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The influence of economic development, capital formation, and internet use on environmental degradation in Saudi Arabia

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Abstract

Sustainable economic growth and environmental degradation are two concerns confronting humanity. Saudi Arabia has seen a dramatic rise in its atmospheric carbon emissions during the last three decades. From 1995 to 2020, this research uses the decoupling index and vector error correction model technique to reveal the variables influencing CO_2 emissions in Saudi Arabia. This research aims to empirically analyze the causal factors that link carbon emissions, energy use, economic growth, and internet usage. The big priority of this research is to use various techniques and methodologies to examine the cointegration and long- and short-run relationships between macroeconomic variables and stock price. According to the augmented Dickey–Fuller unit root test results, the main series is stationary in the first difference but non-stationary at the level. According to Johansen's cointegration study, both relations between the variables exist in the Kingdom of Saudi Arabia. The VEC model's outcome shows that internet use significantly contributes to rising greenhouse gas emissions. When creating strategies for economic growth to achieve sustainable development, policymakers must consider climate change. This may be accomplished by implementing a new policy to switch from conventional to renewable energy sources, emphasizing increased energy efficiency, or reorganizing the energy sector to influence the rise in greenhouse gas emissions.

Keywords Environmental degradation, Energy consumption, Economic development, Internet usage, Cointegration, Decoupling, VECM

Introduction

Understanding the causes of greenhouse gas (GHG) emissions in major energy consumers like Saudi Arabia is crucial for developing effective responses to climate change. U.S. Energy Information Administration estimates that in 2021, Saudi Arabia consumed 3.328 million barrels of petroleum and other liquids per day and 2.95 trillion kilowatt-hours of electricity. The overuse and improper disposal of fossil fuels is a major contributor to Saudi Arabia's environmental problems. This implies that Saudi Arabia confronts a significant task in devising a policy that would both promote economic development and protect the country's natural resources. Global warming and climate change have been critical global environmental issues in recent decades. The primary source of global warming and climate change is GHG, particularly CO_2 emissions [19, 73]. International economic globalization has led to several things that affect people all over the world and their surroundings. For the economy to proliferate, it needs to use a lot of energy, which increases carbon dioxide emissions across the globe. Research into the factors that cause carbon dioxide emission has increased significantly during the past 20 years [3, 17, 32]. The effects of carbon dioxide, which raises the earth's temperature, are all at dangerously high levels. Consequently, several countries ratified the Paris

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Climate Treaty in 2015 to control the rise in global temperature by 1.5 °C. If no action is taken to stop a temperature rise of 2 °C, the planet will be doomed to catastrophe shortly. Burning natural gas instead of coal or petroleum products to create the same amount of energy leads to much lower emissions of almost all airborne pollutants and carbon dioxide (CO_2), which has contributed to the problem of environmental pollution.

The emissions stemming from human industrial activities are a significant contributor to climate change and pose a critical global challenge. The concentration of carbon dioxide in the atmosphere has been steadily increasing over the years. While energy plays a crucial role in driving economic development, the changing patterns of demand at various stages of economic progress necessitate the identification and implementation of effective solutions to address environmental challenges. Saudi Arabia demonstrates a notable level of concern toward environmental matters, as evidenced by its ratification of various climate agreements [62]. Consequently, the country would not be obligated to adhere to any initial commitment involving specific limitations on greenhouse gas emissions. However, it is crucial to acknowledge the factors that are influencing the fluctuations in Saudi Arabia's greenhouse gas emissions in order to gain a more comprehensive understanding of the complex connections between economic growth, technological advancements, energy consumption, and greenhouse gas emissions. Furthermore, the enhancement of energy efficiency has emerged as a primary goal among energy policymakers in Saudi Arabia, serving as a crucial stride toward attaining sustainable economic advancement. Based on the existing scholarly literature, various approaches and hypotheses have been proposed to examine the correlation between economic growth and environmental pollution. On the one hand, it is evident that the state of environmental quality is impacted by both economic growth and internet usage. These factors contribute to alterations in environmental policies and reinforce the notion that as per capita income increases, environmental degradation also tends to rise.

This study contributes to the current scholarly literature. Using vector error correction model (VCEM), unit root tests, and cointegration techniques this study empirically examines the connection between economic growth, capital formation, internet usage, and CO_2 emissions in Saudi Arabia, providing new evidence on these topics. Based on three significant contributions, the research has a wider scope and is a significant addition to the body of literature already in existence. Firstly, First and foremost, environmental sustainability should be prioritized in policy development [76]. In 2019, 11 scientists from 150 sovereign countries declared that economic expansion was to blame for the over-exploitation of the ecology and excessive extraction methods. They suggested that efforts should be shifted away from GDP growth and toward improving human lives. Other researchers have found a significant positive association between carbon dioxide emissions and economic growth and as well as differences in carbon intensity (carbon emissions per GDP). They proposed that world economic richness was related to the rate of global greenhouse gas emissions [8, 26]. Therefore, this study adds to the growing corpus of empirical research by validating these hypotheses in Saudi Arabia on the factors that influence rising CO_2 emissions levels while achieving economic development, particularly the literature examining the effects of economic expansion on environmental deterioration. Secondly, we separate the meaning of economic development on CO_2 emissions and point out that few studies concentrate on the profile of Saudi Arabia, and ignore the biggest contribution of the Gulf nations to the global greenhouse gas emissions. Using two different types of estimators, we show that economic growth, capital formation, and internet usage all have a statistically significant impact on CO_2 emissions. We attribute this finding to the inefficiency of not using the right tools for managing climate risk. Thirdly, we provide a deeper understanding of the connection that exists between increased levels of internet use and the growing need for greater stewardship of the natural environment. We want to bring attention to the need of formulating environmental policies that are able to cut emissions even during times of economic boom. The research not only provides a more accurate depiction of the situation but also serves as a helpful guide for academics, professionals, policymakers, and government officials.

The remainder of this paper is structured as follows: "Literature review" section presents literature review. "Material and methods" section presents what methodology is adopted for empirical analysis. "Results and discussion" section elaborates the results of the analysis. "Discussion" section concludes the present study and shows the limitations and future directions.

Literature review

Relationship between energy from gas and CO_2 emission

Natural gas is a crucial source of energy in Saudi Arabia. It meets the country's growing energy needs and power industries such as steel, aluminum, and water desalinization. Demand for more energy may spur economic expansion, but its consumption also results in emissions of harmful greenhouse gases [45]. Greenhouse gas emissions are being reduced by several countries. Top energy-consuming economies have debated and proposed new policies to reduce carbon dioxide emissions and encourage greener economic growth [36, 66, 79, 80]. It is imperative that a deeper understanding of the linkages among GHG, energy consumption, and economic growth is achieved if there will be any hope of effectively controlling emissions of greenhouse gases and ensuring the long-term viability of economic development.

From 1975 to 2015, a study conducted by Sulaiman et al. [74] examined the correlation between carbon dioxide (CO_2) emissions, energy consumption, and the economic factors in Malaysia. The study employed the autoregressive distributed lag (ARDL) model for analysis. The findings of the analysis indicate that there is no significant impact of energy consumption and CO_2 emissions on economic growth. However, it is observed that energy consumption and economic growth have a positive association with CO_2 emissions. Chen [12] conducted a study in which the autoregressive vector (VAR) model and the Wald test for causality testing were employed to investigate the influence of gasoline energy consumption on economic growth in Cameroon. The findings of the analysis indicate that there is no significant and enduring association between the variables under investigation within the selected sample. A bidirectional causal relationship exists between gasoline consumption and economic development in Cameroon [12]. The findings of the study indicate that the reduction in gasoline consumption alone is not a viable solution for sustaining Cameroon's economic growth, unless accompanied by well-defined and effective energy policies. Between the years 1992 and 2016, Bhat [5] conducted a study investigating the impact of energy consumption and economic growth on carbon dioxide levels. The Panel ARDL model was employed to establish the relationship between the variables under analysis. The reviewed findings indicate a positive relationship between CO_2 emissions and various factors such as resources, labor, population, per capita income, and nonrenewable energy consumption.

Relationship between FDI and CO_2 emission

Emissions of carbon dioxide (CO_2) into the atmosphere have been recognized as a significant contributor to global environmental degradation. Environmental contamination has far-reaching consequences, affecting not just social production but also human lives, the policies pursued, and the geographic distribution of economic interests in future. The dominant sectors of the national economy change as economies go through various phases. One of the critical drivers of economic development, a prospective employer, and a means of transferring cutting-edge technology to host nations, foreign direct investment (FDI) has been recognized [15, 67]. In recent decades, the flow of foreign direct investment has become even more significant than international commerce. Since the rate of development, manufacturing investments has surpassed that of the flow of products in international trade [11]. As trade protectionism spreads globally, FDI opens doors for businesses to enter markets that are protected by doing their production elsewhere. Additionally, there is evidence that FDI boosts productivity [14, 83]. As a consequence of this, a significant number of nations are turning to aggressive forms of advertising to entice FDI [52]. Investing promotion agencies (IPAs), which are often controlled by the government and may be found in numerous countries, are responsible for implementing these various promotional techniques. Many nations have benefited from the influx of international cash and expert knowledge thanks to the successful implementation of these IPAs [31]. Nonetheless, concerns regarding FDI's possible negative effects on the environment are regularly expressed and need special attention [60, 84]. Increases in foreign direct investment (FDI) may coincide with increases in environmental emissions, which might offset any benefits to the economy from the FDI [13]. Both monetary and non-monetary institutions are impacted by environmental degradation and climate change which in turn affects the state of the sustainable economy [28, 58, 75]. The need of making reductions in the intensity of carbon use is crucial. The relevance of low carbon intensity, on the other hand, is brought to light when considering a nation such as Saudi Arabia, whose economy is substantially dependent on fossil fuels [77]. The fact that Saudi Arabia is the country that produces and exports the most oil and petroleum products is the primary reason why its economy is ranked first in the world [6]. Despite this, the country's usage of fossil fuels is rather high since these resources are so readily available. Because all aspects of the Saudi economy rely on oil and other petrochemicals for their energy needs, the country's carbon intensity is very high [20]. It is clear that great efforts have been made to lower the intensity of carbon emissions; nonetheless, the level of these emissions is still quite high. Due to the severity of the problem, prompt action is required to investigate potential strategies for reducing carbon intensity.

Relationship between GDP and CO_2 emission

There are two main lines of inquiry into how CO_2 emissions, energy usage, and GDP growth are connected in the academic research. The first body of work examines how pollution affects economies, finding that environmental deterioration is correlated negatively with GDP per capita (hereafter, GDP). The literature refers to this correlation as the Environment Kuznets Curve (EKC). Increasing pollution levels have been linked to a growing economy, and this correlation has been the subject of several studies. The following studies [1, 9, 29, 44, 82] are examples of recent research that focused on greenhouse gas emissions or CO_2 emissions more explicitly. The outcomes of the research demonstrate that there is no consistent association between the variables. As a result, the evidence in support of the environmental Kuznets curve, which is depicted by an inverted-U function, is, at best, inconclusive. The regional and national characteristics of each area have a significant role in determining the results. The second line of inquiry looks at how increasing energy use correlates with a booming economy. Understanding the impact of energy consumption on economic growth may be gleaned from the correlation between these two variables. Studies by Magazzino [46], Omri and Kahouli [56], Ozturk and Acaravci [59] and Shahbaz and Lean [71] are representative examples. The outcomes of studies and the causal links relating to the problem of energy consumption and economic development may also differ depending on the dataset, model specification, and econometric approach that researchers choose to use. The concept of the "Environmental Kuznets Curve" has been proposed, which is also similar with the concept of sustainable development. According to this idea, environmental pollution continues to reach at peak in the early stage of economic development, until economic growth reaches a "turning point" [47, 78]. After that, environmental pollution will show a declining trend and quality of environment will improve. Briefly, environmental pollution and income level share inverted-U-shaped relationship with each other [30].

Relationship between gross capital formation and CO_2 emission

It is imperative that, in addition to energy based on consumption of gas and oil, the other elements that are contributing to the depletion of the environment in Saudi Arabia be considered. Gross capital formation (GCF) is one of the most important but also most problematic aspects. In addition, excessive energy use is another contributor to carbon emissions, which in turn contribute to environmental damage [61]. A Gross capital formation is the sum of a unit's or sector's investments in new fixed assets, changes in inventories, and purchases minus sales of existing assets. However, there is a body of research, for instance [2, 19, 23, 33, 35, 38, 41, 42, 57, 70, 72, 84], that examines the connections between energy consumption and carbon dioxide emissions, whether they are short-term or long-term and entwined with other factors According to Wood and Hertwich [81], the total proportion of GCF as a component of the global carbon footprint differs among countries more than GCF as a part of total GDP. They claim that the connection between GCF and the environment differs for different countries based on their level of development because developing countries invest more heavily in resource-intensive assets such as industrial equipment and infrastructure, while more developed countries invest less heavily in these areas and more in others such as software, facilities, and computer technology. It is important to do research on the connection between total gross capital formation and total emissions of carbon dioxide, while also taking into consideration the degree of economic growth.

Relationship between internet usage and CO_2 emission

Over the course of the last three decades, there has been a discernible rise in the number of people making use of information and communication technologies (ICT) all over the globe [10]. Some claim that data centers have seen annual growth of 11% over the last decade [25]. In accordance with the available statistics, the data center business is responsible for between 1.1 and 1.5% of the total amount of power used around the globe [18]. The increasing rise in the use of information and communications technology, particularly internet use, puts pressure on the home demand for the consumption of power [64]. Not only does using the internet need a gadget that is physically linked to an electrical outlet or a battery that has been charged with power, but it also requires accessing millions of bits of data that are kept on servers. These servers have a very voracious appetite for energy! [65]. This is due to the method in which they operate, in conjunction with the way in which we make use of them. When it comes to emissions of greenhouse gases, internet usage amounts for 3.7% of worldwide emissions, which is the same as all of the air travel that takes place throughout the globe combined. This number is forecast to more than quadruple by the year 2025 (excluding the effects of Covid-19). There are three potential effects of internet use on greenhouse gas emissions: increased production efficiency, decreased energy use per unit of output, and lower energy costs [21]. In this day and age of the digital economy, the collection of data and the evaluation of resources via the use of the internet have evolved into a vital component of every company operation. This is especially true in regard to the enhancement of production efficiency [24]. In more tangible terms, this equates to an aggregate of 400 g of CO_2 being generated per individual each and every year due to the use of the internet exclusively.

Material and methods

Theoretical framework

A theoretical framework has been formulated to concentrate on particular variables. The framework encompasses the interrelationships among carbon emissions, economic growth (EG), foreign direct investment (FDI), gross domestic product (GDP), gross capital formation (GCF), and internet usage (IU) as illustrated in Fig. 1. This study posits that a direct correlation exists between economic growth and carbon emissions. Nevertheless, it is commonly observed that there exists a positive relationship between foreign direct investment (FDI), gross domestic product (GDP), gross capital formation (GCF), and carbon emissions. This can be attributed to the fact that nations with higher FDI, GDP, and GCF tend to exhibit greater levels of industrialization and energy consumption, consequently leading to elevated carbon emissions [69].

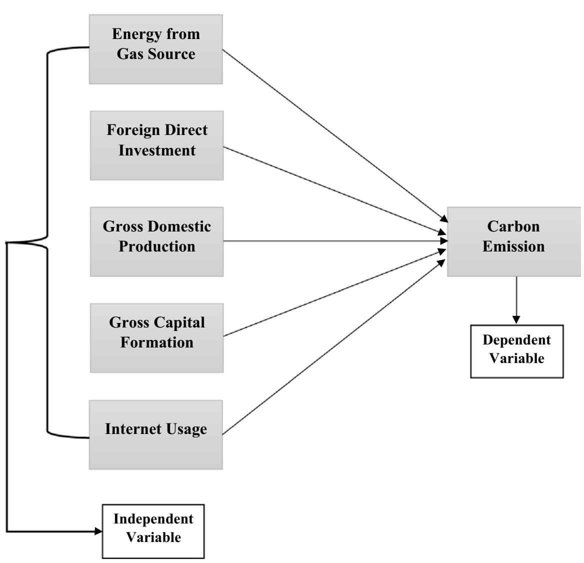

Fig. 1 Theoretical framework

Data description

In the course of our investigation, we have used the annual based data of Saudi Arabia for the time span of 1995–2020. Energy from gas sources (kWh), Foreign Direct Investment (Net inflows % of GDP), Gross Domestic Production (Current US$), Gross capital formation (% of GDP) and internet usage (% of population), use as independent variables, while carbon emission CO_2 (per capita) is the dependent variable. For data analysis, EViews 12 was used. The source of the data is Word Development Indicators (WDI 2022). The source of the data is Word Development Indicators (WDI 2022). Table 1 represents the general description of the data.

Figure 2 exhibits the trends of all independent and dependent variables.

Methodology

Several econometrics methods were used in this research to empirically evaluate the interplay between these independent and dependent variables. Figure 3 depicts a roadmap of methodology that might be used for the analysis of variable relationships. This study used VEC model through VECM we can interpret long-term and short-term equations. It is imperative to ascertain the quantity of cointegrating relationships. The motivation of using this model is that the vector error correction model (VECM) over the vector autoregression (VAR) model is that the coefficient estimates obtained from the VAR representation derived from VECM are more efficient.

Model specification

One of the main thrusts of our study is to determine whether there is a connection between carbon emissions and Energy from Gas, GDP, FDI, GCF, and IU in the context of Saudi Arabia. As such, the following estimation model is offered, which is in line with the aims of this study:

$$\mathrm{CO}_{2t} = \partial_1 + \beta_1 \mathrm{EG}_t + \beta_2 \mathrm{GDP}_t + \beta_3 \mathrm{FDI}_t + \beta_4 \mathrm{GCF}_t + \beta_5 \mathrm{IU}_t + \varepsilon_t \quad (1)$$

The parameter ∂_1 in Eq. (1) signifies the intercept in each of the various models, while $\beta_{1,}$ $\beta_{2,}$ $\beta_{3,}$ β_4, and

Table 1 Variable description

Symbol	Variables	Unit of Measurements	Source
CO_2	Annual CO_2 emissions from gas	Per capita	World Bank (2022)
EG	Energy from gas source	kWh	World Bank (2022)
FDI	Foreign direct investment	Net inflows (% of GDP)	World Bank (2022)
GDP	Gross domestic production	Current US$	World Bank (2022)
GCF	Gross capital formation	% of GDP	World Bank (2022)
IU	Individual using internet	% of Population	World Bank (2022)

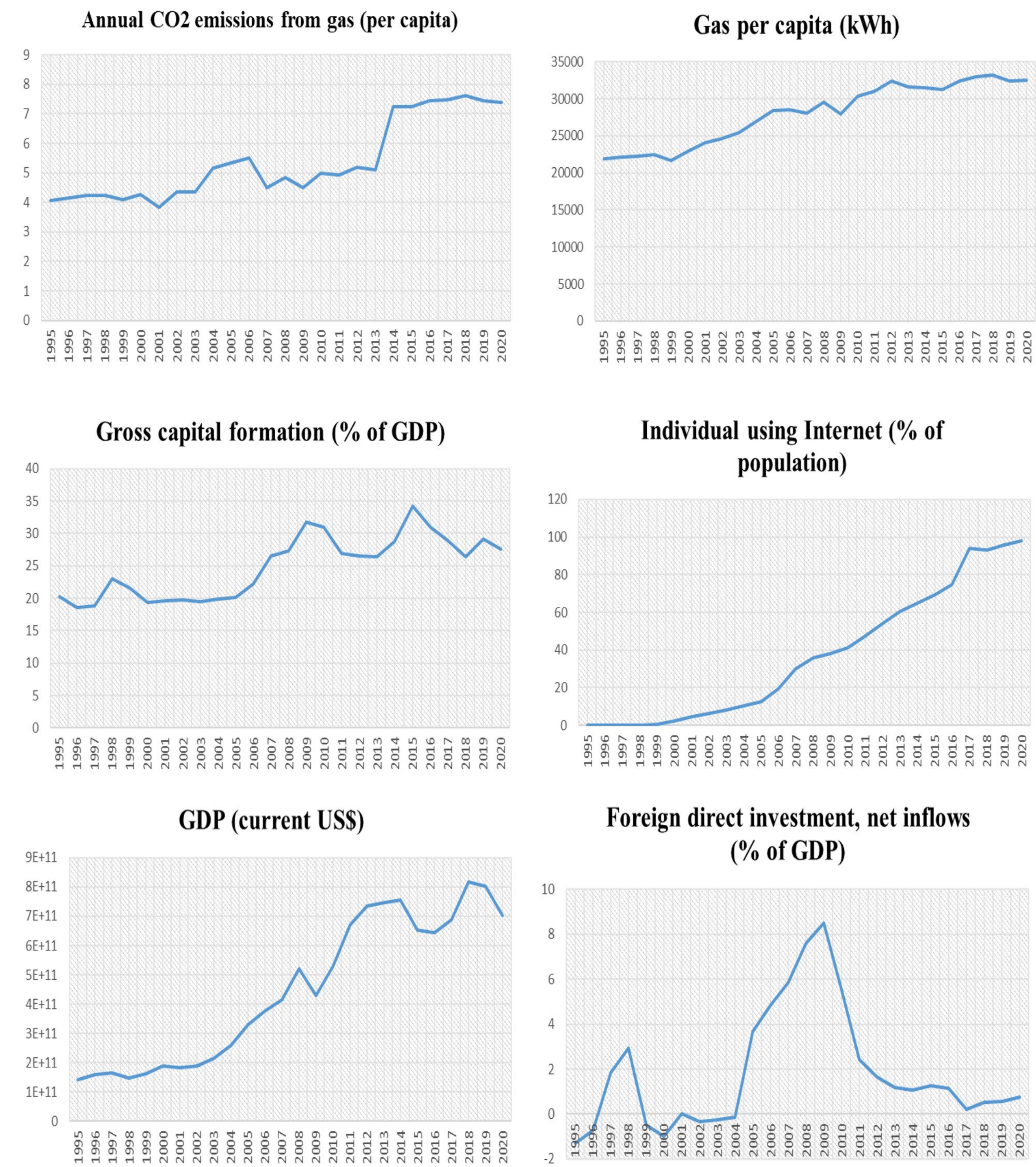

Fig. 2 Trends of all independent and dependent variables

β_5 are the coefficients. The information pertaining to these variables comes from a database known as World Development Indicators (WDI), which is kept up to date by the World Development Indicators (2022).

Unit root test

We initially concentrate on avoiding the problem of incorrect and unreliable conclusions that arises from non-stationary datasets. Because of this, the research

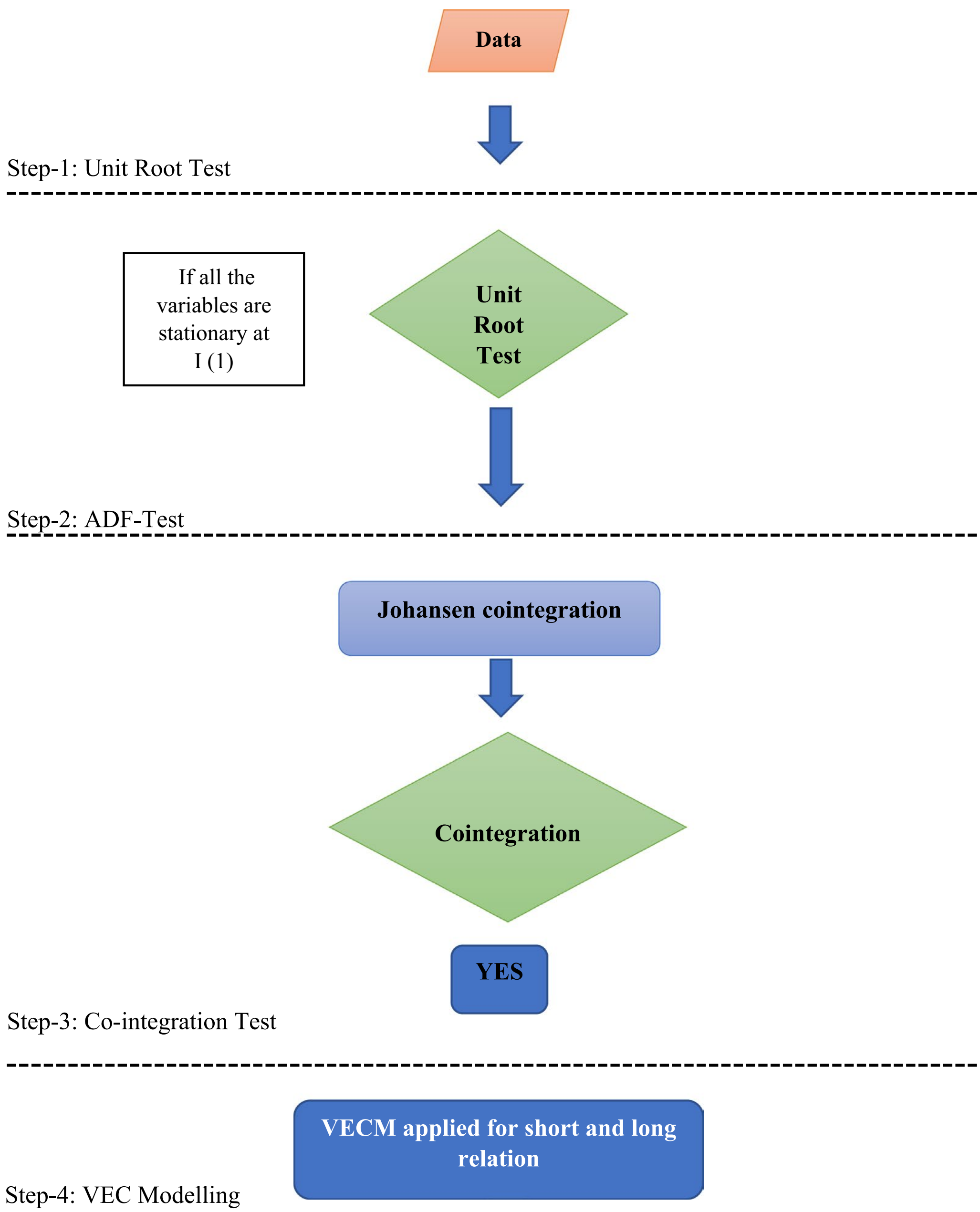

Fig. 3 Methodology roadmap

uses the augmented Dickey–Fuller to assess the integration order of variables [16]. These tests evaluate the presence of a unit root as the null hypothesis and the lack of a unit root as the alternative.

$$\Delta Y_t = \alpha + \beta_t + \rho Y_{t-1} + \sum_{i=1}^{k} \gamma i \Delta Yt + e_t$$

H_0: $\rho = 0$.
$H1$: $\rho < 0$.

In the above equation, Y_t, Δ, T, e_t, σ_2, and K depict the time range, operator differences, trends of time, error term, with zero mean value and variance and lag values. This study uses the ADF test to check whether the data are stationary. Table 2 displays the outcomes of first-order difference estimation for each variable. Since the initial unit root theory was disproved, we may conclude that all variables are consistent.

Table 2 Descriptive statistics

	CO_2	EG	FDI	GDP	GCF	IU
Mean	5.368885	28,027.67	1.820766	4.47E+11	24.79687	36.98621
Maximum	7.632100	33,261.38	8.496352	8.17E+11	34.17260	97.86000
Minimum	3.832200	21,733.61	− 1.307818	1.43E+11	18.57124	0.010956
Std. Dev.	1.336017	4097.330	2.655731	2.48E+11	4.753480	34.82499
Skewness	0.734818	− 0.315690	1.127031	0.097047	0.182303	0.488153
Kurtosis	1.913312	1.593478	3.305448	1.395810	1.744562	1.835474
Jarque–Bera	3.619114	2.575022	5.605272	2.828688	1.851486	2.501736
	0.1637	0.2759	0.0606	0.2431	0.3962	0.2862

Cointegration

After the unit root characteristics of the variables have been found, the next step is to see whether variables are cointegrated and have long-run associations. The Johansen cointegration analysis is used as a result [37]. This method counts the number of cointegrating equations in each model using two different maximum likelihood ratio tests (maximum eigenvalue and trace). These two tests' relative test statistics may be represented as:

$$\mathbf{LR_{trace}} = -\boldsymbol{T}\sum_{i=r+1}^{K}\mathbf{ln}\left(1-\boldsymbol{\gamma}_i^*\right) \tag{2}$$

$$\mathbf{LR_{Maximum}} = -\boldsymbol{T}\mathbf{ln}\left(1-\boldsymbol{\gamma}_{i+1}^*\right) \tag{3}$$

where γ^*_{i+1}, γ^*_k are $(k-r)$ indicate the smallest eigenvalues and T indicates the maximum time at series t. The test procedures are dependent on the link between a matrix's location and the tools that make up its features.

Vector error correction model

After a long-term equilibrium association between variables has been identified by using the technique of cointegration testing, we may use VECM to assess the short-term characteristics of the cointegrated series. Whether there is no cointegration, then the VECM is unnecessary and we can get right to the Granger causality tests to see whether there is a correlation between the variables of interest. VECM's regression equation looks like this:

$$\Delta \boldsymbol{Y_t} = \boldsymbol{\beta}_0 + \boldsymbol{\beta_t}\boldsymbol{\varepsilon}_{\boldsymbol{t}-1} + \sum\nolimits_{i=1}^{m}\boldsymbol{\beta j}\Delta \boldsymbol{Y}_{\boldsymbol{t}-1} + \sum\nolimits_{j=1}^{n}\boldsymbol{\beta j}\Delta \boldsymbol{X}_{\boldsymbol{t}-\boldsymbol{j}} + \boldsymbol{\varepsilon_t} \tag{4}$$

The proportion of cointegrating vectors in VECM is represented by its cointegration rank [34]. For example, a rank of two suggests that two combinations of non-stationary variables that are linearly independent will be stationary [54]. A negative and substantial ECM coefficient (e_{t-1} in the preceding equations) suggests that any short-term oscillations between the independent and dependent variable will result in a stable long-term connection between the variables [51].

Diagnostic tests

The vector error correction (VEC) model aims to identify the optimal linear unbiased estimator (BLUE), and therefore, it is necessary to perform diagnostic tests to ascertain the statistical robustness of the findings. Serial correlation, heteroscedasticity, and normality tests are employed to assess the stability of the residuals. If the model does not possess any of these biases, the obtained results can be utilized for the purpose of analysis. To ascertain the appropriate diagnostic tests, it is necessary for the *p*-value of all tests to exceed 5%.

Serial correlation test

Serial correlation occurs when the error terms from previous periods have an impact on future periods. Despite the linearity and statistical significance of the estimators in ordinary least squares (OLS) regression, as well as the presence of serial correlation, it is important to note that these estimators do not qualify as best linear unbiased estimators (BLUE). The study conducted a serial correlation test, specifically employing the Breusch–Godfrey serial correlation LM test, also referred to as the Lagrange multiplier test. This test is utilized to examine the association between observations of a given variable within defined time intervals. The null hypothesis posited in this test asserts the absence of serial correlation within the lag order p. According to Kirchgässner and Wolters [40], if the

R-squared value exceeds the critical p-value at a significance level of 5%, it leads to the rejection of the null hypothesis, indicating the absence of serial correlation.

Heteroscedasticity test

The heteroscedasticity test is conducted in order to ascertain whether the variability of residuals remains consistent. In order to examine the potential impact of error terms from prior periods on subsequent periods, a heteroscedasticity test was conducted utilizing the ARCH method as proposed by Kirchgässner and Wolters [40]. The subsequent statements outline the hypotheses of the aforementioned test.

- The null hypothesis (H0) posits the absence of heteroskedasticity.
- Alternative hypothesis (H1) shows the existence of heteroskedasticity

If the value of the Chi-square statistic exceeds the critical p-value, the null hypothesis has been rejected. This implies the absence of heteroscedasticity. Alternatively, homoscedasticity is observed.

Normality test

The evaluation of data normality is a fundamental requirement for numerous statistical tests, as the assumption of normality is a foundational principle in parametric testing. In the case of data that follow a normal distribution, the observed data closely approximate the expected data, indicating a statistical equivalence between the two.

Robustness check

Decoupling index

The decoupling phenomenon is shown by the fact that the rate of economic expansion is greater than the rate of environmental degradation [53]. The OECD created an index and decoupling factors in 2002 that quantify the relationship between economic growth and d environmental degradation in a given period of time [63]. The equation of decoupling ratio is as follows:

$$\textbf{Decoulping Ratio} = \frac{\frac{\mathbf{C0_{2t}}}{\mathbf{GDP_t}}}{\frac{\mathbf{CO_{2t-1}}}{\mathbf{GDP_{t-1}}}} \tag{5}$$

The decoupling ratio has a range of $(-\infty, 1)$; $DR = 1$ indicates coupling. Decoupling index is represented by the subtraction of 1 and is defined as:

$$\textbf{Decoulping Index} = 1 - \boldsymbol{D} = 1 - \frac{\frac{\mathbf{C0_{2t}}}{\mathbf{GDP_t}}}{\frac{\mathbf{CO_{2t-1}}}{\mathbf{GDP_{t-1}}}} \tag{6}$$

In this equation, t represents the beginning and $t-1$ represents the last year of the chosen research period. The anticipated outcomes could be: as the economy expands, CO_2 emissions are shown to be decreasing by absolute decoupling (DI > 0, close to one). For economic growth with favorable environmental conditions, this decoupling relationship is more desirable. DI > 0, or close to 0 implies a poor decoupling relationship between carbon emissions and GDP with both expanding simultaneously although the economy is growing faster than carbon emission. When there is coupling or no decoupling (DI 0), both the economy and environmental degradation expand at the same time, but environmental degradation accelerates more quickly than the economy due to rising CO_2 emissions.

Results and discussion

Descriptive statistics

Table 2 illustrates the descriptive statistics of all the variables, which shows the normality of the data. It shows that the results of descriptive statistics of all variables CO_2 (5.368), EG (28,027.67), FDI (1.82), GDP (4.47E+11), GCF (24.79), and IU (36.98) with positive standard deviation. The skewness value of energy from gas is negative, which indicates a long-left tail, and the excess kurtosis value from 3 shows the leptokurtic behavior. The Jarque–Bera test is significant at 1% level, so the statistics value of JB depicts departure from the normality.

Unit root test

The data must be stationary in order to do an accurate analysis. This research employs a unit root test, namely the ADF test, to be certain. As can be seen from Table 3,

Table 3 Summary of unit root test

Augmented Dickey–Fuller (ADF)			
Variables	**Unit root test**	***t*-stats**	***P*-value**
CO_2	I(0)	− 0.65788	0.8398
	I(1)	− 5.95266*	0.0001
EG	I(0)	− 1.06514	0.713
	I(1)	− 5.80602*	0.0001
FDI	I(0)	− 2.37494	0.1588
	I(1)	− 3.36577**	0.0228
GDP	I(0)	− 0.79646	0.8028
	I(1)	− 3.79661*	0.0088
GCF	I(0)	− 1.40809	0.562
	I(1)	− 4.48233*	0.0018
IU	I(0)	1.494823	0.9988
	I(1)	− 4.07507*	0.0046

"*, **, and *** are representative of 1%, 5%, and 10% level of significance, respectively" no variables were determined to have stationarity at the 5% level of significance. Stationary aspects of the first difference were explored to strengthen the arguments for their existence. When analyzing all of the relevant time series, it was discovered that the initial difference was stationary. After discovering that the initial differences were stationary, the researchers set out to produce more evidence for the same.

Cointegration test

The results of the unit root test indicate that the variables in concern are stationary. As a result, it is essential to make use of cointegration tests in order to examine the integration that occurs between variables. In order to do this, five distinct kinds of tests are used, and Table 4 contains the results of these tests. At a threshold of significance of 1%, it is clear that the results are significant in three of the models and tests being used. In light of this evidence, it is reasonable to conclude that the alternative hypothesis should be accepted, whereas the null hypothesis should be rejected. As a result, there is no evidence of a unit root in the data.

Vector error correction model

Cointegration indicates a long-term link between the variables being analyzed. The VEC model may then be used. The long-term link between economic development, gross capital formation, internet usage, and CO_2 emissions for one cointegrating vector in Saudi Arabia is illustrated below over the period 1995–2020.

Table 5 shows that the coefficients for gas source energy are statistically significant at the 10% significance level. In short-run, FDI, EG, GDP, GCF, and IU is significant at 1%, 5%, and 10%; meanwhile, in long-run only internet usage results are significant. The coefficients may be understood as long-run elasticities when the variables are transformed into logarithms and a single cointegrating vector is computed. The estimated model was able to provide a consistent result since higher CO_2 emissions are linked to higher gas production, foreign direct investment, gross domestic product, global climate fund contributions, and internet usage. Contrary to popular belief, analysis demonstrates that heavy internet use actually increases CO_2 emissions over time. A positive correlation between internet use and greenhouse gas emissions is seen. According to current estimates, internet infrastructure is responsible for 1.6 billion tons of yearly greenhouse gas emissions. By 2025, the communications sector will account for 20% of global power usage. In 2019, we created over 50 million tons of e-waste, and that amount is predicted to grow by 8% year. Meanwhile, the internet is responsible for emitting 1.6 billion tons of

Table 4 Cointegration results

Unrestricted cointegration rank test (trace)				
Hypothesized no. of CEs	**Eigenvalue**	**Trace statistics**	**(0.05) critical value**	**Prob.****
None*	0.811505	122.0364	95.75366	0.0003
At most 1*	0.709422	81.98800	69.81889	0.0039
At most 2*	0.642697	52.32683	47.85613	0.0179
At most 3	0.454234	27.62675	29.79707	0.0872
At most 4	0.409360	1.309318	15.49471	0.1114
At most 5	0.018821	0.456009	3.841465	0.4995

"*, **, and *** are representative of 1%, 5%, and 10% level of significance, respectively"

Table 5 VECM results

Variables	Short-run						Long-run ECM (−1)
	CO_2	FDI	EG	GDP	GCF	IU	
(CO_2 -1)	0.00045	0.72707	− 606.386	− 6.4E + 10**	2.51822*	− 4.2030*	− 0.24172
(FDI -1)	0.01534	0.58135**	− 253.404***	− 1.5E + 10	1.18424*	− 1.0919**	− 0.43846
(EG -1)	− 0.00013	− 0.00023	0.094937	2,500,641	− 0.0016*	0.00078	195.1707
(GDP -1)	− 9.80E−13	6.46E−12	− 8.99E−09***	− 0.25851	3.12E−11*	− 5.1E−11*	2.16E + 10
(GCF -1)	− 0.02205	− 0.14519	− 41.1777	− 2.09E + 09	− 0.00222	− 1.0978*	− 0.54644
(IU -1)	0.020526	0.076823	− 21.7031	3.07E + 09	0.007553	− 0.1052	6.85288*

"*, **, and *** are representative of 1%, 5%, and 10% level of significance, respectively" greenhouse gases every year. By 2025, the communications sector will account for 20% of global power usage. Production of electronic garbage has already surpassed 50 million tons for 2019, and experts predict that amount will continue to climb by around 8 percent annually. Furthermore, Saudi Arabia has caused a variety of environmental problems owing to an enormous growth in carbon output. Saudi Arabia has agreed to further global emissions cuts to combat global warming, placing it as the world's tenth highest producer of carbon dioxide.

Diagnostic test

This study employed the diagnostic test to assess the stability, heteroskedasticity, and serial correlation of the model. The LM test is employed to assess the presence of serial correlation in the residual diagnostic of the model. The heteroskedasticity test is employed to assess the presence of heteroskedasticity in the model. The stability test is conducted to assess the stability of data. The findings of these examinations are presented in Table 6.

To ascertain the appropriateness of diagnostic tests, it is imperative that the p-value associated with each test exceeds 5%. According to the results presented in Table 6, the LM test for the null hypothesis (H0) indicates the absence of serial correlation. The *p*-value obtained from the Lagrange multiplier (LM) test is 0.7888, exceeding the significance level of 5%. Consequently, we fail to reject the null hypothesis (H0) and conclude that there is no evidence of serial correlation among the variables. The null hypothesis (H0) regarding heteroskedasticity posits that there is an absence of any heteroskedasticity issue. The *p*-value for heteroskedasticity is 0.3792, indicating that it is greater than the predetermined significance level of 5%. The null hypothesis (H0) is not rejected, indicating the absence of heteroskedasticity issues. Based on the results of the normality test, the null hypothesis (H0) indicates that the residuals conform to a multivariate normal distribution. If the *p*-value obtained from the test is less than or equal to the predetermined significance level, the appropriate decision is to reject the null hypothesis. Consequently, it can be concluded that the data under consideration do not adhere to a normal distribution. When the p-value exceeds the predetermined significance level, the appropriate course of action is to retain the null hypothesis rather than rejecting it.

Robustness check

Decoupling index

The decoupling index findings are derived for three distinct time periods, including 1995–2005, 2006–2015, 1995–2020, and the entire 25 years sample period from 1995 to 2020, as shown in Table 7. Due to the lack of data, these periodic data are different from those used in earlier studies. The whole period gives a real depiction of a country with the absence of specific events from a certain time, making the decoupling index of the total period more significant than the dividend period. In the initial period (1995–2005), Saudi Arabia has a decoupling index value of 0.42. These values are greater than zero and less than one, indicating a poor decoupling in which CO_2 emissions and the economy are both expanding, but the economy is growing faster than carbon emission. In the second phase, the decoupling index value is − 0.1983 (2006–2015), indicating a coupling effect, which suggests that the economy and CO_2 emissions are rising concurrently, but the rate of CO_2 emission growth is quicker than the rate of economic growth [63]. With a decoupling value of 0.630217 (1995–2020) for Saudi Arabia is clearly show that CO_2 emissions are declining as the country's economy rises. Overall, the decoupling index values showed that there is a long-term relationship between carbon dioxide emissions and GDP, which leads to environmental deterioration.

Discussion

The objective of this study is to address a research gap in the existing body of literature by examining the causal link between economic growth and carbon dioxide (CO_2) emissions in the context of Saudi Arabia. The authors conducted cointegration analysis on the economy of the Kingdom of Saudi Arabia (KSA) using the vector error correction (VEC) model, which was developed

Table 7 Decoupling index

Period	Ratio	Index
1995–2005	0.572663	0.427337382
2006–2015	1.198336	− 0.19834
1995–2020	0.369783	0.630217

Table 6 Results of diagnostic tests

Diagnostic tests	Nature of tests	statistics value	Prob	Findings
Residual serial correlation LM tests	Rao *F*-stat	0.749572	0.7888	No serial correlation
Residual heteroskedasticity tests	Chi-sq	300.8429	0.3792	No heteroskedasticity
Residual normality tests	Chi-sq	11.51263	0.0738	Normal distribution

by Canning and Pedroni [7]. Initially, the unit root test and cointegration testing are conducted. Subsequently, a modeling approach is developed based on the vector error correction model, following the methodology proposed by Mikayilov et al. [48], in the presence of cointegration. The findings clearly indicate the presence of a short-term cointegrating relationship between growth, internet usage, and CO_2 emissions in the Kingdom of Saudi Arabia (KSA). Additionally, the vector error correction model (VECM) demonstrates a statistically significant impact of economic growth on CO_2 emissions. The findings presented in this study align with the recent research conducted by Fávero et al. [22] and Khan et al. [39], which provide empirical support for the presence of a global interconnectedness between economic growth and carbon dioxide emissions. The primary distinction between the aforementioned studies and our research lies in the fact that the former estimates the relationships between foreign direct investment (FDI), economic growth (EG), gross domestic product (GDP), gross capital formation (GCF), industrialization (IU), and carbon dioxide emissions (CO_2), whereas our study focuses on conducting a long-term cointegration assessment.

The existing body of literature examining the empirical correlation between economic growth, internet usage, and CO_2 emissions is extensive and subject to debate. The primary challenge in terms of empirical soundness has consistently been the inadequate assessment of the stationarity characteristics of the variables, as well as the presence of cross-sectional dependence in panel data analyses. Hence, we duly acknowledge both critiques and employ contemporary unit root tests and cointegration techniques that exhibit resilience in the face of cross-sectional dependence. The results for Levin et al. [43] are presented in Table 3, which display the outcomes of the unit root tests conducted on each variable in both level and first difference. Upon conducting an analysis of the unit root in the first differences, it is observed that the null hypothesis can be rejected. The findings suggest that the entire dataset exhibits stationarity. The results of our study align with the findings of previous research conducted by Bastola and Sapkota [4], Gün [27], Mohsin et al. [50], Naseem et al. [55], Sarfraz et al. [68], and Mohsin et al. [49]. These studies also observed similar outcomes, indicating that the variables in question are non-stationary at the level but become stationary after taking the first difference. Based on the findings presented in Table 4, it is observed that there exists a positive correlation between economic growth, internet usage, and growth in emissions. Furthermore, the variables in question exhibit cointegration, indicating a shared movement or trend. The findings of the study suggest that there is a positive relationship between higher levels of economic growth and an increased demand for environmental protection. This highlights the importance of developing effective environmental policies that can effectively reduce emissions, particularly during periods of economic growth. Naturally, it should be noted that the mere presence of economic growth in the Kingdom of Saudi Arabia (KSA) does not inherently reduce climate vulnerability. Rather, it is imperative that the specific form of economic growth pursued is appropriate and aligned with the goal of mitigating climate vulnerability. Furthermore, it is worth noting that emissions trading and economic incentive strategies are often met with disapproval by certain environmental analysts, primarily because they are perceived as embodying the principle of "polluter pays." In light of this, we emphasize the importance of enhancing the effectiveness of emissions trading systems. Thirdly, the study demonstrates that while multiple factors contribute to the phenomenon of global warming, the emissions of carbon dioxide (CO_2) hold significant importance. This implies that the economy of the Kingdom of Saudi Arabia (KSA) should align with global policy incentives and endeavor to adopt novel mechanisms and instruments aimed at mitigating CO_2 emissions. Based on contemporary assessments, the internet infrastructure is accountable for an estimated annual emission of 1.6 billion tons of greenhouse gases. According to projections, the communications sector is expected to contribute to approximately 20% of the total global power consumption by the year 2025. In the year 2019, a total of 50 million tons of electronic waste (e-waste) was generated, with projections indicating an anticipated annual growth rate of 8%. Moreover, comprehending the correlation between environmental quality and economic growth holds significant importance in discerning suitable strategies for achieving sustainable development. Hence, it is imperative for policymakers in the Kingdom of Saudi Arabia (KSA) to possess an understanding of the financial burden associated with energy costs and to attain economic advancement by employing suitable mechanisms for climate risk management.

Conclusion

Continuous decreases in CO_2 emissions have been made possible in recent decades because of global attention to sustainable development. Since it has been clear that human activity contributes to climatic changes throughout the globe, every community and institution has started to explore solutions to protect the environment for coming generations. High-consumption activities that rely on nonrenewable energy sources have been shown to be the biggest culprits in the global warming problem. The primary reason why carbon emissions endanger the people who live on Earth is because they destroy the ozone layer, which serves as a shield against the sun's harmful ultraviolet radiation. The ozone layer will begin to deteriorate and the environment will become unlivable if the activities that cause carbon emissions are not controlled. Environmental conservation is a focus of efforts undertaken by governments as well as other multilateral agencies. Regarding carbon emissions per person, Saudi Arabia is among the top emitters. Saudi Arabia's participation in activities that use a lot of energy and emit carbon into the environment.

The primary goal of this research was to analyze the long- and short-term dynamics of carbon emission, energy consumption, economic development, and internet use in the setting of Saudi Arabia from 1995 to 2020. According to the VCEM, a significant relationship exists between GHG emissions and the country's internet use over the long term. A clear association between GDP growth and carbon dioxide emissions is shown by econometric investigation of this study. It has been shown that investment flows and GDP are major drivers of carbon dioxide emissions. Additionally, it is discovered that CO_2 emissions are related to GCF. This link between CO_2 emissions and GDP growth gives credibility to the pollution haven hypothesis, which holds that nations with laxer environmental regulations attract more foreign direct investment because multinational corporations from wealthier nations can save money on environmental compliance by setting up shop in less stringently regulated economies.

The results of the research also point to a stationarity between energy use and CO_2 emissions. The Saudi Arabian government should think about enacting stricter environmental regulations that would limit carbon dioxide emissions. Investment in research and development is essential for achieving this goal since it will encourage the creation of eco-friendly technology and therefore lower CO_2 emissions. Additionally, the government should take the required actions to transition away from fossil fuels in favor of renewable energy sources, which are often more inexpensive and cleaner. The reduction of CO_2 emissions, which improve environmental protection, should be a top priority since global warming is an actual danger to the world. The promotion of energy efficiency and the expansion of clean renewable energy are suggested as strategies for sustainable economic growth in Saudi Arabia with regard to the short-run and long-run links in this study.

Policy implications, limitations, and future research

The existing body of research examining the interconnections among carbon dioxide (CO_2) emissions, economic growth, and internet usage has yielded diverse policy implications. These findings have the potential to inform regional policymakers in their efforts to promote sustainable development strategies. When formulating strategies aimed at mitigating CO_2 emissions, it is imperative to give due consideration to the indirect employment consequences throughout the entirety of the industry supply chain, the induced impacts resulting from alterations in consumer consumption and income, as well as the direct employment effects on the industry itself. In order to mitigate the potential adverse effects of industrial restructuring on the labor market, it is imperative to ensure that industrial strategies are aligned with employment policies. Enhancing collaboration within the industrial chain and attaining interconnected industrial development would play a pivotal role in generating employment opportunities. Moreover, the service sector significantly contributes to the generation of employment opportunities. The promotion of low-carbon industrial development through effective service sector growth serves as a means to address the issue of rural excess labor transfer. It is imperative to allocate substantial resources toward facilitating the growth of emerging low-carbon sectors, such as new and renewable energy. Additionally, there is a need to enhance the adaptability and efficacy of the energy mix, while concurrently expediting the restructuring and advancement of conventional industries. Research indicates that digital technologies currently account for approximately 1.4% to 5.9% of total global greenhouse gas emissions. Data centers exhibit high electricity consumption due to several factors, including the dense concentration of equipment, the energy distribution system, energy reserves, the requirement for robust internet connectivity, the presence of generators, and the necessity for effective ventilation and cooling to sustain their operations.

It is recommended that individuals utilize an ecological search engine, such as Ecosia, due to the significant capacity of trees to sequester carbon dioxide emissions, rendering them one of the most effective solutions in this regard. According to a study conducted by Jean-François Bastin and Thomas Crowther, researchers affiliated with the Swiss Federal Institute of Technology in Zurich, it has been determined that a total of 1200 billion trees would possess the capacity to sequester approximately two-thirds of the 300 gigatons of carbon dioxide that has been released into the Earth's atmosphere by human activities since the nineteenth century. This study was published in the esteemed scientific journal Science. It is advisable to restrict the utilization of cloud services and instead opt for storing data on personal computers or external hard drives. The process of transferring documents involves the utilization of USB sticks. It is advisable to deactivate switches whenever feasible, and in cases where this is not possible, it is recommended to disconnect electronic devices from power sources when they are not being utilized. Public policies designed to enact economic reforms and enhance energy efficiency have the potential to augment the economic productivity of energy consumption within a nation's economy, while concurrently mitigating its adverse environmental consequences. The implementation of these policies necessitates a combination of energy policy instruments, including tax measures, financial and investment preferences, and the provision of appropriate training for both newly hired and retrained personnel. These measures aim to enhance energy efficiency, productivity, and environmental sustainability across all sectors of the economy. If the implementation of these policies leads to a decrease in energy consumption, it is recommended that the resulting energy savings be allocated toward addressing social issues.

The primary limitation of this study pertains to the unavailability of data with sufficiently extended timeframes for certain indicators that influence CO_2 emissions, economic growth, and internet usage. However, the inclusion of additional explanatory variables in this type of analysis may provide valuable insights for future research endeavors. The exogenous variables considered in this study encompass the globalization index and urbanization, as previous scholarly investigations have consistently shown their substantial influence on carbon emissions and economic activity. One limitation of the study is the failure to account for variations in the developmental stages of the country under observation, as well as the failure to distinguish between energy derived from renewable and nonrenewable sources. An alternative avenue for future investigation could involve examining the environmental Kuznets curve (EKC) with regard to the Kingdom of Saudi Arabia (KSA), in order to assess the potential influence of distinct economic development stages on pollution levels. An additional area of inquiry that warrants investigation is the examination of the distinct effects of nonrenewable and renewable energy sources on carbon emissions within the context of this particular nation. It is worth considering the inclusion of other Gulf states for the purpose of comparison. Hence, it is imperative to conduct comparative research involving a broader range of countries in order to provide policy makers at the international level with more substantial and relevant information.

Abbreviations

IPA	Investing promotion agencies
GCF	Gross capital formation
FDI	Foreign direct investment
IU	Internet usage
EKC	Environment Kuznets curve
ICT	Information and communication technologies
WDI	Word development indicators
GHG	Greenhouse gas
KSA	Kingdom Saudi Arabia

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Author contributions
MADA analyzed and interpreted the data regarding the economic development, gross capital formation, internet usage, and the carbon emission. SM performed the empirical analysis of data and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

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