2\) and, finally, the Tobit regression was estimated.

The research on factors affecting energy efficiency mainly focuses on technical progress (Liu et al. 2020; Wang & Wang, 2022; Zhu et al. 2019a, b; Li and Lin 2018), industrial structure (Liu et al. 2020; Xiong & Ji, 2019; Zhu et al. 2019a, b; Wang et al. 2019a, b; Rongdi et al. 2019), energy price (Wang & Wang, 2022; Liu et al. 2020; Barkhordar et al. 2018; Antonietti & Fontini, 2019; Wang et al. 2019a, b), economic level and growth (Liu et al. 2020; Sener & Karakas, 2019; Wang and Wang, 2020), industrial agglomeration (Wang et al. 2020; Liu et al. 2017), market openness (Yu et al. 2019), foreign trade (Rongdi et al. 2019), degree of openness (Liu et al. 2020; Imbruno & Ketterer, 2018; Montalbano & Nenci, 2019; Pan et al. 2020), foreign direct investment (Wang & Wang, 2022; Vital Caetano et al. 2022; Yao et al. 2021), urbanization level (Li et al. 2018; Liu et al. 2020; Wang et al. 2019a, b), human capital (Borozan, 2018), and population size (Tachega et al. 2021; Asare’s et al. 2020).

The general form of this Tobit equation is as follows:

\[
EE_{it} = F\left(P_{it}, GDP_{it}, LnP_{it}, T_{it}, POP_{it}, FDI_{it}\right) \tag{11}
\]

In order to study the relationship between the variables, the multivariate Tobit regression was used:

\[
EE_{it} = \alpha + \beta_1\text{LnP}_{it} + \beta_2\text{LnGDP}_{it} + \beta_3\text{LnI}_{it} + \beta_4\text{LnPOP}_{it} + \beta_5\text{LnFDI}_{it}
\]

where \(EE_{it}\) represents total-factor energy efficiency, \(P_{it}\) is OPEC oil price (in US $), \(GDP_{it}\) represents real GDP per capita (in 2010 dollars), \(I_{it}\) stands for the degree of industrialization—defined as the ratio of GDP of industry to the whole GDP (in 2010 dollars), \(T_{it}\) indicates the degree of commercial openness (representing the ratio of the totality of exports and imports to the GDP of each country, which shows the degree of the commercial relationships of one country with others), \(CD_{it}\) is the journal paper citation rate (i.e., the number of citations a paper received in a certain
period of time from other papers) used as an index of science, technology, and innovation\footnote{This index, along with a number of other indexes, was proposed by the World Bank (World Bank, 2016), the Organisation for Economic Co-operation and Development (OECD, 2015), the RAND model of science and technology evaluation (RAND, 2001), and the European Union. Also, this was the only index with data for the countries studied in this research.} (acquired from www.scimagojr.com). FDI\textsubscript{it} represents the foreign direct investment (defined by the International Monetary Fund as an investment made in a foreign country with the intent of lasting interest and exerting significant influence) POP\textsubscript{it} indicates the population of the Persian Gulf countries, and \(\epsilon\textsubscript{it}\) is the residual for country at time \(t\).

### Empirical results and discussion

Descriptive statistics and trends of the variables used in this study, including real GDP, CO2 emission, labor force, capital, energy consumption, population size, oil price, degree of industrialization, degree of commercial openness, foreign direct investment, and paper citation rate as the index of science, technology, and innovation in each of the Persian Gulf countries are given in Appendix Tables 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23 and Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17 are given below.

The amount of total-factory energy efficiency is determined by dividing the optimal energy consumption value by that of the real energy consumption. The value of the real energy consumption in the period studied in this paper was taken from the website of the World Bank, and the optimal energy consumption value was calculated using model (1).

Table 1 shows the results of the Persian Gulf countries’ total-factor energy efficiency in 2000–2014, assuming variable returns to scale with an input-oriented approach. Below, the TFEE of Iran \((i)\) is given as an example to minimize the inputs of the year 2000.

\[
\text{Min} Y = \theta
\]

\[
\text{St:}
\begin{align*}
\sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_j \text{GDP}_{i2000} & \geq \text{GDP}_{i2000} \\
\sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_j \text{CO}_2_{i2000} & \geq \text{CO}_2_{i2000} \\
\sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_j K_{i2000} & \leq \theta K_{i2000} \\
\sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_j L_{i2000} & \leq \theta L_{i2000} \\
\sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_j E_{i2000} & \leq \theta E_{i2000} \\
\sum_{j=1}^{n} \lambda_j = 1 
\end{align*}
\]

\(i = 1, 2, \ldots, 8; j = 1, 2, \ldots, n\)

\(\theta\) is unrestricted in sign and \(\lambda_j \geq 0\).

In 2000, the value of real energy consumption in Iran was 421.621 kg equivalent of crude oil while the optimum value gained as the output of the model was 99.813 kg equivalent of crude oil. The value of Iran’s total-factor energy efficiency in 2000, 0.70, is calculated by dividing the optimum value by the real value. This calculation was performed for each of the eight countries in each of the 15 years covered in this study. TFEE results for the Persian Gulf countries in 2000–2014 is given in Table 1 and Fig. 3, assuming variable returns to scale and using an input-oriented approach.

Considering the values of TFEE, it can be seen that none of these countries had an average energy efficiency of 1, which means that none of them used energy efficiently. The average TFEE in the above-mentioned period was 82\%, indicating that the countries of the Persian Gulf region, using their current inputs, could potentially increase their GDP and decrease their carbon dioxide emissions by reducing their energy consumption by 18\%. Of the energy inefficient countries, Oman and Iran had the lowest average TFEE. This means that Oman and Iran could potentially reduce their energy consumption by 28\% and 42\%, respectively, to become energy efficient.

Iran’s economy enjoys better diversification than those of other Middle Eastern countries, but the problem is that it still greatly depends on revenues from oil and gas production. According to the International Monetary Fund (IMF, 2018a, b), in 2016, nearly 40\% of Iran’s total revenues came from exportation of crude oil. It is estimated that, in 2019, Iran’s economy consumed an 11.7 quadrillion British thermal units of primary energy, which means that, in that year, it was the largest energy consumer in the Middle East. Almost all of Iran’s primary energy consumption was accounted for by natural gas and oil, and there were very limited contributions from hydropower, coal, nuclear, and non-hydro power renewables (BP, 2020). Oman’s total final consumption has
steadily increased in recent years. While in 2000, the energy consumption accounted for 588 ktoe (6833 GWh), energy consumption reached 1591 ktoe (18,512 GWh) in 2011. Comparing various sectors with each other in this country in that period shows that the residential sector consumed the most energy, namely, 49%, followed by the sector of
Fig. 7 Labor force in the Persian Gulf countries (2000–2014)

Fig. 8 Capital stock in the Persian Gulf countries (2000–2014)

Fig. 9 GDP per capita (billion US dollars) in the Persian Gulf countries (2000–2014)
commercial and public services (34%) and industry (14%) (IEA, 2000, 2012).

Environmental efficiency was calculated for the countries of the Persian Gulf region using an output-oriented approach, by dividing the real amount of carbon dioxide emissions by the ideal amount of carbon dioxide emissions, assuming variable returns to scale. The real amount of carbon dioxide emissions was taken from the World Bank website, and the ideal amount was calculated using model (2). Table 2 and Fig. 4 show the environmental efficiency results.

The average environmental efficiency in the above-mentioned period was 78%, which shows that the countries of the Persian Gulf region could become efficient by reducing 20% of their carbon dioxide emissions on average, using existing inputs. The real and optimal averages of (potential) excess carbon dioxide emissions of the Persian Gulf countries are given in Table 3 and Fig. 5.

According to the results of this table, Iran, Saudi Arabia, and Iraq had the worst while the United Arab Emirates, Qatar, and Bahrain, in spite of their highest carbon dioxide emissions in the world (Crippa et al. 2021), had the best environmental performance in the Persian Gulf region. Iran, with a real average of 496,000 tons and optimal average of 326,000 tons, could potentially reduce its carbon dioxide emissions by 170,000 tons, which was the highest potential in the region. In Iran, most of the greenhouse (especially CO₂) emissions have been due to increase in energy intensity (Falahi & Hekmati Farid, 2013; Damankeshide et al. 2011), that is, overconsumption of cheap energy in various economic sectors, especially for heating residential buildings.
(Waseghi & Esmaeili, 2009), the high amount of energy consumed by the worn-out transportation system, the use of old technologies in various industries, rapid growth of cities (Ashena & Hossein Abadi, 2020), the development of energy-intensive and polluting industries (Pourabadollah Koich et al. 2016), the production of low-quality petrol by domestic petrochemical factories, and the excessive consumption of fossil fuels and creating of polluting gases in the oil, gas, and petrochemical industries which have become out of date and have not been overhauled because of American sanctions on Iranian economy.

In Saudi Arabia, almost all electricity is produced by burning fossil fuels: in 2010, approximately 53.85% of the country’s electricity was produced using oil and the rest using natural gas (Saad Alshehry & Belloumi, 2015; Algarini 2019). In this country, economic growth (Salahuddin and Gow, 2014; Alqudair, 2011), the production of electricity using fossil fuels, the development of oil industry, and drinking water equipment, as well as other industrial activities, have led to the production of a huge amount of wastewater and greenhouse gasses as well as chemical pollution. Also,
Vehicle exhaust emissions are responsible for 50% of the hydrocarbon gasses and environmental pollution.

Severe shortage of electricity is an important barrier to Iraq’s social and economic development even though there has been a significant growth in the power grid capacity of the country. Iraq needs to increase its power generation capacity and make sure that there is enough fuel for that purpose (Iraq Energy Outlook, 2020). At the moment, the country lacks a reliable national electricity network, and this has made for the use of various kinds of generators in homes, farms, factories, and various public and private institutions. A mixture of fuel oil and gas oil is now used as a cheap solution due to lack of kerosene, and this has led to an increase in GHG emissions and other air pollutants (Ministry of Environment, 2013). The energy sector in Iraq is responsible for a great amount of GHG emissions (Bassim et al. 2020) as it normally creates 75% of total GHG emissions in CO₂ equivalent terms (Ministry of Health and Environment, 2016).

The United Arab Emirates, Bahrain, Qatar, and Kuwait need to focus on the quality of their environments. The
various environmental projects which have begun in recent years must be expanded. The UAE government, for example, has taken special measures over the past 10 years to reduce environmental pollution. In 2008, the largest solar power project in the Middle East and North Africa, The Green Community, was launched in Dubai. The project was expected to prevent the country’s annual production of 351 tons of carbon dioxide.

At this stage, using Tobit regression, we will study the factors affecting TFEE. Before estimating the model, the stationarity of variables was determined using the Levin-Lin-Chu test (2002). Table 4 shows the results of this test for the variables of this study.

The results given in the above table show that most of the variables were stationary, and only the oil price and GDP per capita became stationary with intercept and first-differencing. Then, the Kao cointegration test (1999) was used to study the long-term relationships between the variables. Table 5 contains the results of this test.

According to the results of this test, at a confidence level of 99%, the null hypothesis, which indicates the absence of a cointegration vector, was rejected while long-term relationships between the variables were confirmed. The Wooldridge autocorrelation test (2002) was used to study the autocorrelation between the disturbances. Table 6 shows the result of this test.
According to the results of this test, at a confidence level of 99%, the null hypothesis, which indicates the absence of autocorrelation between the disturbances, could be accepted, and there was no autocorrelation between the components of the model of this study. In order to choose between the two sets of panel data and pooled data, we used the Chow test; the results of which are given in Table 7.

The results presented in this table reveal that, at a confidence level of 95%, the null hypothesis, which indicates the use of pooled data, was rejected while the use of panel data was confirmed. Finally, the Hausman (1978) test was applied to determine the model estimation in terms of fixed and random effects, as shown in Table 8.

The results of this test showed that the null hypothesis was accepted at a confidence level of 95%, and the model was used with random effects. Therefore, the Tobit panel data method with random effects was used to estimate the model. Table 9 shows the results of this estimation.

According to the results presented in this table, only the commercial openness coefficient was not significant at the confidence level of 95%. In the next stage, the best set for each number of explanatory variables and information

| Country     | Iran  | Iraq  | Saudi Arabia | United Arab Emirates | Qatar   | Oman  | Kuwait | Bahrain |
|-------------|-------|-------|--------------|----------------------|---------|-------|--------|---------|
| 2000        | 0.57  | 0.69  | 1            | 1                    | 1       | 1     | 0.79   | 1       |
| 2001        | 0.57  | 0.67  | 1            | 1                    | 1       | 1     | 0.84   | 1       |
| 2002        | 0.53  | 0.63  | 0.82         | 0.93                 | 0.83    | 0.95  | 0.73   | 1       |
| 2003        | 0.57  | 0.42  | 0.97         | 0.97                 | 1       | 0.89  | 1      | 0.9     |
| 2004        | 0.53  | 0.67  | 1            | 1                    | 1       | 0.86  | 0.99   | 0.88    |
| 2005        | 0.55  | 0.7   | 1            | 0.97                 | 0.94    | 1     | 1      | 0.79    |
| 2006        | 0.57  | 0.8   | 0.97         | 1                    | 0.76    | 0.67  | 0.89   | 0.74    |
| 2007        | 0.61  | 0.81  | 0.96         | 0.98                 | 0.74    | 0.6   | 0.84   | 0.7     |
| 2008        | 0.57  | 0.85  | 0.98         | 0.88                 | 0.8     | 0.64  | 0.78   | 0.66    |
| 2009        | 0.58  | 0.82  | 0.9          | 0.78                 | 0.8     | 0.64  | 0.67   | 0.66    |
| 2010        | 0.63  | 0.82  | 0.88         | 0.78                 | 0.93    | 0.59  | 0.76   | 0.64    |
| 2011        | 0.65  | 0.85  | 1            | 0.87                 | 1       | 0.52  | 0.84   | 0.64    |
| 2012        | 0.56  | 0.93  | 1            | 0.9                  | 1       | 0.49  | 0.82   | 0.65    |
| 2013        | 0.55  | 0.99  | 1            | 0.97                 | 0.82    | 0.47  | 0.82   | 0.63    |
| 2014        | 0.55  | 1     | 1            | 0.89                 | 0.48    | 0.82  | 0.63   |         |
| Average     | 0.58  | 0.78  | 0.97         | 0.94                 | 0.91    | 0.72  | 0.84   | 0.78    |

| Country     | Iran  | Iraq  | Saudi Arabia | United Arab Emirates | Qatar   | Oman  | Kuwait | Bahrain |
|-------------|-------|-------|--------------|----------------------|---------|-------|--------|---------|
| 2000        | 0.67  | 0.57  | 1            | 0.98                 | 0.99    | 0.99  | 0.66   | 0.99    |
| 2001        | 0.62  | 0.68  | 1            | 0.98                 | 1       | 1     | 0.64   | 0.99    |
| 2002        | 0.82  | 0.57  | 1            | 0.98                 | 0.87    | 0.81  | 0.68   | 0.99    |
| 2003        | 0.92  | 0.43  | 1            | 1                    | 1       | 0.64  | 0.8    | 0.86    |
| 2004        | 0.77  | 0.38  | 0.84         | 0.98                 | 0.76    | 1     | 0.82   | 0.82    |
| 2005        | 0.71  | 0.38  | 0.83         | 0.95                 | 0.89    | 0.75  | 0.85   | 0.74    |
| 2006        | 0.65  | 0.38  | 0.77         | 1                    | 0.65    | 0.61  | 0.84   | 0.75    |
| 2007        | 0.64  | 0.64  | 0.85         | 0.92                 | 0.71    | 0.53  | 0.83   | 0.57    |
| 2008        | 0.61  | 0.53  | 0.81         | 0.9                  | 0.77    | 0.58  | 0.8    | 0.52    |
| 2009        | 0.6   | 0.79  | 0.71         | 0.85                 | 0.84    | 0.6   | 0.76   | 0.59    |
| 2010        | 0.58  | 0.74  | 0.64         | 0.88                 | 0.91    | 0.58  | 0.79   | 0.56    |
| 2011        | 0.56  | 0.62  | 1            | 1                    | 1       | 0.51  | 0.84   | 0.58    |
| 2012        | 0.54  | 0.59  | 0.88         | 0.94                 | 0.96    | 0.48  | 0.81   | 0.6     |
| 2013        | 0.53  | 1     | 0.92         | 0.97                 | 0.98    | 0.49  | 0.84   | 0.55    |
| 2014        | 0.76  | 0.98  | 0.83         | 0.94                 | 0.84    | 0.54  | 0.87   | 0.55    |
| Average     | 0.66  | 0.64  | 0.9          | 0.96                 | 0.92    | 0.67  | 0.8    | 0.71    |
criteria was determined. Table 10 provides the information criteria results for the optimal models. The above results reveal the superiority of the model without commercial openness.

Below, the results of estimating the optimal model using the Tobit panel data with random effects are given in Table 11.

The results show the direction and degree of the impact of oil prices, GDP per capita degree of industrialization, article citation rate, foreign direct investment, population sizes, and energy efficiency of the Persian Gulf countries. According to the results, the random effects model is well-specified and all explanatory variables are significant. The effects of various variables on energy efficiency are as follows.

Oil prices are positively related to energy efficiency. When other variables remain unchanged, the average value of energy efficiency increases by 0.74 efficiency units as the relative energy price increases by 1 unit. An increase in the relative energy price can make for reductions to the companies’ profit. In order to keep their own benefits and competitive advantages, they increase their technology input, and use fewer resources to improve their energy utilization. This is consistent with the results of Liu et al. (2020) while Yang and Wei (2019) and Wang et al. (2019a, b) argued that low energy price could restrict the improvement of energy efficiency, and changing the energy price could affect energy consumption. On the other hand, energy price rises could make manufacturers use poor and cheap raw materials, which could lead to low efficiency and high pollution.

| Table 3 Real and optimal average carbon dioxide emissions (1000 tons) in the Persian Gulf countries (2000–2014) |
| **Country** | **Real average** | **Optimal average** | **Reduction potential** |
| --- | --- | --- | --- |
| Iran | 496 | 326 | 170 |
| Iraq | 102 | 57 | 44 |
| Saudi Arabia | 411 | 357 | 54 |
| United Arab Emirates | 132 | 127 | 4 |
| Qatar | 56 | 51 | 5 |
| Oman | 35 | 24 | 10 |
| Kuwait | 74 | 58 | 15 |
| Bahrain | 21 | 15 | 6 |

| Table 4 Results of Levin-Lin-Chu test |
| **Variables** | **Function form** | **LLC** | **Degree of reliability** |
| --- | --- | --- | --- |
| Total energy efficiency factors | With trend and width of origin | 0.0036 | I(0) |
| Oil prices | 0.72 | 0.0000 | I(1) |
| GDP per capita | 0.9 | 0.0000 | I(1) |
| Degree of industrialization | 0.0001 | I(0) |
| Degree of commercial openness | 0.0054 | I(0) |
| Article citation rate | 0.0058 | I(0) |
| Foreign direct investment | 0.0036 | I(0) |
| Population | 0.0000 | I(0) |

| Table 5 Results of Kao cointegration test |
| **Statistic** | **Prob** |
| --- | --- |
| −6.24 | 0.000 |

| Table 6 The Wooldridge autocorrelation test |
| **F** | **df** | **Prob** |
| --- | --- | --- |
| 3.446 | 7 | 0.1 |

| Table 7 Results of Chow test |
| **Statistic** | **Prob** |
| --- | --- |
| 3.26 | 0.0036 |

| Table 8 Results of Hausman test |
| **Statistic** | **Prob** |
| --- | --- |
| 2.89 | 0.89 |

| Table 9 Results of Tobit panel data estimation |
| **Variables** | **Coefficient** | **Standard normal test** | **Prob** |
| --- | --- | --- | --- |
| Constant | 0.8 | 8.78 | 0.000 |
| Oil price | 0.74 | 67.06 | 0.000 |
| GDP per capita | 0.75 | 75.71 | 0.000 |
| Degree of industrialization | 0.04 | 2.83 | 0.005 |
| Degree of commercial openness | 0.002 | 0.27 | 0.78 |
| Article citation rate | −0.002 | −2.81 | 0.005 |
| Foreign direct investment | −0.002 | −1.67 | 0.095 |
| Size of population | 0.007 | 3.16 | 0.002 |
| Wald statistics | 6030.42 | 0.000 |
| Probability | 212.95 | 0.89 |
| Log likelihood | 10575 | 0.000 |

| Table 10 Results of Tobit panel data estimation |
| **Variables** | **Coefficient** | **Standard normal test** | **Prob** |
| --- | --- | --- | --- |
| Constant | 0.8 | 8.78 | 0.000 |
| Oil price | 0.74 | 67.06 | 0.000 |
| GDP per capita | 0.75 | 75.71 | 0.000 |
| Degree of industrialization | 0.04 | 2.83 | 0.005 |
| Degree of commercial openness | 0.002 | 0.27 | 0.78 |
| Article citation rate | −0.002 | −2.81 | 0.005 |
| Foreign direct investment | −0.002 | −1.67 | 0.095 |
| Size of population | 0.007 | 3.16 | 0.002 |
| Wald statistics | 6030.42 | 0.000 |
| Probability | 212.95 | 0.89 |
| Log likelihood | 10575 | 0.000 |
Rising oil and energy prices are also causing households in rich Persian Gulf countries to use state-of-the-art cooling devices and reduce their energy consumption. However, in lower income per capita countries such as Iran and Iraq, and in rural areas where more modern technologies are not possible, rising energy prices are likely to force households to use alternatives that are more polluting. Rising energy prices are also causing people to use hybrid or electric vehicles instead of gasoline and diesel ones in the region, or to use public transportation instead of private cars, which helps reduce fossil fuel consumption.

Real GDP per capita (in 2010 dollars) is positively related to energy efficiency. When other variables remain unchanged, the natural logarithm of real GDP per capita increases by 1 unit, and energy efficiency increases by 0.75 on average. This indicates that with the improvement of Persian Gulf countries GDP, energy efficiency will be further improved, which is similar to the conclusions of Liu et al. (2020), Yang and Wei (2019), and Yu et al. (2019).

Countries such as Saudi Arabia, Qatar, and the United Arab Emirates, which have advanced infrastructure and technology, especially in the fields of oil, gas, and energy, and which have good economic growth and development, have more potential and opportunities for optimal allocation of resources and energy efficiency. Countries such as Kuwait, Bahrain, and Oman, despite having weaker infrastructure than the countries of the previous category, have high per capita incomes and the necessary conditions for efficient use of energy. Iran and Iraq, however, despite their good size of population and access to human capital, have old economic infrastructure, especially in energy production, and need high investment in infrastructure to be able to increase their energy efficiency by increasing economic growth and per capita income. Conversely, countries with high energy efficiency can produce more economic output, thus improving the GDP. Energy efficiency and GDP are mutually interactive and increase each other. This is consistent with the results of Liu et al. (2020) but opposite to those of the Wang and Wang (2020) article, which states that the improvement of GDP has a negative impact on energy efficiency, increases the development of industrialization and urbanization, increases energy consumption, and weakens the positive influence of productivity improvement on energy efficiency. The article citation rate as a proxy for science, technology, and innovation is negatively associated with energy efficiency. Keeping other variables unchanged, the energy efficiency increases by $-0.02$ efficiency units for each unit of a natural logarithm of article citation rate in each country, which demonstrates that scientific progress plays a negative role in improving countries energy efficiency. This negative effect can mean that the quality of science, technology, and innovation in these countries, as represented by their article citation rates, does not necessarily reflect their technological innovations in energy-related industries or innovations that can help improve energy efficiency. Wang and Wang (2022) and Liu et al. (2020) argue that scientific innovations cannot only improve the energy efficiency by using low energy consumption equipment, but also optimize the production process to enhance the efficiency of production factors, so as to exert a positive influence on the improvement of energy efficiency.

The size of population is positively related to energy efficiency. Energy efficiency increases by 0.007 as the total population size increases by one percentage point. This

| Variables                  | Coefficient | Standard normal test | Prob  |
|----------------------------|-------------|----------------------|-------|
| Constant                   | 0.82        | 81.72                | 0.000 |
| Oil prices                 | 0.74        | 67.58                | 0.000 |
| GDP per capita             | 0.75        | 77.00                | 0.000 |
| Degree of industrialization| 0.04        | 2.93                 | 0.003 |
| Article citation rate      | $-0.02$     | $-3.2$               | 0.001 |
| Foreign direct investment  | $-0.002$    | $-1.65$              | 0.099 |
| Size of population         | 0.007       | 3.38                 | 0.001 |
| Wald statistics            | 6214.68     |                      |       |
| Probability                | 0.000       |                      |       |
| Log likelihood             | 212.91      |                      |       |

### Table 10 Information criteria result for the optimal models

| Number of regressions in optimal models | Number of constituent regressions in optimal models | Information criteria |
|----------------------------------------|----------------------------------------------------|----------------------|
| 1 GDP                                  | 1 GDP                                               | $-108.7$ $-114.06$ $-114.27$ 0.22 |
| 2 GDP, P                               | 2 GDP, P                                            | $-622.44$ $-630.46$ $-630.8$ 0.98 |
| 3 GDP, POP                             | 3 GDP, POP                                           | $-624.84$ $-635.46$ $-635.98$ 0.99 |
| 4 GDP, P, POP, I                       | 4 GDP, P, POP, I                                     | $-624.5$ $-637.69$ $-638.43$ 0.99 |
| 5 GDP, P, POP, I, CD                   | 5 GDP, P, POP, I, CD                                 | $-626.95$ $-642.67$ $-643.67$ 0.99 |
| 6 GDP, P, POP, I, CD, FDI              | 6 GDP, P, POP, I, CD, FDI                            | $-623.78$ $-642.00$ $-643.29$ 0.99 |
| 7 GDP, P, POP, I, CD, FDI, T           | 7 GDP, P, POP, I, CD, FDI, T                         | $-619.5$ $-639.71$ $-641.35$ 0.99 |

### Table 11 Results of estimating the optimal model

Schwartz Akaike Corrected Akaike Adjusted $R^2$

1 $-619.5$ $-639.71$ $-641.35$ 0.99
2 $-622.44$ $-630.46$ $-630.8$ 0.98
3 $-624.84$ $-635.46$ $-635.98$ 0.99
4 $-624.5$ $-637.69$ $-638.43$ 0.99
5 $-626.95$ $-642.67$ $-643.67$ 0.99
6 $-623.78$ $-642.00$ $-643.29$ 0.99
7 $-619.5$ $-639.71$ $-641.35$ 0.99
coefficient is very small, which means that in the Persian Gulf countries, increase in the population size leads to better energy efficiency in the long run. This is consistent with the results of Tachega et al. (2021) and Asare et al. (2020) who found the population size indicator to be positively correlated with TFEE in Africa. This positive relationship is possible when with investment in education and hygiene, people are turned into human capital, which makes for creativity and innovation and helps improve energy efficiency in the long run.

Degree of industrialization has a significant negative impact on energy efficiency. When other variables remain unchanged, the energy efficiency drops by 0.04 efficiency units as the degree of industrialization increases by one percentage point. Degree of industrialization prevents the improvement of energy efficiency to some extent, and this is identical with the conclusions of Liu et al. (2020), Zhu et al. (2019a, b), and Xiong et al. (2019).

The countries of the region are among the largest oil producers and exporters in the world, and their economy is completely dependent on the production and export of oil and gas. Also, the oil and gas industry is the most important industrial sector of these countries. The more this sector is developed due to higher global demand for fossil fuels, the higher energy consumption and, consequently, the lower energy efficiency in these countries. The way out of this problem is diversity in production and moving toward a diverse and knowledge-based economy.

Foreign direct investment negatively influences energy efficiency, which is consistent with the conclusions of most studies. When other factors remain unchanged, the energy efficiency will decrease by −0.002 efficiency units for every one-percentage-point increase in foreign direct investment. Wang and Wang (2022) showed that FDI had a negative effect in the western region and positive effect in the eastern and central regions of China but no effect on the whole country. Yao et al. (2021) showed that FDI positively increased the energy efficiency after controlling the unobserved fixed effects of country and year. Vital Caetano et al. (2022) showed that FDI could boost pollution only by raising energy consumption.

The negative coefficient of foreign direct investment in this study can be due to more investment in oil, gas, and energy industries than in services and other economic sectors, so that the introduction of new technologies due to foreign direct investment led to an increase in total energy consumption and increased greenhouse gas emissions in these countries.

Conclusion and policy implications

Carbon emissions have become a public concern since Paris Climate Conference in 2015, while energy efficiency improvement and the development of clean energy are crucial to carbon reduction. The main goal of this paper was the evaluation of a two-stage performance, combination of data envelopment analysis, and Tobit regression to assess the energy efficiency of the Persian Gulf countries in the years 2000–2014. At first, the TFEE and environmental efficiency values were calculated using data envelopment analysis and assuming variable returns to scale. In the second stage, the relationships of GDP per capita, oil price, degree of industrialization, population size, science and technology (paper citations), foreign direct investment, and degree of commercial openness with TFEE were studied. The results of this study showed that:

First, none of the countries was completely energy efficient. Saudi Arabia and United Arab Emirates had the highest and second highest levels of TFEE, respectively, while Oman and Iran had the lowest and second lowest levels, respectively. The Persian Gulf countries have the highest levels of energy consumption per capita and energy intensity in the world. Development of heavy industry and petrochemical plants, and energy-intensive industries in general, as well as using traditional and old means of transportation and warm and dry climates are some of the reasons for high energy intensity in these countries. The energy subsidies have also caused an increase in the consumption of energy. Also, the dependence of these countries on highly fluctuating oil and gas revenues, economic crises, sanctions (Iran), wars (Iraq), and regional political confusion are among the reasons for the energy inefficiency of these countries.

Second, the results of assessing the environmental efficiency showed that the United Arab Emirates and Qatar had the best and second best performance, respectively, while Iran and Iraq had the worst and second worst performance, respectively. The rising trend of demand for fossil fuel energies has had a key role in increasing carbon dioxide emissions. Due to the fact that the economies of the Persian Gulf countries depend on the oil, gas, and petrochemical industries and their revenues mainly rely on fossil fuels and also because the production and consumption of greenhouse gases, these countries are highly exposed to carbon dioxide emission due to the production and consumption of such fuels. Iran, Saudi Arabia, and Iraq are among the largest producers of carbon dioxide in the world and do not have an appropriate environmental performance.

Third, the results of the Tobit analysis showed that there was a direct relationship between TFEE and the variables of GDP per capita, oil price, degree of industrialization, and population size in a way that an increase in any of these variables led to an enhancement in the energy efficiency of these countries. Foreign direct investment and paper citation rates (representing the variable of science...
and technology), however, had an inverse relationship with TFEE. It seems that most of the foreign direct investments in the Persian Gulf countries had been made in energy-intensive industries. In other words, the imported technologies had increased the consumption of energy in these countries. On the other hand, while science, research, and publications of scientific papers grew in these countries, the new scientific findings did not help them to increase their energy efficiency, or it could be claimed that there was no effective relationship between academic research and industries or energy efficiency. No significant relationship was found between commercial openness and energy efficiency.

Some policy implications that could be drawn from what has been found in this study are as follows:

First, according to the results, oil prices, GDP per capita, population size, and degree of industrialization made for improvements in TFEE during the period studied in this research. Therefore, it can be claimed that the countries of the Persian Gulf region could enhance their energy efficiency by diversifying their income sources and avoiding mono-product economies that almost solely depend on oil, implementing quality population development policies, focusing on skill training, improving their human capital, and increasing investment in a knowledge-based economy and energy-saving industries.

Second, the negative effect of the paper citation rate as a proxy for science, technology, and innovation on energy efficiency clearly shows that more attention should be paid to research and training of labor force, as well as to the improvement of the relationship between the university and the industry as the two main creators of technology and innovation. It can be seen that the findings of the academy were not utilized in the industry, knowledge was not converted to technology, and priority knowledge areas were not appreciated in these countries.

Third, the negative effect of foreign direct investment (FDI) on energy efficiency indicates that such investments focused on energy-intensive industries. Therefore, the governments of these countries should prevent the import of old technologies by adopting stricter laws and should attract foreign investment to develop their service sectors, especially in knowledge-based and energy-saving areas. Accurate formulation and implementation of environmental requirements and standards in the import of new technology in these countries is recommended.

Fourth, improving energy efficiency is a fundamental way to ensure energy security and sustainable development. It is, therefore, proposed that regional governments increase investment in clean energy, especially solar energy, which could be helped by the hot and dry climate of these countries. These governments are also encouraged to prioritize the design and implementation of environmental projects such as planting trees (especially mangroves), and to use emission reduction technologies in oil and gas industries, especially in Iran and Iraq, Kuwait, and Oman. The use of hybrid and electric vehicles and modernization of transportation (in Iran and Iraq), implementation of the right tax policies and energy pricing policies are recommended for these countries.

Fifth, the Persian Gulf countries face many common environmental problems such as gas emissions from fossil fuels, oil pollution, dust storms, seasonal heavy rains, sea water pollution, drought, and scarcity of fresh water. Many of these issues will not be resolved without development of regional cooperation, establishment of friendly relations, and mutual trust between these countries.

Of all the environmental variables, we focused only on carbon dioxide. It is clear that by considering other greenhouse gasses such as methane, carbon monoxide, nitrogen oxide, sulfur hexafluoride, as well as water and soil pollution, more comprehensive conclusions can be reached. Moreover, the Persian Gulf countries can be examined in two categories, with the first category consisting of Saudi Arabia, Iran, and Iraq, which have a higher population size, and the second including Oman, Kuwait, UAE, Qatar, and Bahrain, which have a lower population size. It is also recommended that instead of the article citation rate, the number of patents be used in other studies to study the relationship between technological progress and energy efficiency.
## Table 12 A review of studies on environmental and energy efficiency

| Author(s) | Article title | Model | Data | Results |
|-----------|---------------|-------|------|---------|
| Mohanta et al. (2021) | Efficiency analysis in the management of COVID-19 pandemic in India based on data envelopment analysis | DEA | 32 states and union territories (UTs) of India | The states and UTs are completely ranked with the help of efficiency score and maximal balance index, and evaluated benchmarking for each states and UTs |
| Tsaples and Papathanasiou (2021) | Data envelopment analysis and the concept of sustainability: a review and analysis of the literature | Review | Review the literature from 2017 until 2020 | Recent efforts focus on including new dimensions in sustainability like technology. The study of sustainability has shifted toward urban environments. The lack of a unified definition of sustainability persists in current research |
| Lina and Saiab (2022) | Sustainable transitioning in Africa: a historical evaluation of energy productivity changes and determinants | Meta frontier Malmquist framework (MMEPI) | 2000–2016 | Energy productivity improved, but average distribution density shows a backward trend. Technological advances play a pivotal role in energy productivity improvement. Energy price, GDP growth, and population density positively support energy productivity |
| Aziz et al. (2020a) | The role of tourism and renewable energy in testing the environmental Kuznets curve in the BRICS countries: fresh evidence from methods of moments quantile regression | f moments quantile regression (MMQR) | 1995–2018 | The finding shows that tourism has stronger significant negative effects from 10 to 40th quantile while the effects are insignificant at remaining quantiles. Furthermore, an inverted U-shape EKC curve is also apparent at all quantiles excluding 10th and 20th quantiles. For renewable energy, the results are found negatively significant across all quantiles (10th–90th) which claim that CO2 emission can be reduced by opting renewable sources |
| Anwar et al. (2021) | The nexus between urbanization, renewable energy consumption, financial development, and CO2 emissions: evidence from selected Asian countries | Panel cointegration decomposition analysis | 1990–2014 | Based on the study outcomes, a comprehensive SDG-oriented policy framework has been recommended, so that these economies can make progression toward attaining the objectives of SDG 13 and SDG 7 |
| Author(s)             | Article title                                                                 | Model                                      | Data          | Results                                                                                                                                 |
|----------------------|-------------------------------------------------------------------------------|--------------------------------------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| Aziz et al. (2020c)  | The role of natural resources, globalization, and renewable energy in testing the EKC hypothesis in MINT countries: new evidence from method of moments quantile regression approach | Moments quantile regression-EKC            | 1995–2018     | The outcome validates the EKC curve between economic progress and carbon emissions from the third quantile to the extreme highest quantile |
| Danish et al. (2021) | Investigate the role of technology innovation and renewable energy in reducing transport sector CO2 emission in China: a path toward sustainable development | QARDL approach                            | 1990–2018     | That economic growth, technology innovation, and renewable energy significantly influence CO2 emission in the transportation sector in China. Both renewable energy consumption and innovation show a negative impact on emissions of CO2 related to transport. It depicts that due to the increase in renewable energy and innovation, the CO2 emission in the transport sector is likely to decrease |
| Aziz et al. (2020b)  | Revisiting the role of forestry, agriculture, and renewable energy in testing environment Kuznets curve in Pakistan: evidence from quantile ARDL approach | Quantile autoregressive distributed lag (QARDL) | 1990–2018     | The result of this study validates the EKC hypothesis for Pakistan and shows quantile-dependent relationship, and in that case, using the conventional methods may somewhat lead to biased results |
| Khan et al. (2020)   | Determinants of economic growth and environmental sustainability in South Asian Association for Regional Cooperation: evidence from panel ARDL | Panel ARDL                                 | 2005–2017     | The findings revealed that environmental sustainability is strongly and positively associated with national scale-level green practices, including renewable energy, regulatory pressure, and eco-friendly policies, and sustainable use of natural resources. Conversely, in our model, the “regulatory pressure” has an insignificant effect on economic growth |
| Suki et al. (2022)   | The paradigms of technological innovation and renewables as a panacea for sustainable development: a pathway of going green | Bootstrap ARDL                             | 1971–2017     | The result reported that green innovation has a positive and negative relationship with growth and CO2 emissions respectively in both the short and long run, whereas the relationship of renewable energy with CO2 emission remains negative for both short and long run |
| Author(s)          | Article title                                                                 | Model                                | Data          | Results                                                                                                                                                                                                                                                                                                                                 |
|-------------------|-------------------------------------------------------------------------------|--------------------------------------|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Anser et al. (2021) | Does globalization affect the green economy and environment? The relationship between energy consumption, carbon dioxide emissions, and economic growth | Fully modified ordinary least square (FMOLS) | 1985–2019     | The individual country as Bangladesh shows a positively significant impact on the CO2 emissions and destroys the level of environment regarding non-renewable energy and globalization index. However, negative and positive growth levels (GDP) and square of GDP confirm the EKC hypothesis in this region. This study has identified the causality between GDP growth and carbon emission and found bidirectional causality between economic growth and energy use. |
| Batool et al. (2019) | Green is clean: the role of ICT in resource management                         | Novel Morlet wavelet approach        | 1973–2016     | The outcomes reveal that the connections among the stated variables progress over frequency and time domain. From an economic point sight, the wavelet method displays that ICT helps to reduce environmental degradation in a medium and long run in the South Korean economy.                                                                 |
| Amin et al. (2022)  | Blessing or curse: the role of diversity matters in stimulating or relegating environmental sustainability—a global perspective via renewable and non-renewable energy | Generalized method of moments models (GMM) | 1990–2020     | The results show that ethnic and religious diversity have significant positive impacts on renewable energy consumption and vice versa on non-renewable energy consumption. Policymakers need to promote collective action and communication among different groups while acknowledging that investment for public benefits often requires broad social consensus and solidarity. |
| Author(s)               | Article title                                                                 | Model                      | Data                        | Results                                                                                                                                                                                                 |
|------------------------|-------------------------------------------------------------------------------|----------------------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fatima et al. (2022)   | Households perception and environmentally friendly technology adoption: implications for energy efficiency | Structural equation modeling | 782 Pakistani households    | The main findings are: firstly, the drivers of adoption intention of EFTs include technological awareness, perceived environmental importance, perceived behavioral control, and perceived benefits. Secondly, significant barriers to the adoption intention of EFTs involve the perceived cost of EFTs and the perceived risk-averse behavior of households. Thirdly, among all factors, perceived environmental importance reveals the most substantial contribution, whereas perceived risk-averse behavior shows the least contribution to the adoption intention of EFTs. |
| Ahmad et al. (2021)    | Heterogeneous links among urban concentration, non-renewable energy use intensity, economic development, and environmental emissions across regional development levels | Principal component analysis | 31 Chinese provinces       | Environmental Kuznets curve (EKC) hold at national as well as highest development levels. Urban concentration (UC)/economic development (ED) had inverted U-shaped link with EEI. Medium/lowest development regions (non-EKC) had positive linear links of UC and ED with EEI. Degree of long-run effects exceeded short-run for all models at all development levels. |
| Author(s)          | Article title                                                                 | Model                        | Data                          | Results                                                                                                                                                                                                 |
|-------------------|-------------------------------------------------------------------------------|------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Yasir et al. (2021) | Factors affecting electric bike adoption: seeking an energy-efficient solution for the post-COVID era | Structural equation modeling | 507 Chinese bike riders      | The main findings are: first, speed capacity, mileage capacity, and real-time camera positively drove E-bike adoption intention. Second, price differentiation negatively affected E-bike adoption intention. Third, the theory of planned behavior factors, including perceived relative advantage, cost savings, subjective norms, perceived behavioral control, and attitudes toward E-bike adoption, proved to be drivers of E-bike adoption intention. Finally, cost savings are the most critical factor of E-bike adoption intention, whereas perceived behavior control is the least critical factor. |
| Pata and Isik (2021) | Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting | Novel dynamic ARDL simulation model | 1981–2016                    | The study validate the existence of the EKC for load capacity factor in China. Income, energy intensity, and resources rent reduce the load capacity factor. Human capital have a pivotal role in improving environmental quality. |
| Alvarado et al. (2021) | Ecological footprint, economic complexity and natural resources rents in Latin America: empirical evidence using quantile regressions | Quantile regressions         | Latin America                 | Economic complexity has an asymmetric impact on the ecological footprint. The natural resources rents has an asymmetric impact on the ecological footprint.                                                                 |
| Author(s)          | Article title                                                                 | Model                                      | Data        | Results                                                                                                                                                                                                 |
|-------------------|--------------------------------------------------------------------------------|--------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rehman et al. (2021) | An asymmetrical analysis to explore the dynamic impacts of CO2 emission to renewable energy, expenditures, foreign direct investment, and trade in Pakistan | Nonlinear autoregressive distributed lag | Pakistan    | Study outcomes revealed that the adverse shocks of renewable energy consumption exposed expressively to upsurge CO2 emission in the short-run dynamics. Conversely, constructive shocks of renewable energy consumption display an adversative association with CO2 emission. Furthermore, the decreasing trend in foreign direct investment tends to impede the detrimental effects of CO2 emission. In order to improve the environmental policies for sustainable growth, the study provides direction toward a sustainable environment by reducing carbon dioxide emission. |
| Ahmad et al. (2022) | Assessing long- and short-run dynamic interplay among balance of trade, aggregate economic output, real exchange rate, and CO2 emissions in Pakistan | Bayer and Hanck’s combined cointegration and ARDL | 1970–2018   | Balance of trade and real exchange rate imparted the CO2 emissions mitigation influence in both the long run and the short run. In contrast, the aggregate economic output exhibited the CO2 emissions driving influence in the long run and short run. (2) Balance of trade and real exchange rate induced enhancing and impeding influence on aggregate economic output, respectively, in the short run. Aggregate economic output revealed a balance of trade improvement influence for both the long run and short run. |
| Ali et al. (2021)  | Evaluating green technology strategies for the sustainable development of solar power projects: evidence from Pakistan | Partial least squares structural equation modeling (PLS-SEM) | 44 (chief financial officers and chief executive officers) | The results reveal that green technology strategies positively impact the sustainable development of solar power projects. The profitability index is a good source of higher financial performance of the solar power projects. |
| Author(s)         | Article title                                                                 | Model                                      | Data             | Results                                                                                                                                                                                                 |
|------------------|-------------------------------------------------------------------------------|--------------------------------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Shahzad et al. (2021) | Environment-related policy instruments and technologies facilitate renewable energy generation? Exploring the contextual evidence from developed economies | Fully modified ordinary least square (FMOLS) and quantile r | 1994–2018        | The heterogeneous panel empirics revealed that environmental regulations and income level support renewable electricity generation. The conclusions further mention that bureaucratic qualities such as decision-making and trade openness tend to reduce renewable energy generation. The empirical findings allowed us to draw new narrative and implications |
| Işik et al. (2017)   | Analyzing the causalities between economic growth, financial development, international trade, tourism expenditure and/or the CO₂ emissions in Greece | ARDL                                        | 1970–2014        | The empirical findings show that economic growth, financial development, international trade, and tourism expenditures caused increases in Greece’s CO₂ emissions. It should be noted that tourism, as a leading sector in the Greek economy |
| Sinha et al. (2021)   | Does green financing help to improve environmental & social responsibility? Designing SDG framework through advanced quantile modelling | Advanced quantile modeling approaches            | 2010–2020        | Green financing mechanism might have gradual negative transformational impact on environmental and social responsibility. They design a policy framework to address the relevant SDGs objectives |
| Raza et al. (2019)    | Time frequency relationship between energy consumption, economic growth and environmental degradation in the United States | Wavelet transform framework                  | The monthly data 1973 (January) to 2015 (July) | The result shows energy consumption has a positive influence on carbon dioxide emission. The study recommends that policy makers should pay more consideration to this association |
| Khan et al. (2018)    | Environmental, social and economic growth indicators spur logistics performance: from the perspective of South Asian Association for Regional Cooperation countries | GMM and FGLS                                  | South Asian Association for Regional Cooperation | The macro-level social factors to determine the relationship between the social indicators and green supply chain business and/or green logistics operations are examined. The study is determined the relationship between green logistics performance index (GLPI) and macro-level social, environmental, economic indicators |
| Author(s) | Article title | Model | Data | Results |
|-----------|---------------|-------|------|---------|
| Işık et al. (2022) | Reinvestigating the environmental Kuznets curve (EKC) hypothesis by a composite model constructed on the Armey curve hypothesis with government spending for the US states | AC and EKC | US states | The composite model created may also allow US state policymakers to determine a single maximum spending level that will maximize or minimize CO₂ emissions. Empirical findings indicate that the composite model is capable of testing the EKC hypothesis for 7 US states. Additionally, for 7 US states, maximum spending level was calculated to be around 15% of their RGDPPCs. |
| Ongan et al. (2021) | Economic growth and environmental degradation: evidence from the US case environmental Kuznets curve hypothesis with application of decomposition | EKC Decomposition ARDL | 1990M1 and 2019M7 | Empirical findings of decomposed and undecomposed models are exactly opposite to each other. While the undecomposed model does not detect evidence of the EKC hypothesis for the USA, the decomposed model strongly does so. This can lead to the interpretation that the decomposed model discovers the existing but concealed validity of the EKC hypothesis, which the undecomposed model is not capable of detecting. Based on this result, this study proposes using this method as well, as an alternative technique for the EKC hypothesis testing models. |
| Işık et al. (2020) | An evaluation of the tourism-induced environmental Kuznets curve (T-EKC) hypothesis: evidence from G7 countries | EKC panel bootstrap cointegration test and an augmented mean group (AMG) estimator | 1995–2015 | The empirical findings indicate that the tourism-induced EKC hypothesis is valid only for France. Additionally, it was detected that a rise in renewable energy consumption has a negative (reduction) impact on CO₂ emissions in France, Italy, the UK, and the USA. However, an increase in the receipt of international tourism has a positive (additional) impact on Italy's CO₂ emissions. |
| Author(s)       | Article title                                                                 | Model | Data               | Results                                                                                                                                 |
|----------------|--------------------------------------------------------------------------------|-------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Işik et al. (2017) | Analyzing the causalities between economic growth, financial development, international trade, tourism expenditure and/or the CO2 emissions in Greece | ARDL  | 1970–2014         | The empirical findings show that economic growth, financial development, international trade, and tourism expenditures caused increases in Greece’s CO2 emissions. It should be noted that tourism, as a leading sector in the Greek economy, has serious negative environmental impacts for Greece in the long run. |
| Shanif et al. (2020) | The role of tourism, transportation and globalization in testing environmental Kuznets curve in Malaysia: new insights from quantile ARDL approach | QARDL | 1995Q1–2018Q4     | The results demonstrate that economic growth is significantly positive with CO2 emissions at lower to upper quantiles. Interestingly, tourism has a negative effect on CO2 emissions at higher quantiles. Moreover, globalization and transportation services are positive, with CO2 emissions at upper-middle to higher quantiles. Furthermore, we tested the environmental Kuznets curve, and the outcomes confirm the presence of the inverted U-shaped curve in the Malaysian economy. |
| Işik (2010)            | Natural gas consumption and economic growth in Turkey: a bound test approach       | ARDL  | 1977–2008         | The results show that the natural gas consumption positively impacts the economic growth of Turkey in the short-run and a negative relationship between the variables in long run. |
| Işik et al. (2021)       | The increases and decreases of the environment Kuznets curve (EKC) for 8 OECD countries | EKC   | 8 OECD countries  | Empirical findings indicate that while the undecomposed model with undecomposed per capita GDP series supports the EKC hypothesis for 4 out of 8 countries, the decomposed model with decomposed per capita GDP series does not do so for any country. |
| Işik et al. (2019a)      | Testing the EKC hypothesis for ten US states: an application of heterogeneous panel estimation method | EKC    | Ten states of USA | The empirical findings of the study indicate that the EKC (inverted U-shaped) hypothesis is valid only for Florida, Illinois, Michigan, New York, and Ohio. |
| Author(s)               | Article title                                                                                   | Model          | Data         | Results                                                                                                                                                                                                 |
|------------------------|------------------------------------------------------------------------------------------------|----------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Işık et al. (2019b)    | The economic growth/development and environmental degradation: evidence from the US state-level  | EKC            | 1980–2015    | The empirical findings of the AMG estimation indicate that only 14 states verify the EKC hypothesis. Additionally, the expected negative impacts of fossil energy consumption on the environment (CO₂ emissions) are strongly detected in all states except Texas. |
| Khan et al. (2021)     | Moving towards sustainability: how do natural resources, financial development, and economic growth interact with the ecological footprint in Malaysia? A dynamic ARDL approach | ARDL-EK        | 1980–2019    | It was identified that financial development, economic growth, and natural resources are the determinants behind the upsurge of the ecological footprint as all three show a positive and significant effect on ecological footprint. However, in the long run, the presence of the environmental Kuznets curve hypothesis was also validated in Malaysia. |
| Sharif et al. (2021)   | Disaggregated renewable energy sources in mitigating CO₂ emissions: new evidence from the USA using quantile regressions | Quantile-on-quantile regressions | 1995–2017    | Findings support the deployment of various types of renewables in combating CO₂ emissions for each quantile.                                                                                          |
Table 13  Descriptive statistics of energy consumption (kg equivalent of crude oil) (billion dollars) in the Persian Gulf countries (2000–2014)

| Statistics          | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|---------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| **Average**         | 52                   | 148          | 23    | 15   | 27     | 32   | 182  | 11      |
| **Middle**          | 50                   | 140          | 22    | 15   | 26     | 27   | 190  | 11      |
| **Standard deviation** | 12                   | 38           | 10    | 6    | 5      | 9    | 35   | 2       |
| **Minimum**         | 31.52                | 97.85        | 10.92 | 7.56 | 18.71  | 24.93| 123.02| 7.96    |
| **Maximum**         | 70.47                | 213.15       | 44.07 | 24.43| 37.19  | 49.48| 237.07| 14.15   |
| **Skewness**        | 1.5 –                | 1.37 –       | 0.60 –| 1.54 –| 1.28 – | 0.73 –| 1.24 –| 1.42 –  |
| **Kurtosis**        | 0.03                 | 0.25         | 0.72  | 0.17 | 0.03   | 0.94 | 0.30 –| 0.25 –  |
| **Quadrant**        | 40                   | 112          | 14    | 8    | 21     | 25   | 142  | 9       |
| **Number of views** | 15                   | 15           | 15    | 15   | 15     | 15   | 15   | 15      |

Table 14  Descriptive statistics of labor force (thousand people) in the Persian Gulf countries (2000–2014)

| Statistics          | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|---------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| **Average**         | 4139                 | 8913         | 930   | 1224 | 1403   | 7459 | 23,504| 550     |
| **Middle**          | 4054                 | 8647         | 817   | 1088 | 1292   | 7524 | 24,639| 556     |
| **Standard deviation** | 1818                | 1906         | 526   | 424  | 372    | 1352 | 1972  | 170     |
| **Minimum**         | 1771                 | 6403         | 338   | 786  | 987    | 5623 | 18,973| 305     |
| **Maximum**         | 66,367               | 12,391       | 1778  | 2097 | 2100   | 9619 | 24,960| 758     |
| **Skewness**        | 1.82 –               | 0.85 –       | 1.5 – | 0.36 –| 0.92 – | 1.47 –| 0.80  | 1.71 –  |
| **Kurtosis**        | 0.01                 | 0.47         | 0.35  | 0.88 | 0.65   | 0.06 | 1.43 –| 0.12 –  |
| **Quadrant**        | 2261                 | 7235         | 414   | 865  | 1073   | 6086 | 22,261| 378     |
### Table 15 Descriptive statistics of capital stock (million dollars) in the Persian Gulf countries (2000–2014)

| Statistics | Country          | United Arab Emirates | Saudi Arabia | Qatar   | Oman   | Kuwait | Iraq   | Iran      | Bahrain |
|------------|------------------|----------------------|--------------|---------|--------|--------|--------|-----------|---------|
| Average    |                  | 63,014               | 119,458      | 33,006  | 13,569 | 16,861 | 17,378 | 147,953   | 5712    |
| Middle     |                  | 75,459               | 121,283      | 39,134  | 14,380 | 19,902 | 16,804 | 158,008   | 6207    |
| Standard deviation |          | 20,712               | 55,859       | 20,623  | 7068   | 7438   | 12,521 | 3384      | 2217    |
| Minimum    |                  | 35,760               | 47,536       | 4911    | 3943   | 4741   | 3110   | 81,566    | 2523    |
| Maximum    |                  | 92,891               | 197,786      | 68,894  | 25,275 | 28,058 | 44,125 | 196,106   | 8617    |
| Skewness   |                  | 1.77                 | 1.76         | 1.36    | 1.36   | 1.1    | 0.59   | 0.43      | 1.43    |
| Kurtosis   |                  | 0.17                 | 0.01         | 0.04    | 0.04   | 0.26   | 1.06   | 0.58      | 0.33    |
| Quadrant   |                  | 40,758               | 58,279       | 11,115  | 5997   | 10,298 | 6523   | 130,738   | 3312    |

### Table 16 Descriptive statistics of GDP (billion US dollars) in the Persian Gulf countries (2000–2014)

| Statistics | Country          | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|------------|------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| Average    |                  | 274                  | 493          | 88    | 51   | 110    | 125  | 421  | 22      |
| Middle     |                  | 285                  | 483          | 79    | 48   | 117    | 116  | 454  | 22      |
| Standard deviation |          | 50                   | 93           | 47    | 9    | 22     | 34   | 61   | 4       |
| Minimum    |                  | 198                  | 364          | 36    | 42   | 73     | 64   | 316  | 15      |
| Maximum    |                  | 355                  | 651          | 161   | 67   | 137    | 183  | 499  | 29      |
| Skewness   |                  | 1.02                 | 1.0          | 1.56  | 1.19 | 1.02   | 0.34 | 1.02 | 1.39    |
| Kurtosis   |                  | 0.17                 | 0.27         | 0.35  | 0.56 | 0.61   | 0.39 | 0.58 | 0.004   |
| Quadrant   |                  | 224                  | 404          | 41    | 43   | 89     | 101  | 371  | 17      |
Table 17  Descriptive statistics of carbon dioxide emissions (thousand tons) in the Persian Gulf countries (2000–2014)

| Statistics                  | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|-----------------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| Average                     | 140                  | 432          | 63    | 40   | 77     | 110  | 511  | 23      |
| Middle                      | 135                  | 430          | 63    | 41   | 75     | 104  | 519  | 26      |
| Standard deviation          | 35                   | 98           | 21    | 14   | 16     | 32   | 89   | 6       |
| Minimum                     | 84                   | 296          | 34    | 20   | 53     | 62   | 372  | 13      |
| Maximum                     | 211                  | 601          | 107   | 61   | 102    | 168  | 649  | 31      |
| Skewness                    | 0.29                 | 1.08         | 0.53  | 1.22 | 1.44   | 0.46 | 1.31 | 1.84    |
| Kurtosis                    | 0.29                 | 0.16         | 0.50  | 0.15 | 0.00   | 0.60 | 0.10 | 0.15    |
| Quadrant                    | 112                  | 327          | 41    | 27   | 62     | 87   | 418  | 17      |

Table 18  Descriptive statistics of population size (million people) in the Persian Gulf countries (2000–2014)

| Statistics                  | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|-----------------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| Average                     | 6                    | 25           | 1.3   | 3    | 2.6    | 28   | 72   | 1       |
| Middle                      | 6                    | 2.5          | 1.1   | 2.7  | 2.5    | 2.8  | 7    | 1       |
| Standard deviation          | 2                    | 3            | 0.7   | 0.5  | 0.5    | 3.5  | 4    | 0.2     |
| Minimum                     | 3                    | 20           | 0.6   | 2/2  | 2      | 23   | 66   | 0.6     |
| Maximum                     | 9                    | 30           | 2.3   | 4    | 4      | 35   | 78   | 1.3     |
| Skewness                    | 1.7                  | 1.14         | 1.5   | 0.23 | 0.88   | 0.98 | 1.09 | 1.6     |
| Kurtosis                    | 0.03                 | 0.17         | 0.37  | 0.91 | 0.7    | 0.28 | 0.07 | 0.12    |
| Quadrant                    | 3.7                  | 22           | 0.7   | 2.4  | 2.1    | 25   | 68   | 0.8     |
### Table 19: Descriptive statistics of the degree of industrialization (percentage of GDP) in the Persian Gulf countries (2000–2014)

| Statistics        | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|-------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| Average           | 64.14                | 58.72        | 85.08 | 62.36| 66.94  | 53.39| 44.87| 46.12   |
| Middle            | 61.83                | 58.38        | 89.57 | 63.53| 68     | 52.77| 45.05| 46      |
| Standard deviation| 8.9                  | 4.7          | 9.3   | 5.3  | 5.12   | 3.6  | 3.3  | 2.19    |
| Minimum           | 51.98                | 51.52        | 69.75 | 55.47| 58     | 47.5 | 39.62| 43      |
| Maximum           | 84.79                | 66.75        | 96.61 | 71.64| 74.81  | 58.5 | 49.63| 5.40    |
| Skewness          | 0.72                 | 1.13−        | 1.34− | 0.09−| 0.66−  | 1.31−| 1.18−| 0.42−   |
| Kurtosis          | 1.07                 | 0.03−        | 0.64− | 0.24 | 0.36−  | 0.12−| 0.29−| 0.36    |
| Quadrant          | 57.69                | 54.61        | 73.46 | 56.40| 64     | 49.67| 42.88| 44      |

### Table 20: Descriptive statistics of the degree of commercial openness (percentage of GDP) in the Persian Gulf countries (2000–2014)

| Statistics        | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Iran | Bahrain |
|-------------------|----------------------|--------------|-------|------|--------|------|------|---------|
| Average           | 97.25                | 80.26        | 93.63 | 94.25| 92.03  | 130.43| 47.37| 147.15  |
| Middle            | 81.05                | 82.54        | 94.74 | 90.24| 91.73  | 136.79| 48.17| 140.73  |
| Standard deviation| 26.81                | 10.13        | 6.73  | 12.9 | 5.83   | 28.84| 4.3  | 23.76   |
| Minimum           | 72.17                | 61.86        | 80.14 | 77.01| 81.22  | 85   | 40.53| 117.96  |
| Maximum           | 154.23               | 96.10        | 105.74| 116.55| 101.01 | 168.05| 54.44| 191.87  |
| Skewness          | 0.70−                | 0.74−        | 0.15− | 0.9− | 0.83−  | 1.35−| 1.13−| 0.64−   |
| Kurtosis          | 0.76                 | 0.25−        | 0.10− | 0.46 | 0.038− | 0.24−| 0.05−| 0.76    |
| Quadrant          | 74.09                | 89.83        | 89.43 | 82.55| 86.84  | 102.3| 43.69| 128.09  |
## Table 21: Descriptive statistics of paper citation rate in the Persian Gulf countries (2000–2014)

| Statistics | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Bahrain |
|------------|----------------------|--------------|-------|------|--------|------|----------|
| Average    | 13                   | 13           | 12    | 9    | 12     | 9    | 13       |
| Middle     | 14                   | 13           | 13    | 9    | 12     | 9    | 13       |
| Standard deviation | 3                   | 2            | 3     | 4    | 4      | 4    | 3        |
| Minimum    | 6                    | 9            | 8     | 6    | 6      | 5    | 6        |
| Maximum    | 17                   | 17           | 18    | 17   | 18     | 17   | 17       |
| Skewness   | 0.3                  | −0.36        | 0.53  | −0.61 | −0.85  | −1.32| −1.6     |
| Kurtosis   | 0.81                 | −0.26        | −0.53 | 0.02  | 0.02   | 0.02 | 0.02     |
| Quadrant   | 11                   | 10           | 10    | 9    | 9      | 6    | 7        |

## Table 22: Descriptive statistics of oil price (US dollars) in the Persian Gulf countries (2000–2014)

| Statistics | OPEC member countries | Oman | Bahrain |
|------------|-----------------------|------|----------|
| Average    | 64                    | 64   | 24       |
| Middle     | 61                    | 62   | 24       |
| Standard deviation | 3.2                  | 3.2  | 12       |
| Minimum    | 2.3                   | 2.2  | 9        |
| Maximum    | 10.9                  | 10.9 | 39       |
| Skewness   | 1.5                   | 1.5  | 0.04     |
| Kurtosis   | 0.07                  | 0.07 | 13       |
| Quadrant   | 28                    | 27   | 13       |
Table 23 Descriptive statistics of foreign direct investment (percentage of GDP) in the Persian Gulf countries (2000–2014)

| Country        | United Arab Emirates | Saudi Arabia | Qatar | Oman | Kuwait | Iraq | Bahrain |
|----------------|----------------------|--------------|-------|------|-------|------|---------|
| Average        | 2.87                 | 2.70         | 3.07  | 2.43 | 0.48  | 1.19 | 0.9     |
| Middle         | 2.63                 | 2.70         | 3.07  | 2.43 | 0.48  | 1.19 | 0.9     |
| Standard deviation | 2.25             | 3.09         | 2.71  | 2.23 | 0.31  | 0.71 | 0.7     |
| Minimum        | 0.31                 | 0.71         | 0.7   | 0.7  | 0.49  | 0.17 | 0.17    |
| Maximum        | 6.76                 | 15.75        | 8.3   | 7.91 | 2.18  | 2.73 | 2.73    |
| Skewness       | 0.87                 | 0.94         | 0.94  | 0.94 | 0.94  | 0.94 | 0.94    |
| Kurtosis       | 0.36                 | 1.13         | 1.13  | 1.13 | 1.13  | 1.13 | 1.13    |
| Quadrant       | 1.14                 | 1.14         | 1.14  | 1.14 | 1.14  | 1.14 | 1.14    |

Author contribution Nikbakht: sample collection, data curation, software. Ghorbanpur: conceptualization, methodology, resources, preparation, review and editing. Hajian: conceptualization, methodology, formal analysis, writing—original draft and editing, preparation, project administration. All authors have read and agreed to the published version of the manuscript.

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Declarations

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