Economic and Environmental Sustainability through Trade Openness and Energy Production

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Abstract

Background: Energy production plays a major role in the Saudi Arabian economy, but energy production can lead to an increase in environmental pollution. **Objectives**: This study investigated the impact of energy production and trade openness on Saudi Arabia's economic growth and environmental pollution using annual data from 1970 to 2020. **Methods/Approach**: The fully modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) methods were employed to develop two models, including an economic growth model and an environmental Sustainability or pollution model. **Results**: The results of the two tests ensured that both expanding trade openness and increasing energy production led to faster economic growth. Nevertheless, the expansion of trade openness and energy production also led to environmental pollution; hence, the increase in energy production did not support sustainable development. **Conclusions**: Thus, policymakers should develop a green economy strategy to reduce the use of fossil fuels and increase renewable energy in energy production to reduce environmental pollution. Moreover, the Saudi Arabian government should highly promote investment in renewable energy production through trade openness.

Keywords: pollution; growth; Saudi Arabia; FMOLS; DOLS

JEL classification: C5; E2; F1; Q4; Q5
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Introduction

Trade openness refers to the degree to which one country deals with another country in trade, including exports, imports, foreign direct investments (FDIs), lending, borrowing, and repatriation of funds from abroad (Amna Intisar et al., 2020). Trade openness also enhances economic growth in several ways, including an increase in capital formation and the expansion of markets, as well as the development of new production methods, the creation of more job opportunities, and the reduction of poverty. Previous studies have shown that trade openness has led to technological transformation in the Asian economy and helped enhance human capital (Amna Intisar et al., 2020). Furthermore, financial openness is another route through which economic growth can be supported. In this way, the level of foreign direct investment and capital flows into the country can be determined (Aremo & Arambada, 2021).

The results of literature reviews regarding the impact of trade openness on economic growth differ widely. Several literature reviews have indicated that the impact of trade openness is positive for economic growth, as demonstrated by Amna Intisar et al. (2020). Al-Shayeb and Hatemi (2016) and Alam and Sumon (2020) showed that trade openness improved new technology for transfers and facilitated technological progress and productivity. These advantages are proportional to the degree of trade openness, reducing resource misallocation in the short term while facilitating technological development transfers in the long term (Mallick & Behera, 2020). However, Gries, Kraft, and Meierrieks (2009), Hye and Lau (2014), Zahonogo (2016), and Belloumi and Alshehry (2020) found a negative impact. Moreover, Kim (2011) and Vlastou (2010) discovered that trade openness boosted economic growth in developed countries while harming developing countries. Other previous studies have shown no significant relationship between trade openness and economic growth (Eris & Ulasan, 2013); Menyah et al., 2014; Ulaşan, 2015; Yanikkaya, 2003).

The increasing concern about the environmental impact of fossil fuels has grown over the last four decades. Considering that oil production consumes oil to generate thermal energy to process oil and convert it into its related products, the industry should be more energy efficient and consider renewable energy resources as well (Halabi et al., 2015). Increases in greenhouse gas emissions represent a significant hazard to the environment. The rapid economic growth and expansion of industrialisation processes in newly industrialised countries necessitate the intensive use of energy and other natural resources. This energy use leads to the release of more residues and wastes into the environment, which can result in environmental pollution. Carbon dioxide is widely regarded as the primary cause of the greenhouse effect, and it has received considerable attention in recent years. The majority of carbon dioxide emissions ($CO2$ emissions) are caused by the use of fossil fuels such as coal, oil, and gas (Hossain, 2011). The global oil companies have implemented strategies and taken a series of steps towards developing technologies that lower greenhouse gas emissions, especially that concerns focus on the relationship between greenhouse gas emissions and global warming, which is expected to increase by approximately 40% over the coming two decades. This increase in greenhouse gas emissions should be addressed by adopting environmental regulations on various levels, especially for industrial and oil-producing businesses (Halabi et al., 2015).

Regarding the impact of trade openness on environmental pollution, Mahmood, Maalel, and Zarrad (2019) noted that an increase in trade openness would increase energy consumption and pollution as a country's income level rose. However, a decline in trade openness does not always correlate with a decline in energy consumption. Some researchers have studied the relationship between trade openness and carbon dioxide. However, the findings of previous studies have differed regarding the impact of trade openness on carbon dioxide emissions. Chen, Jiang, and Kitila (2021), Rahman, Zaman, and Górecki (2020), and Zamil, Furqan, M., and Mahmood (2019) found that an increase in trade openness leads to an increase in CO2 emissions. Thus, environmental pollution is increasing. Conversely, Hossain (2011) found that trade openness leads to a decrease in environmental pollution.

Oil production represents a large proportion of the national GDP in oil-producing countries, and an increase in oil prices can strengthen the value of the country's currency by increasing export earnings and real national income. Previous studies have concentrated on the impacts of energy consumption on economic growth and environmental pollution but have ignored the impact of energy production on economic growth and environmental pollution. Although energy production leads to economic growth, it also leads to environmental pollution. Kingdom Saudi Arabia (K.S.A.) is the world's largest oil producer and one of the most severely polluted countries (Algarini, 2019).

KSA is the second largest holder of oil reserves in the world, and oil exports significantly contribute to its GDP. Despite this, it is predicted that if KSA continues to consume its reserves at the current rate, it will have to import oil by 2038. Moreover, its power consumption is three times higher than the world average; the housing sector consumes about 70% of the total electricity consumption in the country. Hence, the future demand for electricity in KSA is expected to continue to grow, accompanied by population growth, a fast industrialisation pace, and urbanisation. The matter that harms the environment (Ali & Khan, 2018). According to the World Bank (2023) data, renewable energy consumption accounted for only 0.06 % of total final energy consumption in 2020, and fuel exports accounted for 77% of merchandise exports in 2021. Accordingly, the data show that KSA is still heavily reliant on non-renewable energy sources, with almost no use of renewable energy.

In 2014, CO2 emissions totalled 19.52 metric tons per capita in Saudi Arabia, compared to 16.49 metric tons per capita in the United States (WDI, 2019). The environmental challenges facing the Kingdom of Saudi Arabia (KSA) are represented by environmental damage due to the oil and gas industry. Air pollution is caused by the mining industry, the large expansion of the transportation sector, and increases in the per capita production of waste. According to Vision 2030, Saudi Arabia aims to achieve environmental sustainability using renewable energy, green cities, and waste recycling (Saudi-Vision, 2030, n.d.).

To cite further knowledge, a few studies (Algarini, 2019; Danlami et al., 2019; Hdom Fuinhas, 2020) have discussed the relationship between energy production and carbon dioxide emissions and concluded that increased energy production leads to an increase in carbon dioxide emissions. Only Algarini's study (2019) focused on Saudi Arabia, while two other studies (Chen et al., 2019; Hdom & Fuinhas, 2020) focused on the impacts of trade openness and energy production on economic growth and carbon dioxide emissions. However, neither of these studies analysed Saudi Arabia.
This study aims to clarify the impact of energy production and trade openness on economic growth and environmental pollution at the same time in Saudi Arabia. Because there is no clear consensus about these relations. Although Algarini (2019) and Belloumi and Alshehry (2020) carried out the two studies focusing on Saudi Arabia, these studies did not combine energy production with economic openness. Therefore, this study attempts to bridge the gap between the impact of energy production and trade openness on economic growth and environmental pollution and enrich Saudi Arabian studies. The following questions were raised:

- Does energy production have a significant positive impact on economic growth?

- Does trade openness have a significant positive impact on economic growth?
- Does increased energy production lead to increased environmental pollution?
- Does trade openness have a significant impact on increasing environmental pollution?

The study covered the period 1970–2020 only due to data availability. The data were collected from the World Bank and the BP Statistical Review of World Energy. The fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) models were employed to determine the impact of energy production and trade openness on economic growth and environmental pollution. The FMOLS and DOLS methods were employed according to Le et al. (2023) and Ngong et al. (2022). The FMOLS represents a nonparametric method of testing serial correlation by using the disturbance parameters' Kernal estimators on the OLS asymptotic distribution by modifying OLS, correcting the impact of serial correlation, and ensuring regressors' endogeneity. It is superior to both OLS and Engle–Granger methods for its ability to correct inference problems. Accordingly, it ensures the long-term validity of estimates. The DOLS is a parametric method that uses leads and lags to solve correlation problems among variables of investigation. Moreover, it is dynamic and can solve the problems of endogeneity, ensuring co-integration and unbiased coefficients. Both FMOLS and DOLS ensure robustness (Ngong et al., 2023; Kalim & Shahbaz, 2009).

The following sections comprise the remainder of the paper: Section 2 reviews the relevant literature, and Section 3 presents the research design. Section 4 contains the empirical results, and Section 5 contains the conclusions, recommendations for policy and limitations.

Literature Review

The literature review was classified into four categories. The first category focused on studying the link between trade openness and economic growth; the second category focused on the link between trade openness and environmental pollution. The third category focused on the links between energy production, economic growth, and environmental pollution. Moreover, the fourth category focused on the links between economics and sustainability.

Trade Openness and Economic Growth

Trade openness serves as a conduit for the flow of FDI, capital, goods, and services to host countries or areas. These are the engines of economic growth in developing countries. In recent years, scholars and researchers have argued over and sought to verify the relationship between trade openness and economic growth. This section presents a literature review of the relationship above.

Aremo and Arambada (2021) examined the relationship between trade, financial openness, and economic growth in Sub-Saharan Africa (SSA) in the period 1980–2017. The authors applied a dynamic analysis using the techniques of the general method of moments (GMM) and the general method of moments system (GMM system). They found a positive impact of trade openness on economic growth in low-income countries. However, financial openness and joint trade did not have a significant positive effect on economic growth. Generally, there was no evidence to support the hypothesis of simultaneous openness in sub-Saharan African economies. Hdom and Fuinhas (2020) used the co-integration regression methods FMOLS and DOLS. They found that the Brazilian economy was affected by electricity generation, gross domestic product (GDP), and international trade in both positive and negative ways. A bidirectional correlation was observed between trade openness and all energy production in Brazil. Saleem et al. (2020) used the autoregressive distributed lag (ARDL) approach on annual data (1975–2016) for Bangladesh, India, Nepal, Pakistan, and Sri Lanka. The authors found that trade openness was significantly related to economic growth, especially in Bangladesh, India, and Sri Lanka. The study concluded that foreign direct investments and trade openness contributed to the economic growth of these countries. Belloumi and Alshehry (2020) employed the ARDL approach in Saudi Arabia for the years 1971–2016. The results indicated that trade openness did not affect economic growth in the short term. In the long term, the effect of openness on economic growth was negative when the indicators of the ratio of exports to GDP and total exports and imports divided by GDP were applied. However, a positive impact was noted when the authors used the ratio of imports to GDP. Anam Intisar et al. (2020) used the FMOLS and DOLS models to examine the impact of trade openness and human capital on economic growth. The findings showed that trade openness had a significant and positive relationship with economic growth. Al-Shayeb and Hatemi (2016) employed asymmetric generalised impulse response functions and asymmetric causality tests. The results indicated that a positive perpetual shock of trade openness leads to a significant positive response in GDP per capita. No such response was noted to yield significant negative shocks in trade openness.

Kim (2011) revealed that increased trade openness would benefit high-income countries in terms of real development. Conversely, other studies, such as Vlastou (2010), used dynamic OLS and found that trade openness had a significant negative impact on real income in low-income countries. The study revealed a significant negative impact of trade openness on economic growth.

In conclusion, results from previous studies differed regarding the impact of trade openness on economic growth. This can be attributed to the different economies and policies followed, the multiplicity of ways to measure foreign trade, and the different methodologies used in each study.

The Trade Openness and Environmental Pollution

Recently, studies have discussed the impact of trade openness on the quality of the environment, considering environmental quality as one of the indicators for evaluating economic development. An excessive increase in trade openness leads to the growth of production, the creation of infrastructure, and the increase of industrialisation and industrial entities, which results in negative consequences in terms of environmental quality and the emission of carbon dioxide. Nevertheless, some academics, based on empirical evidence and the application of the Kuznets theory, disagree with the results indicating that trade has a negative impact on environmental quality. Instead, they hold that good economic performance, including trade, is positively correlated with good environmental performance (Antweiler et al., 2001; Atici, 2009; Chen et al., 2019; Kalmaz & Kirikkaleli, 2019; Pham et al., 2022). The second category of literature that focused on the link between trade openness and carbon dioxide emissions was led by the work of Zamil et al. (2019). The authors employed the ARDL approach to examine Oman's economy from 1972 to 2014. The results showed that GDP and increased trade openness had exacerbated carbon dioxide emissions problems. Hossain (2011) applied the Granger Causality Test in newly industrialised countries over the years 1971–2007. The findings indicated that, in the long run, environmental quality was generally good in terms of economic growth and trade openness. Rahman et al. (2020) used the ARDL-bound test to study Lithuania during the period 1989–2018. The study concluded that trade and energy consumption were key determinants of carbon dioxide emissions. Kalmaz and Kirikkaleli (2019) used ARDL, FMOLS, DOLS, and the wavelet coherence technique to measure the impact of energy consumption, economic growth, and urbanisation as the main causes of carbon dioxide emissions in the long term. The study covered the Turkish economy from 1960–2015. In Turkey, it was also found that trade openness had no significant impact on CO2 emissions in the long term. Chen et al. (2021) used the quintile regression approach for the years 2001–2019 and concluded that an improvement in trade openness had reduced carbon dioxide emissions. Atici (2009) examined the effects of GDP, energy consumption, and trade openness on CO2 emissions in Central and Eastern European nations using panel data from 1980 to 2002 and the extended environmental Kuznets curve. The results offer some proof that an environmental Kuznets curve exists. CO2 emissions gradually decrease as GDP rises. Alkhateeb et al. (2017) used the bound ARDL model in Saudi Arabia from 1970-2016. The findings showed that trade had a negative impact on carbon dioxide emissions. As a result, expanding trade openness is beneficial in reducing pollution levels in Saudi Arabia. Pham et al. (2022) used the Bayesian model averaging approach to sample 64 developing countries from 2003 to 2017. The findings showed that increased trade openness in developing countries did not cause environmental deterioration.

Previous studies showed different points of view on the relationship between trade openness and carbon dioxide. The difference in the results may be due to the different measures of trade openness, the methodology of data analysis, the period, and the country categories.

The Energy Production, Economic Growth, and Environmental Pollution

The world's countries are highly dependent on oil to generate energy. Therefore, it is important to investigate the impact of oil production on economic growth. Oil is a strategic source of energy, which is also non-renewable and is going to be depleted in the future (Tamba, 2017). According to Ike, Usman, and Sarkodie (2020), many researchers have investigated the relationship between economic growth and environmental impact and found it to be positive. Based on the assumptions provided, we chose oil production in a large country with a large oil producer, expecting it to have a strong negative impact on the environment.

The relationship between economic growth and carbon dioxide emissions does not remain constant along the development path of countries. Because it fluctuates between positive and negative. The increase in national income influences people to demand cleaner production to ensure environmental sustainability, which is referred to by the inverted U-shaped relationship between environmental degradation and per capita income, or the 'environmental Kuznets Curve'. Countries' early levels of development witnessed a limited environmental impact accompanied by a limited economic impact and a low level of resource consumption. The growth in development accelerated with resource extraction and agricultural and industrial activities, the matter that put pressure on the quality of the environment. The higher levels of development are usually accompanied using more energy-efficient technologies and a higher demand for lower carbon emissions, which causes a decrease in environmental degradation (Panayotou, 2016).

In the last category of literature that focused on the links between energy production, economic growth, and carbon dioxide emissions, Danlami et al. (2019) used ARDL and FMOLS models to examine LMI Middle Eastern and North African countries over the years 1980–2011. In low- and middle-income countries, the results showed that increasing energy production leads to more CO2 emissions in the long term. Danish, Danish, Zhang, Wang, and Wang (2018) applied the ARDL approach to Pakistan's economy during the period 1970–2011. They discovered that the production of energy from fossil fuels caused increased carbon dioxide emissions.

Chen et al. (2019) used ARDL, VECM, and Granger causality approaches to study the effect of trade openness on carbon dioxide emissions. The study focused on China from 1980 to 2014. The results showed an increase in non-renewable energy over the long term. The GDP effect revealed an increase in carbon dioxide emissions, whereas renewable energy and foreign trade reduced carbon dioxide emissions. In a study of Iran's economy, Ahmad, and Du (2017) employed DOLS, FMOLS, and ARDL approaches to study the period from 1971 to 2011. The results showed that increasing economic growth leads to more carbon dioxide emissions. Further environmental pollution with increased energy production.

Algarini (2019) used the vector auto-regressive (VAR) model, Granger causality, and the Wald test for the period 1990–2017. The results indicated that there were bidirectional relationships between economic growth and carbon dioxide emissions, gas electricity production, and carbon dioxide emissions. The increased growth in the number of pollutant factors around the world has highly driven scientists, governments, and civil society agents to fight vigorously against high greenhouse gas emissions. The climate change agents argue for sustainable development through the green economy, which is based on the use of clean technology, green energy, green industry, and green business (Bogdan et al., 2014).

Green energy depends on using clean sources of energy, like solar, wind, and water energy, and it acts as a competitor to the traditional resources of fossil fuels. Recently, and due to increased awareness of the negative impact of the use of greenhouse gas, green energy has been used in the extraction and production of fossil fuels, a matter that made both sources of energy compatible rather than competitors. The electricity supply for the oil and gas industry currently uses green technology to supply the thermal energy needed to enhance oil recovery (Choi et al., 2017). According to Pickl (2019), renewable energy sources will grow enormously over the next two decades and become major sources of energy. In addition, he expects that renewable energy will account for approximately two-thirds of power plant investments globally. Accordingly, it is a problematic issue to compromise green energy sources with oil and gas, and it is difficult to predict the capital allocation between them. Further, Pickl (2019) adds that global oil companies are actively changing their strategies to use renewable energy sources in the energy sector. This matter influences them to create new strategies that enable them to catch up with the highly growing market of renewable energy against oil and gas and prepare for the capital allocation between them to reduce greenhouse gas and limit the environmental impact.

Not only have global oil companies responded to the environmental impact of the use of traditional non-rentable sources of energy, but governments across the world have begun to adopt policy support schemes for renewable energy sources (Guliyev, 2023). The downstream processes in the petroleum industry are different from the upstream processes because of their high dependence on energy at high temperatures. The downstream processes include hydrogen production, distillation, and the generation of high-pressure steam (Halabi et al., 2015). Moreover, the use of renewable energy in upstream processes can reduce both fuel consumption and operation costs. Different sources of renewable energy can be used in the stages of production. In addition, it can reduce noise and increase safety (Ericson et al., 2019). Balamurugan, Seenivasan, Rai, and Agrawal (2022) argue that oil, coal, diesel fuel, and gasoline are responsible for about 80% of air pollution. These energy resources are used in producing electricity, industrial manufacturing, transportation, and heating. They further argue that biodiesel, which is made from fatty acids, represents renewable sources, including vegetable oils, recycled cooking oil, or animal fats, and can be used as a kind of green fuel for internet consumption, power generation, and household energy needs.

Economics and Sustainability
Pejić Bach et al. (2023) aimed to examine stakeholders' perceptions of development. They found four groups: three with high economic growth and high and medium sustainability and one group with low economic growth and low sustainability. Al-Tit et al. (2020) studied a model for investigating the key driving factors based on two external variables and one variable. It showed that social support had a significant relationship with trust and social commerce intention. Prelipcean & Boscoianu (2020) studied a case of emerging markets represented by Romania. The problem of the study was very complex. The criteria of sustainable investment and global market drivers should be examined. The investment in social responsibility would be possible if it were implemented effectively.

Several studies have empirically examined trade openness and energy production and their impacts on economic growth and environmental pollution. Indeed, these studies were carried out in one country or a group of countries. Notably, however, no study focused on Saudi Arabia has yet combined trade openness and energy production to study the effects on economic growth and environmental pollution. Therefore, the present study provides a unique contribution to the literature.

Methodology

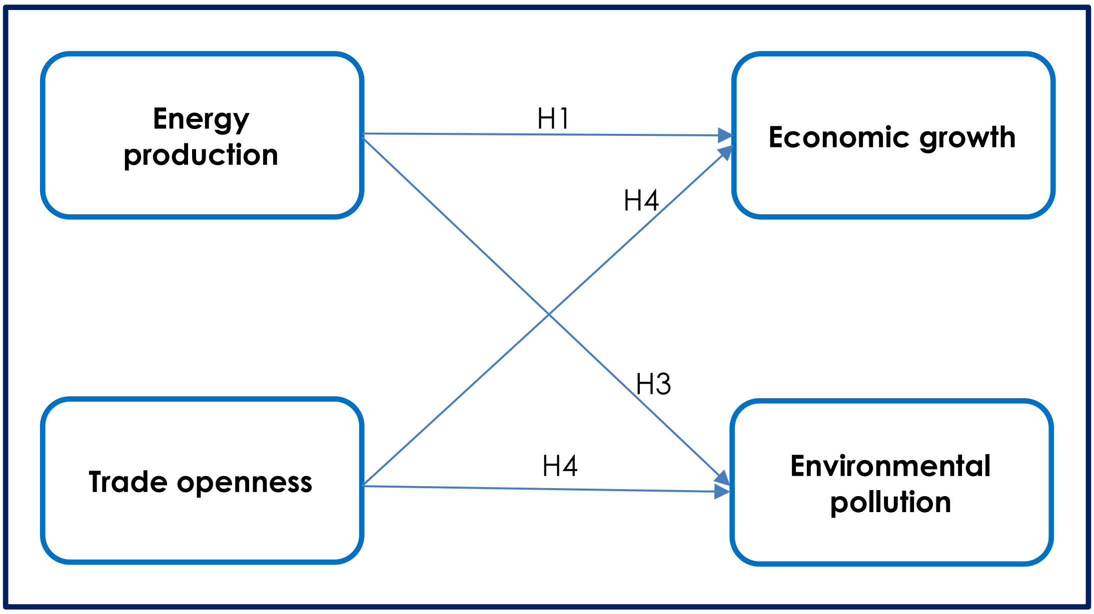
Data and Sources
The data were collected from the World Bank and BP Statistical Review of World Energy to study the impact of energy production and trade openness on economic growth and environmental pollution. The study covered the years 1970–2020. The study variables were as follows: Economic growth (GDP) was measured by the real gross domestic product per capita; trade openness (TO) was measured by the equivalent import + export / GPD; energy consumption (EN) was measured by the per capita oil equivalent (kg); and energy production (EP) was measured by oil production. Environmental pollution (CO) was measured by the emissions of millions of metric tons of carbon dioxide.

Model Specification
Based on the research question, the study's proposed hypotheses are as follows:

- H1: It is the likelihood that Increased Energy production will increase economic growth,
- H2: There will be a positive relationship between Trade openness and economic growth,
- H3: It is the likelihood that Increased Energy production will increase environmental pollution, and
- H4. There will be a positive relationship between Trade openness and environmental pollution

Figure (1) shows the expected relationships between variables. Two models were used to investigate the impact of energy production and trade openness on economic growth and environmental pollution. The first model studied the effect of trade openness and energy production on economic growth, as illustrated by Equation (1). The second model studied the relationship between the effects of trade openness and energy production on environmental pollution, as explained by Equation (2).

Figure 1
The Research Model



Source: Author's work

The variables of the investigation were selected for theoretical considerations, including selection consistency that identifies the best method for statistical inference, scientific knowledge, and interpretation of the relationships between variables based on the discussed literature (Ding et al., 2018). Accordingly, the variables of the models of this study were chosen based on the models of previous studies (Aremo & Arambada, 2021; Hdom & Fuinhas, 2020; Saleem et al., 2020; Belloumi & Alshehry, 2020; Danish et al, 2018; Chen et al., 2021; Rahman et al., 2020; Algarini, 2019; Danlami et al., 2019; Ahmad & Du, 2017). Moreover, variables are selected for practical considerations, considering data availability from credible sources (Ding et al., 2018). According to data available for the Saudi Arabian economy, before estimating the models, the Relevance of variables and their Measurability, the solution of the multicollinearity problem, and the Sufficiency of the variables to explain the phenomena under study, all variables are transformed into natural logarithms to reduce non-normality and heteroscedasticity (Hdom & Fuinhas, 2020). The functional form of the models is as follows:

$$LnGDP_t = \alpha_0 + \alpha_1 LnTO + \alpha_2 LnEN + \alpha_3 LnEP + \alpha_4 LnCO + \varepsilon_{1t} \text{.........}(1)$$

Where LnGDP is the natural logarithm of economic growth, LnTO is the natural logarithm of trade openness by the equivalent (import + export)/GPD, and the expected sign is positive. LnEN is the natural logarithm of energy consumption. The expected sign is positive, LnEP the natural logarithm of energy production by oil production (Including crude oil, shale oil, oil sands, condensates, and natural gas liquids), and the expected sign is positive. LnCO is the natural logarithm of Environmental pollution by the carbon dioxide emissions per capita in metric tons, and the expected sign is positive. Denote the intercept, and ε_{1t} this is the stochastic disturbance term.

$$LnCO = b_0 + b_1 LnTO + b_2 LnEN + b_3 LnEP + b_4 LnGDP + \varepsilon_{2t} \text{.......... ...}(2)$$

Where LnCO is the natural logarithm of Environmental pollution by the carbon dioxide emissions per capita in metric tons, LnTO is the natural logarithm of trade openness by the equivalent (import + export)/GPD, and the expected sign is positive. LnEN is the natural logarithm of energy consumption, and the expected sign is positive. LnEP is the natural logarithm of energy production by oil production, and the expected sign is positive. LnGDP is the natural logarithm of economic growth b_0 denotes the intercept, and ε_{2t} is the stochastic disturbance term. In addition, variables are selected for their relevance to the outcomes of interest and their sufficiency in interpreting the phenomenon of investigation, as we assume a lack of studies on the relationship between energy production and economic openness (Ding et al., 2018).

Stationary Tests

The Unit root tests are used to ensure the stationarity of the variables. If the variables are non-stationary, this leads to spurious regression. This study uses the augmented Dickey-Fuller (ADF) and Philips-Perron (PP) tests to perform the unit root test.

Co-Integration Test

The presence of cointegration demonstrates that the model variables are balanced in the long run. Furthermore, using the ordinary least squares method to estimate the coefficients ensures consistent results (Hdom & Fuinhas, 2020). The Johansen co-integration method was used for the Co-Integration Test. The Johansen test is highly sensitive to the lag length in the VECM; several statistics are used to determine the best lag length (Bashier & Siam, 2014).

FMOLS and DOLS Methods

FMOLS and DOLS methods are used because they have co-integration relationships between variables, and to overcome the problem of serial correlation and homogeneity, Phillips, and Hansen (1990) developed the FMOLS. To test long-term relationships between variables. FMOLS has the advantage of providing reliable estimates for small sample sizes and a robustness test on the results. Its application is also beneficial in dealing with non-stationary issues in the selected series (Adom & Bekoe, 2013). The FMOLS method produces unbiased results that are also fully efficient and consistent. More specifically, FMOLS is a non-parametric approach, whereas DOLS is a parametric approach developed by Stock and Watson (1993). That can control the endogenous effect, correcting heteroskedasticity problems, and providing unbiased co-integrating coefficient estimates (Anam Intisar et al., 2020; Ngong et al., 2021)

Diagnostic Tests

The diagnostic tests are used to check whether the model is well specified, which means that the regression assumptions are not compromised (Hdom & Fuinhas, 2020).

Empirical Results and Discussion

Stationary Tests

Two tests were used to check the stationarity of the variables: the augmented Dickey–Fuller test (Dickey & Fuller, 1979) and Phillips–Perron (Phillips & Peron, 1988) tests, as shown in Table 1.

Table 1
Stationary Tests

Variable	Augmented Dickey-Fuller (ADF)				Phillips–Perron (PP)			
	Level	p-Value	1st diff.	p-Value	Level	p-Value	1st diff.	p-Value
LnGDP	−2.3398	0.1641	−6.0791	<0.0001	−2.3492	0.1612	−6.1051	<0.0001
LnTO	−1.4856	0.5325	−9.0897	<0.0001	−2.0590	0.2617	−9.1178	<0.0001
LnCO	−1.9562	0.3047	−5.2300	<0.0001	−1.8288	0.3626	−5.2343	<0.0001
LnEP	−2.4559	0.1325	−3.8030	0.0054	−2.7643	0.0707	−6.3125	<0.0001
LnEN	−1.3975	0.5761	−7.9764	<0.0001	−1.4810	0.5350	−7.97347	<0.0001

Source: Author's analysis using EViews 12, 2022

Table 1 shows that the null hypothesis H0 was rejected for all the variables at the 1% and 5% significance levels, which means that all the variables are stationary at the first difference.

The Appropriate Lag Length

Several tests were used to determine the optimal lag length appropriate for the tested model, as shown in Table 2.

Table 2
VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	157.982	NA	6.26e-11	−6.467	−6.231	−6.378
1	585.618	727.890	3.67e-18	−23.132	−21.479	−22.510
2	691.036	152.519	2.06e-19	−26.086	−23.016 *	−24.931
3	752.450	73.174	8.58e-20	−27.168	−22.680	−25.479
4	807.470	51.508 *	5.92e-20 *	−27.977 *	−22.072	−25.755 *

*denotes the lag order chosen by the criterion; LR - sequentially modified LR test statistic (each test at 5% level); FPE - Final prediction error; AIC – Akaike information criterion; HQ – Hannan-Quinn information criterion; SC - Schwarz information criterion. NA – not available, Source: author's analysis using EViews 12, 2022

The lag length appropriate for the tested model was also examined. According to the test results, the appropriate lag length is four, so if the model estimates a lag length other than four, the results become biased. As presented in Table 2, most of the tests (LR, FPE, and HQ) had the smallest lag length from them by the fourth year.

Co-Integration Test

To confirm the long-term relationship between variables, Johansen and Juselius (1990) used a co-integration test. The researcher also applied this test, and the results are shown in Table 3.

Table 3
Johansen Tests for Co-Integration

Hypothesised No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**	Results
None *	0.9549	361.22	95.753	<0.0001	Reject H0
At most 1 *	0.8856	218.60	69.818	<0.0001	Reject H0
At most 2 *	0.6992	118.84	47.856	<0.0001	Reject H0
At most 3 *	0.5707	63.580	29.797	<0.0001	Reject H0
At most 4 *	0.3211	24.681	15.494	<0.0016	Reject H0

(*) indicates that the hypothesis was rejected at the 0.05 level, (**) Significant at 1%. Source: author's analysis using EViews 12, 2022.

The results of the Johansson test, shown in Table 3, indicate that the co-integration null hypothesis (none) and hypotheses 1, 2, 3, and 4 were all rejected. In contrast, the 5 co-integration equations did not reject the null hypothesis. The results show that model variables had co-integration relationships between variables, enabling the use of the FOMLS and DOLS methods.

Economic Growth Model

Table 4 outlines the results of the impact of energy production and trade openness on economic growth based on the FMOLS and DOLS methods. The elasticity coefficient of LnEN had statistical significance at a 5% level. According to the FMOLS findings, on average, a 1% increase in LnEN would decrease economic growth by 0.73%. Moreover, the DOLS findings demonstrate that, on average, a 1% increase in LnEN would decrease economic growth by 0.75%. This result indicates that energy consumption has a negative impact on economic growth, which conflicts with the results of Belloumi and Alshehry (2020).

Table 4
Results of FMOLS and DOLS (Equation (1) Economic Growth)

FOMLS MODEL					**DOLS Model**				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**	**Variable**	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LnEN	−0.7325	0.1221	−5.997	<0.0001	**LnEN**	−0.7545	0.1519	−4.9652	<0.0001
LnTO	0.3279	0.1512	2.1679	0.0355	**LnTO**	0.6001	0.1639	3.6607	0.0009
LnCO	0.6198	0.1742	3.5563	0.0009	**LnCO**	0.6145	0.2305	2.6660	0.0121
LnEP	0.2948	0.1179	2.5000	0.0161	**LnEP**	0.3324	0.1412	2.3546	0.0251
C	7.1988	0.6844	10.517	<0.0001	**C**	7.2001	0.6800	10.588	<0.0001
R-squared			0.795947			**R-squared**		0.956280	
Adjusted R-squared			0.777809			**AdjustedR-squared**		0.933714	
S.E. of regression			0.126088			**S.E. of regression**		0.070276	
Diagnostic test			**Statistical test**			**p-value**			
LM (4)			22.87273			0.5960			
Heteroskedasticity			620.9332			0.2688			
Jarque–Bera			0.412197			0.813753			
Skewness			4.756904			0.4463			
Kurtosis			6.420678			0.2674			

Source: author's analysis using EViews 12, 2022.

The elasticity coefficient of LnTO was found to be statistically significant at a 5% level. According to the FMOLS findings, on average, a 1% increase in LnTO would increase economic growth by 0.32%. Furthermore, DOLS findings show that, on average, a 1% increase in LnTO would increase economic growth by 0.60%. The findings show that trade openness had a positive impact on economic growth, which agrees with the previous findings by Ho, Pham, and Nguyen (2021), Malefane (2020), Amna Intisar et al. (2020), and Hdom and Fuinhas (2020). However, these previous results conflict with those of Belloumi and Alshehry (2020) and Saleem et al. (2020).

The elasticity coefficient of LnCO had statistical significance at a 5% level, and, according to the FMOLS findings, on average, a 1% increase in LnCO would increase economic growth by 0.62%. Moreover, the DOLS findings reveal that, on average, a 1% increase in LnCo would increase economic growth by 0.61%. These findings indicate that environmental pollution would lead to an increase in economic growth. The previous findings revealed by Hdom and Fuinhas (2020), however, did not support sustainable development.

The elasticity coefficient of LnEP had statistical significance at a 5% level, and, according to the FMOLS findings, on average, a 1% increase in LnEP would increase economic growth by 0.29%. Additionally, the DOLS findings demonstrate that, on average, a 1% increase in LnEP would increase economic growth by 0.33%. These findings indicate that energy production would lead to an increase in economic growth, which conflicts with the previous findings provided by Hdom and Fuinhas (2020) but supports the findings of Ahmad and Du (2017). This contrast confirmed the different results of the different studies.

Diagnostic Test for Economic Growth Model

Table 4 illustrates that the Breusch-Godfrey Serial Correlation LM Test had no serial correlation since the p-value (0.5960) was greater than 0.05. The heteroskedasticity test findings showed no problems because the p-value (0.2688) was greater than 0.05. The Jarque–Bera, skewness, and kurtosis test results demonstrate that the residuals were normally distributed since the p-values (0.8137, 0.4463, and 0.2674) were higher than 0.05.

Environmental Pollution Model

Table 5 presents the results for the impact of energy production and trade openness on environmental pollution after applying the FMOLS and DOLS methods. According to the FMOLS findings, the elasticity coefficient of LnTO did not significantly affect environmental pollution. However, the DOLS findings indicate that the elasticity coefficient of LnTO did not significantly affect Environmental pollution. The results confirm that the expansion of trade openness is not a creation of more environmental pollution. These results support the previous findings by Pham et al. (2022)and Kalmaz and Kirikkaleli (2019). but conflicts with previous findings by Zamil et al. (2019), Rahman et al. (2020), Chen et al. (2021), Alkhateeb et al.(2017), and Belloumi and Alshehry (2020). Moreover, according to Choi et al. (2017), the adoption of low-priced oil for decades will not be available in the future and could rebound. The matter requires considering the efficient use of green energy technologies (Choi et al., 2017).

Table 5
Results of FMOLS and DOLS (Equation (2) Environmental pollution)

	FOMLS Model:				DOLS Model				
Variable	**Coeff.**	**Std. Error**	**t-Statistic**	**Prob.**	**Variable**	**Coeff.**	**Std. Error**	**t-Statistic**	**Prob.**
LnTO	−0.0635	0.1339	−0.4746	0.6373	**LnTO**	0.1850	0.1069	1.7309	0.0934
LnEN	0.7966	0.0514	15.485	<0.0001	**LnEN**	0.6872	0.0425	16.169	<0.0001
LnGDP	0.5152	0.1356	3.7993	0.0004	**LnGDP**	0.2536	0.1146	2.2121	0.0345
LnEP	0.2134	0.1049	2.0328	0.0480	**LnEP**	0.5844	0.0919	6.3586	<0.0001
C	−2.6875	1.2785	−2.1020	0.0412	**C**	−1.7673	0.9608	−1.8392	0.0755
	R-squared		0.964028		**R-squared**		0.991649		
	Adjusted R-squared		0.960831		**Adjusted R-squared**		0.987339		
	S.E. of regression		0.117740		**S.E. of regression**		0.063397		
	Diagnostic test		**Test statistic**		**p-value**				
	LM (4)		22.87273		0.5960				
	Heteroskedasticity		620.9332		0.2688				
	Jarque–Bera		0.247449		0.883623				
	Skewness		2.916336		0.7129				
	Kurtosis		1.061784		0.9574				

Source: author's estimates using EViews 12, 2022.

The elasticity coefficient of LnEN was found to be statistically significant. According to the FMOLS findings, on average, a 1% increase in LnEN would increase environmental pollution by 0.79%. Furthermore, the DOLS findings show that, on average, a 1% increase in LnEN would increase environmental pollution by 0.68%. As a result, energy consumption was found to be the primary source of environmental pollution in Saudi Arabia. These results suggest that as energy consumption increases in Saudi Arabia, CO2 emissions will also increase, and the environment will become more polluted. These results support the previous findings by Hossain (2011), Rahman et al. (2020), Kalmaz and Kirikkaleli (2019), Rahman et al. (2021), and Belloumi and Alshehry (2020).

KSA is in high need of utilising renewable energy sources in the coming years, especially solar energy. KSA can act as a solar hub for its neighbouring countries because of its large land areas. Therefore, an initiative towards exporting green power will benefit both KSA and the Gulf countries and contribute to a sustainable environment and climate (Ali & Khan, 2018).

The elasticity coefficient of LnGDP had statistical significance at a 5% level. According to the FMOLS findings, on average, a 1% increase in LnGDP would increase pollution emissions by 0.52%. Moreover, the DOLS findings reveal that, on average, a 1% increase in LnGDP would increase pollution emissions by 0.25%. These findings indicate that an increase in economic growth would lead to an increase in environmental pollution. This result supports the supported by Environmental Kuznets curve theory and the previous findings by Zamil et al. (2019), Kalmaz and Kirikkaleli (2019), Chen et al. (2019), and Ahmad and Du (2017) but conflicts with previous findings by Hdom and Fuinhas (2020), Hossain (2011) and Belloumi and Alshehry (2020).

Access to green energy requires providing it at a wide range to ensure the reduction of greenhouse gas emissions and, hence, the environmental impact. This requires the Saudi government to collaborate with the global business sector and society to achieve integration that comes with a secure supply (Comakli et al., 2008). Russia and KSA have announced green energy transition plans (McKillop, 2012).

The elasticity coefficient of LnEP had statistical significance at a 5% level. According to the FMOLS findings, on average, a 1% increase in LnEP would increase environmental pollution by 0.21%. Furthermore, the DOLS findings show that, on average, a 1% increase in LnEP would increase environmental pollution by 0.58%. As a result, energy production was found to be the primary source of pollution in Saudi Arabia. This result indicates that as Saudi Arabia's energy production increased, CO2 emissions also increased, making the environment more polluted. These findings conflict with previous findings by Hdom and Fuinhas (2020) but are consistent with those of Danlami et al. (2019), Danish et al. (2018), and Chen et al. (2019). Despite that, national oil companies should generate returns for their governments, and private oil companies should generate returns for shareholders. Accordingly, all of the involved parties should ensure cost-effectiveness. Subsidies provided to renewable energies, accompanied by a reduction in the use of renewable technologies, can increase the value of using green energies (Ericson et al., 2019).

Diagnostic Test of Equation Environmental pollution

Table 5 shows that the LM test had no problems with serial correlation because the p-value (0.596) was greater than 0.05. The heteroskedasticity test results show no problems because the p-value (0.2688) was greater than 0.05. The Jarque–Bera, skewness, and kurtosis test results demonstrate that the residuals were normally distributed since the p-values (0.8836, 0.2791, and 0.9574) were higher than 0.05.
Granger causality Wald tests

Table 6
Granger Causality Wald Tests of Economic Growth Model

Direction of Causality	Chi-sq	Prob.
LnGDP → LnCO	8.121039 *	(0.0872)
LnCO → LnGDP	6.580123	(0.1598)
LnGDP → LnEN	5.055096	(0.2817)
LnEN → LnGDP	20.74741 ***	(0.0004)
LnGDP → LnEP	387.9472 ***	(0.0000)
LnEP → LnGDP	8.183075 *	(0.0851)
LnGDP → LnTO	5.052581	(0.2819)
LnTO → LnGDP	6.580123	(0.1598)
LnTO → LnEN	3.525245	(0.4741)
LnEN → LnTO	29.40909 ***	(<0.0001)
LnTO → LnEP	6.721914	(0.1513)
LnEP → LnTO	4.891183	(0.2986)

(***) Significant at 1%, (**) Significant at 5%, and (*) Significant at 10%. Source: Author's analysis using EViews 12, 2022.

The results of the Granger causality and Wald tests are shown in Table 6. If the p-value is significant at 1%, 5%, or 10%, H0 is rejected, which suggests that X did not homogeneously cause Y (Ali, Khan, & 2018). (LnDGP, LnTO) is not significant at any level, so the null hypothesis is accepted. This result indicates that trade openness does not lead to economic growth and thus does not support the results of the study. The result of the causality test shows that there is a bidirectional relationship between economic growth and energy production, indicating that both economic growth and energy production can predict each other in Saudi Arabia. This finding is consistent with FMOLS and DOLS models that support long-run relationships between variables. While there is a unidirectional causality running from economic growth to environmental pollution, this result indicates that economic growth increases environmental pollution and from energy consumption to economic growth.

Table 7
Granger Causality Wald Tests of Equation Environmental Pollution

Direction of Causality	Chi-sq	Prob.
LnGDP → LnCO	8.121039 *	(0.0872)
LnCO → LnGDP	6.580123	(0.1598)
LnTO → LnCO	4.505072	(0.3419)
LnCO → LnTO	12.33504 **	(0.0150)
LnCO → LnEN	7.682901	(0.1039)
LnEN → LnCO	22.44043 ***	(0.0002)
LnCO → LnEP	7.532495	(0.1103)
LnEP → LnCO	23.16543 ***	(<0.0001)
LnEN → LnEP	21.16212 ***	(0.0003)
LnEP → LnEN	14.65739 ***	(0.0055)

(***) Significant at 1%, (**) Significant at 5%, and (*) Significant at 10%. Source: Author's analysis using EViews 12, 2022.

The result of the causality test is shown in Table 7. A unidirectional causality runs from environmental pollution to trade openness. This result indicates that trade openness does not lead to environmental pollution and thus supports the results of the FMOLS and DOLS models. There is a unidirectional causality running from energy consumption to environmental pollution and from energy production to environmental pollution. These results are consistent with the estimates for FMOLS and DOLS, as increased energy production and consumption lead to more environmental pollution.

Conclusions

The main goal of this study is to identify the impact of energy production and trade openness on economic growth and environmental pollution. Due to the lack of studies on environmental pollution in Saudi Arabia, no study has combined energy production with economic openness. Therefore, this study attempted to bridge the gap between the impact of energy production and trade openness on economic growth and environmental pollution while enriching Saudi Arabian studies. The results of this study would represent a real addition to Saudi Arabia's knowledge. This study employs FMOLS and DOLS and co-integration regression methods; the data spanned the period 1970–2020. Based on the results of FMOLS and DOLS, it was found that trade openness had a statistically significant impact on economic growth. In the context of expansion, trade openness would lead to an increase in economic growth. According to this result, the null hypothesis of no positive relationship between Trade openness and economic growth is rejected, and the alternative hypothesis is accepted, meaning that a positive relationship between Trade openness and economic growth. It was also found that energy production had a statistically significant impact on economic growth, confirming that an increase in energy production would lead to an increase in economic growth. According to this result, the null hypothesis that Increased Energy production will not increase economic growth is rejected, and the alternative hypothesis is accepted, meaning that Increased Energy production will increase economic growth.

According to the results of FMOLS and DOLS, energy production had a statistically significant impact on environmental pollution, indicating that an increase in energy production would lead to an increase in environmental pollution. This result indicates that energy production represents the primary source of environmental pollution in Saudi Arabia. According to this result, the null hypothesis that Increased Energy production will not increase environmental pollution is rejected, and the alternative hypothesis is accepted, meaning that Increased Energy production will increase environmental pollution. According to the FMOLS estimates, trade openness did not significantly affect environmental pollution. The results of the Granger causality and Wald tests confirmed this finding. The DOLS estimates show no statistically significant impact on environmental pollution. According to this result, the null hypothesis of no positive relationship between Trade openness and environmental pollution is accepted. In this regard, an increase in trade openness would not lead to greater environmental pollution.

The result of the causality test of the economic growth model is consistent with the FMOLS and DOLS models, as increased energy production leads to increased economic growth. While the results of the causality test for the relationship of trade openness to economic growth do not support the results of the estimates for the FMOLS and DOLS models, the results of the environmental pollution model's causality test are consistent with the estimates for FMOLS and DOLS, as increased energy production leads to increased environmental pollution. Furthermore, trade openness does not cause environmental pollution.

This study recommends that decision-makers in Saudi Arabia and all MENA countries should pursue two policies to reduce environmental pollution in Saudi Arabia. Firstly, green technology and green transportation should be used to reduce the use of fossil fuels. Secondly, carbon pricing is a sustainable policy instrument that is effectively used to restrict dirty production by imposing high taxes on polluted industries.

This study was limited to studying the impact of non-renewable energy production on economic growth and environmental pollution. It excluded renewable energy production due to a lack of data covering the study period. Among the proposed future studies, a study that includes the impact of renewable and non-renewable energy on economic growth and environmental pollution in Saudi Arabia will complete this study.

Future studies should focus on the impact of energy consumption and energy production on environmental pollution. Addressing the concept of a 'circular economy of carbon', which includes reducing, reusing, recycling, and removing carbon, is also required for future research. Moreover, the effects of carbon pricing on environmental sustainability or pollution.

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