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Green growth is a pathway to sustainable development: An empirical study of Saudi Green Initiative

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Abstract:
For climate change adaptation and mitigation, a sustainable transition to green growth is essential. The aim of this study is to evaluate green growth indicators using three methods to assess the situation of green growth in Saudi Arabia. The vector error correction model (VECM) was used to estimate the relationship between electricity generation and carbon emissions (CO_2), and then examine the mitigation scenario, followed by analysing Saudi green growth indicators versus Organisation for Economic Co-operation and Development (OECD) indicators. The results indicate carbon emissions are influenced by the GDP and electricity generation in Saudi Arabia. Environmental scenarios findings indicate that the baseline scenario (BAU) result shows that carbon emissions from 2021 to 2030 will continue rising, while the scenario 1 result implies that Saudi Arabia's carbon emissions will decrease from 2021 to 2030. In addition, it analyses the green growth indicators for Saudi Arabia, comparing Saudi initiatives with OECD green growth indicators to explore if these actions align. After reviewing Saudi Arabia's green initiatives, Saudi is in alignment with OECD indicators. Finally, the study highlights some policies which could help the country achieve its initiatives and reach zero carbon emissions. Thus, this study contributes to the literature by evaluating the effect of green growth initiatives represented in energy abatement policies on CO_2 emissions to explore if it is consistent with the Paris Agreement and NDC.
Keywords Carbon emissions; Vector error correction model (VECM); environmental scenarios; Saudi green initiative; green growth indicators
JEL Classification: Q4, Q5, Q58

1.Introduction:

Due to the global climate, ecological, and energy crises, the green economy—which aims to address environmental challenges while promoting economic growth, social stability, and the creation of favorable conditions for sustainable economic growth—has drawn more focus. The concept of green growth was first introduced by the Organisation for Economic Co-operation and Development (OECD). "Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD, 2011, p.9). Green growth's fundamental concept is to decouple economic growth from degradation of the environment by cultivating green technology innovation, boosting resource efficiency, lowering carbon emissions, and supporting eco-friendly regulations across all sectors of the economy. The OECD has produced five indicators to measure progress toward sustainable economic growth that minimizes environmental impact (OECD, 2017).

Saudi Arabia used 3,649 thousand barrels per day of petroleum and other liquids in 2022 and 393 billion kilowatt hours of electricity in 2022 (U.S. Energy Information Administration, 2024). According to International Energy Agency, electricity and heat produce 49% of total energy-related CO_2 emissions in Saudi Arabia (International Energy Agency, 2022). Where domestic electricity generation has increased significantly, from 65 (billion kWh) in 1990 to 432 (billion kWh) in 2022 (U.S. Energy Information Administration, 2024), carbon dioxide (CO_2) emissions from electricity generation increased from 71.1 million tonnes (MT) in 1990 to 272.8 MT in 2021 (Ritchie et al., 2020). However, the Saudi government has developed an ambitious reform program called Vision 2030 and the National Transformation Program because it understands the dangers of its economy's reliance on oil and rising domestic energy consumption. Saudi Arabia First Nationally Determined Contributions (NDC) is taking action and making plans to diversify its economy while avoiding greenhouse gas emissions, to contribute to the United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement goals (Kingdom of Saudi Arabia, 2021). In 2016, Saudi Arabia has taken steps towards a more sustainable future. Saudi Green Initiative (SGI) was established in 2021 to unite environmental protection, energy transition and sustainability programs with the overarching goals of lowering and offsetting emissions, protecting Saudi land and sea, and boosting afforestation and land restoration. The SGI is leading several ambitious projects that will lower emissions in addition to changing the domestic energy mix (Saudi Green Initiatives, 2024).

Modeling tools and trustworthy metrics and measures are two essential tools for accelerating the transition to an inclusive green economy while meeting the sustainable development goals. The creation of these can help nations assess their progress in relation to both national and international development goals and predict the effects of policies in the future, then direct policymakers to the green economy (UNEP, 2024). In this context, the objective of this study is to analyse Saudi Arabia's green growth indicators to assess the country's progress with respect to both domestic and global development goals, estimate the relationship between green initiatives, economic and environmental, and then project the impacts of green initiatives in advance.

This is achieved by three steps: First is investigating empirically Saudi's initiative related to reducing electricity generation from fossil fuels by 50% and replacing it with renewable energy, through employing the vector error correction model (VECM) for data from 1990 and 2020. The second step is to examine the future scenario up to 2030. Therefore, this step will build on the VECM model results for creating environmental scenarios for Saudi Arabia from 2021 to 2030 to evaluate the effect of energy abatement policies on CO_2 emissions to explore if it is consistent with the Paris Agreement and NDC. The last step is comparing Saudi initiatives with OECD green growth indicators to evaluate the current situation in terms of the country's commitments to achieve the Paris Agreement goals and its NDC.

The rest of the paper is structured as follows: a literature review is presented in Section 2. Section 3 presents the methodological approach and data. Section 4 presents the results of the three methods. Discussion of the findings and conclusion with policy implications appear in Section 5 and Section 6 respectively.

2.Literature review:

Trustworthy green growth metrics are an important instrument for monitoring advancement, evaluating results, and guiding economy and policy changes among various countries. There are many studies that have discussed and reviewed the indicators of green growth.

2.1 Studies examining green growth :

Kim et al. (2014) evaluated South Korea's OECD metrics. According to the study, Korea has relatively high natural capital and quality of life indices, but low economic activity scores. These results imply that more economically and environmentally sustainable production and consumption methods are needed. Baniya et al. (2021) examined the empirical data on the greening of economic growth in Bangladesh and Nepal from 1985 to 2016 and discussed the outlook for both environmental and economic goals until 2030. Using models of energy and material consumption, they looked at six green growth indicators. However, it has been discovered that these are not enough to produce green growth. Using the CS-ARDL model, Hao et al. (2021) examined the impact of green growth on CO_2 emissions for the G7 nations between 1991 and 2017. The results show that while using renewable energy reduces CO_2 emissions, GDP growth depletes the ecosystem. Also, Zhao et al. (2022) using provincial panel data from 2004 to 2018, investigate the possible impact of China's green growth on carbon dioxide (CO_2) emissions. The results suggest that China's green growth has a significant negative effect on CO_2 emissions.
Recent studies, such as Abro et al. (2023) examined the independent and joint effects of financial development, globalisation, and energy efficiency rates on the green growth of the Saudi Arabian economy. They estimated green growth of Saudi Arabia as a proxy for the difference between the nation's annual per capita growth rates of gross domestic product and carbon dioxide emissions from 1972 to 2018. Their findings from the regression and causality techniques confirm the green growth–inhibiting impacts of financial development and trade globalisation. However, it has been discovered that more effective energy resource utilization not only directly promotes green growth but also partially offsets the long-term negative effects on green growth linked to the growth of the financial sector. Amara & Qiao (2023) examined the impact of carbon emissions, eco-innovation adoption, and international collaboration on economic growth and the influence of economic growth on green growth in 54 African nations between 2010 and 2019. The results of the generalized method of moments (GMM) suggested a favourable correlation between economic growth, eco-innovation, international cooperation, and carbon emissions. Sarkodie et al. (2024) investigated a thorough assessment of green growth indicators in 203 economies. Their empirical findings demonstrate how sustainable development's effects on green growth policies enhance a nation's natural resource base, socioeconomic dynamics, environmental quality of life, policy responses, and emission productivity.
Dhayal et al. (2024) analysed the impact of the energy mix including green energy consumption towards carbon emissions in India from the period 1990 to 2019. Findings showed that green energy reduces CO_2 emissions. Also, Song et al. (2024) explored the relationship between energy efficiency and the development of green technologies in the top 10 economies with green innovators. According to estimates, energy efficiency is improved by green technology innovation in most of the economies selected, at specific quantiles. Between 2010 and 2020, Usman & Saheed (2024) aimed to examine the factors that contribute to green growth in 13 developed nations. Green growth was positively impacted by renewable energy use, according to the coefficient. Green growth was negatively impacted by fossil fuel energy consumption. Based on the coefficient, investments in clean energy are needed.

Most previous studies of green growth were systematic reviews and the results they reached were mostly that nations must urgently address the interconnected problems of sustainability and economic growth (Yeboah, 2023; Islam & Ali, 2024).

2.2Studies examining the relationship between CO_2 emissions and energy consumption:

The overall effect of economic expansion and renewable energy on lowering CO_2 emissions in Saudi Arabia between 1990 and 2016 was investigated by Kahia et al. (2021). Economic growth raises carbon emissions, according to the results of all estimated models using the completely modified ordinary least-squares and dynamic ordinary least-squares estimators. Sun et al. (2022) explored the relationship between carbon dioxide emissions and the economic growth in Nanjing city for the period from 1993 to 2018. They employed the ARIMA algorithm to forecast CO_2 emissions from 2019–2025. The results reveal that economic growth will cause increased carbon dioxide emissions.

Recently, Darandary et al. (2024) examined CO_2 emissions under several assumptions on the underlying drivers in Saudi Arabia. The finding indicated that under a baseline scenario and other scenarios Saudi CO_2 emissions will rise from 2019 to 2030 and 2060. Based on Altouma et al. (2024), which analysed the interaction between CO_2 emissions and other variables, for various sectors between 1990 and 2020 in Saudi Arabia, the ARDL model results reveal that the electricity sector is the largest contributor to emissions.

There are many studies that have discussed and examined the relationship between energy consumption in general or the electricity generation in particular and emissions in Saudi Arabia. These studies found that energy consumption, especially electricity generation will increase carbon dioxide emissions (Alkhathlan et al., 2015; Raggad, 2020; Mahmood et al., 2020; Alajmi, 2021; Alajmi, 2022; Alajmi, 2024; Kahia et al., 2021). To the best of our knowledge, no study has analysed the green growth indicators for Saudi Arabia. This we believe will bridge the gap in the existing literature and provide the basis for policymakers regarding green energy transition aligned with Vision 2030.

3. Methodology framework:

In evaluating the green growth indicators for Saudi Arabia and then comparing them with green growth indicators developed by OECD (2017), this study following the existing literature, such as Baniya et al., 2021; Hao et al., 2021; Abro et al., 2023, expects that economic growth, electricity generation and population growth are key drivers of environmental degradation, particularly CO_2 emissions. This section employed three techniques given the likely non-stationary nature of these macroeconomic and environmental variables and the theoretical expectation of a long-run equilibrium relationship among them. Thus, this paper employs a Vector Error Correction Model (VECM) firstly to capture both the short-run dynamics and long-run cointegrating relationships. A theoretical long-run equilibrium relationship between CO_2 emissions and other variables can be written as follows:

$$CO_{2t} = \alpha_0 + \delta_1 \, GDP_t + \theta_2 \, EG_t + \psi_3 \, POP_t + \varepsilon_t \ldots (1)$$

Where α is the constant, δ, θ and ψ reflect the dynamic short-run coefficients of independent variables and ε is the error term. CO_2 is carbon emissions; GDP is real gross domestic; EG is electricity generation and POP is population growth.

The second approach is examining one of Saudi's green growth indicators: carbon emissions under the area of the environmental and resource productivity of the economy. Saudi Arabia's environmental policy assumes 50% of electricity generation will be generated from renewable sources; the VECM model estimates coefficients to build the future environmental scenarios to 2030. The final approach is reviewing the Saudi green growth initiatives and nationally determined contributions (NDC) under the Paris Agreement by comparing them with the OECD indicators.

3.1 Unit Root Tests:

To estimate the long-run relationship between CO_2 emissions and other variables from 1990–2020 the VECM method will be employed. Before running VECM we need to check data stationarity and then test cointegration between variables.

In order to be sure that our model would not contain the false regression noted by Granger & Newbold (1974), the unit root tests are needed. Therefore, we used Philip & Perron (PP) and the Augmented Dickey-Fuller (ADF) to check the unit roots of the series. The ADF test is given below (Dickey & Fuller, 1981):

$$\Delta y_t = \alpha_0 + \alpha_1 t + \gamma y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + u_t \dots (2)$$

where y_t represents the time series, Δ represents the first difference, α is a constant, βt is the time trend, $\gamma = \rho - 1$ where ρ is a real number and u_t stands for the error term. The null hypothesis asserts that the series has a unit root, while the alternative hypothesis proposes stationarity. The time series y_t is non-stationary and has a unit root when $|\gamma| = 1$, but it becomes stationary when $|\gamma| < 1$.

3.2 The vector error correction model (VECM)

Before applying the VECM method, the Johansen cointegration test has to be conducted to examine the long-term cointegration among the variables in the model. According to Johansen & Juselius' (1992) cointegrating methodology, a VECM can be estimated as follows if the variables of y_t are cointegrated:

$$\Delta y_t = \pi y_{t-1} + \sum_{i=1}^{k-1} \Gamma_j \Delta y_{t-i} + \varepsilon_t \dots (3)$$

When the ECT coefficient is negative and statistically significant, that means over time, the variable corrects any deviations and goes back to equilibrium. The previous equation gives details about both short-run and long-run relationships in y_t. The rank r of the matrix π determines the number of cointegrating vectors. The short-run dynamic adjustment to the changes of the variables in the system is measured by the parameters Γ_j. Δy_{t-i} is the error correction term and error terms are measured by ε_t.

3.3 Scenario analysis:

Saudi Arabia developed its first nationally determined contribution (NDC) under the Paris Agreement that included its carbon mitigation goals through 2030. Therefore, in order to comply with the Paris Agreement and attain sustainable growth by lowering CO_2 emissions, Saudi Arabian policymakers move toward a low carbon economy. In an effort to meet the NDC targets, Saudi Arabia has recently begun enacting significant economic reforms, such as the Saudi green initiative, paving the way towards a greener future and achieving global climate targets.

This study evaluates two scenarios to project CO_2 emissions up to 2030. The first scenario is a benchmark scenario called a business as usual (BAU) or baseline scenario to explore the future situation and then compare this scenario with another scenario. The BAU scenario assumes that Saudi Arabia policymakers will not follow any environmental strategy to reduce CO_2 emissions up to 2030. The second scenario is a mitigation scenario based on the Saudi Arabia green growth initiatives, which supposes that by 2030 the country will generate 50% of electricity from renewable sources. These two scenarios will build on the VECM model results from 1990–2020, to run scenarios from 2021–2030.

3.4 Green growth indicators:

According to the OECD, there are five primary areas: 1) The environmental and resource productivity of the economy: it measures how well economic activities, including production and consumption, use energy, other natural resources, and environmental services. This captures important elements of the shift to a resource-efficient, low-carbon economy. 2) The natural asset base: this indicator shows if the quantity, quality, and value of the natural asset base are being maintained within sustainable bounds. Monitoring the flows of environmental services as well as the stocks of natural resources and other environmental assets can help track progress. 3) The environmental dimension of quality of life: this metric shows the relationship between environmental dangers and conditions and people's well-being and quality of life. Additionally, it can demonstrate the degree to which an increase in general well-being coincides with (or does not coincide with) income development. 4) Economic opportunities and policy responses: the objective of this indicator is to capture the economic potential that comes with green growth. It monitors policy initiatives aimed at facilitating the shift to green growth and removing obstacles to it. Additionally, it can assist in evaluating how well policies deliver green growth. 5) The socio-economic context and the characteristics of growth: it facilitates monitoring how green growth policies and initiatives affect development and growth. Additionally, it connects social objectives like decreasing poverty, equity in society, and inclusion in the green growth metrics (OECD, 2017). Also, the OECD's list of green growth indicators has been left open-ended to allow nations to modify them to fit their specific circumstances. Not every indicator that is significant to green growth can be quantified. Not every one of the indicators suggested here is equally applicable to every nation (OECD, 2017).

Section 4.3 will compare OECD indicators with the Saudi Geen Initiative (SGI) and nationally determined contributions (NDC) under the Paris Agreement, to explore if Saudi actions align with OECD green growth indicators and to know whether these initiatives will actually achieve their goal, which is to contribute to protecting the environment.

3.5 Data:

Exploratory data to analyse the green growth indicators are annual time series data from 1990 to 2020 for Saudi Arabia. These data were used to estimate the impact of electricity generation on CO_2 emissions. Electricity generation (EG) data were obtained from the U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration, 2024). Carbon dioxide (CO_2) emissions caused by electricity generation data were obtained from Our World in Data (Ritchie et al., 2020). Data on real GDP and population growth (POP) were obtained from World Development indicators (World Bank, 2024). The out-of-sample will be extended for the medium-term up to 2030 through using growth rates method for the variables to apply environmental scenarios.

It is worth noting that during the period from 1990 to 2020 CO_2 emissions from electricity generation in Saudi Arabia showed a continuous rising trend, with an increase from 71 MT in 1990 to 272.8 MT in 2020 (Ritchie et al., 2020). This rise in emissions is caused by the increase in electricity generation which comes from traditional fuel types, with an increase from 65 billion Kwh in 1990 to 394 billion Kwh in 2020 (U.S. Energy Information Administration, 2024). These in turn influence the environment quality adversely.

Since we have four variables and the optimal lag is three lags, which gives better results, thus the VECM equation (3) can be as follows:

$$\Delta LCO_{2t} = \alpha_0 + \beta_1 \Delta LCO_{2t-1} + \beta_2 \Delta LCO_{2t-2} + \beta_3 \Delta LCO_{2t-3} + \delta_1 \Delta LGDP_{t-1} + \delta_2 \Delta LGDP_{t-2} + \delta_3 \Delta LGDP_{t-3} + \theta_1 \Delta LEG_{t-1} + \theta_2 \Delta LEG_{t-2} + \theta_3 \Delta LEG_{t-3} + \psi_1 \Delta POP_{t-1} + \psi_2 \Delta POP_{t-2} + \psi_3 \Delta POP_{t-3} + \gamma\, ECT_{t-1} + \varepsilon_t \dots (4)$$

Where α is the constant, β, δ, θ and ψ reflect the dynamic short-run coefficients of independent variables, γ is the long-run coefficient of the error correction term and ε is error terms. ECT is the error correction term which indicates the speed at which variables return to long-term equilibrium after fluctuations. LCO_2 is log of carbon emissions by electricity generation in million tonnes (MT); LGDP is log of real gross domestic product in billion Saudi Riyals (SAR); LEG is log of electricity generation by billion kilowatt-hour (Kwh) and POP is population growth as an exogenous variable affecting the short-term dynamics.

4.Empirical results:

4.1 The VECM results:

Before analysing VECM results we will represent the ADF test results which show that the variables are non-stationary at the level I (0) but stationary at the first difference I (1). Our variables (CO_2 emissions, GDP, POP, and electricity generation) are found to be integrated with the same order I (1) at a 5% significance level. Also, the PP test results indicated that after first differentiation I (1) all the variables became stationary (see Table (1)).

Table (1): Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests

Null Hypothesis: Variable is not-Stationary				
	ADF		PP	
Variable	Level	First differences	Level	First differences
LCO_2	-0.99	-4.33*	-1.36	-4.33*
LGDP	-1.69	-5.15*	-1.84	-5.17*
LEG	-2.88	-9.43*	-1.59	-16.94*
POP	-2.64	-4.59*	-0.89	-3.95*

* denotes reject at 5%.
Source: EViews software output.

Table (2) presents Johansen's cointegration test with three lags and the results reveal that the null hypothesis of no cointegration is rejected, meaning that there are two stable long-run equilibrium relationships among variables. Both trace statistics and the maximum eigenvalue test are significant at a 5% level, which means that all the four variables are cointegrated with two cointegrating vectors between carbon dioxide emissions and other independent variables.

Table (2): Johansen co-integration tests results

Null	**Trace statistic**	**5% Critical Value**	**Prob.**
None *	0.575364	29.79707	0.0009
At most 1 *	0.518447	15.49471	0.0103
At most 2	0.005089	3.841465	0.7105
Null	**Max-eigen statistic**	**5% Critical Value**	**Prob.**
None *	0.575364	21.13162	0.0259
At most 1 *	0.518447	14.26460	0.0062
At most 2	0.005089	3.841465	0.7105

*Indicates that the null hypothesis is rejected at the 5% significance level.
Source: EViews software output.

Cointegration tests were conducted to confirm that our variables are cointegrated. Table 3 shows estimation results of VECM. The ECT coefficient is negative and statistically significant, which means that any fluctuation between the dependent variable and independent variables in the short-run will lead to a stable relationship between the variables in the long-run.

Table 3 presents the long-run relationship between CO_2, GDP, and electricity generation for Saudi Arabia over the period 1990–2020. The model states that CO_2 converges to long-run equilibrium with a 0.42% speed of adjustment every year by the impact of the variables, GDP and EG. The estimated long-run equation is as follows:

$$LCO_2 = -10.28263 + 0.965185\ LGDP + 0.249251 LEG$$

The signs of this model are as expected. Thus, for a 1% increase in GDP, CO_2 emission is increasing by 0.96% and this estimate was significant at a 5% level. In other words, environmental pollution represented by CO_2 emissions is influenced by the level of GDP in Saudi Arabia. Also, when electricity generation increases by 1%, it is likely to raise the CO_2 emissions by 0.24% and this estimate also was significant at a 5% level (see Table (3)).

Table (3): Vector Error Correction Model (VECM) Results

Dependent Variable LCO_2			
Variables	Coefficient	Standard Error	t-statistic
LGDP (-1)	0.965185*	0.16243	5.94208
LEG (-1)	0.249251*	0.08874	2.80889
ECT (-1)	-0.420634***	0.23296	-1.80563
POP	0.051454**	0.02283	2.25333
C	-10.28263		
R^2	0.532748		

* denotes significance at the 1% level, ** denotes significance at the 5% level and *** at the 10% level

Source: EViews software output.

The short-run results are reported in Table (4). The short-run results show that GDP does not have a statistically significant impact on emissions. However, electricity generation in the dynamic short run has had a significant influence on CO_2 emissions at the 5% level. Additionally, population growth included as an exogenous variable has a positive and statistically significant coefficient at the 5% level. This means that population growth is associated with an increase in CO_2 emissions. This implies that higher population growth leads to greater energy consumption, transportation use, or industrial activity, which contributes to more CO_2 emissions in the short run.

Table (4): VECM estimation of variable short-run coefficients

Dependent Variable ΔLCO_2			
Variables	Coefficient	Standard Error	t-statistic
ΔLGDP(-1)	-0.056100	0.22615	-0.24807
ΔLGDP(-2)	-0.041374	0.19243	-0.21501
ΔLGDP(-3)	-0.291517	0.17694	-1.64759
ΔLEG(-1)	-0.241173**	0.11105	-2.17172
ΔLEG(-2)	-0.284603**	0.13800	-2.06237
ΔLEG(-3)	-0.140585	0.12458	-1.12846

**denotes significance at the 5% level.

Source: EViews software output.

We used a few diagnostic tests to look at the model's overall stability in order to assess the study's robustness. As indicated in Table 5, we discovered that the VECM model passes the necessary diagnostic tests. The normality test indicates that the residuals show a normal distribution, and the auto-correlation LM test suggests that there is no serial correlation issue. According to the Breusch-Pagan Godfrey test, there is no heteroscedasticity in the model.

Table (5): VECM Diagnostic Tests

Tests	R-square (P value)
Autocorrelation, LM test	2.714 (0.2573)
Normality Test, JB-test	0.178 (0.55)
Heteroskedasticity Test: Breusch-Pagan Godfrey	6.735.9153)

Source: EViews software output.

4.2 Environmental scenarios results:

In this section we investigate one of Saudi's green growth indicators (based on data availability), which is the carbon emissions indicator under the area of the environmental and resource productivity of the economy (see Section 3.4). Two scenarios from 2021 to 2030 are constructed using EViews software to estimate the scenarios.

The practical steps are: (1) there is a need to generate out-of-sample forecasts for the medium-term up to 2030 by using a growth rates method. (2) Then, we will obtain a baseline scenario through solving the VECM model from 2021 to 2030. (3) Next, adjusting endogenous variables to examine the policy intervention effect (e.g. reducing electricity generation by 50%) then solving the model again to obtain the second scenario.

In terms of scenario plausibility and economic coherence, model stability and diagnostic testing results are satisfied. Also, this study examined out-of-sample forecast evaluation metrics: these metrics assess forecast accuracy, and the overall assessment is there is a good forecast accuracy result (see, Table (6)). The model's output under scenario 1 aligns with expected policy impacts, indicating its suitability for counterfactual forecasting. These evaluations confirm that the VECM is appropriate for forecasting in this context and that it demonstrates strong predictive performance.

Table (6): Statistical Forecast Evaluation Tests

Variable	MAE	RMSE	TAPE	Theil's U-statistic
LCO_2	0.25	0.28	4.50	0.02
LEG	0.05	0.07	0.85	0.01
LGDP	0.31	0.34	2.10	0.01

MAE: Mean Absolute Error
RMSE: Root Mean Square Error
MAPE: Mean Absolute Percentage Error
Theil: Theil inequality coefficient
Source: EViews software output.

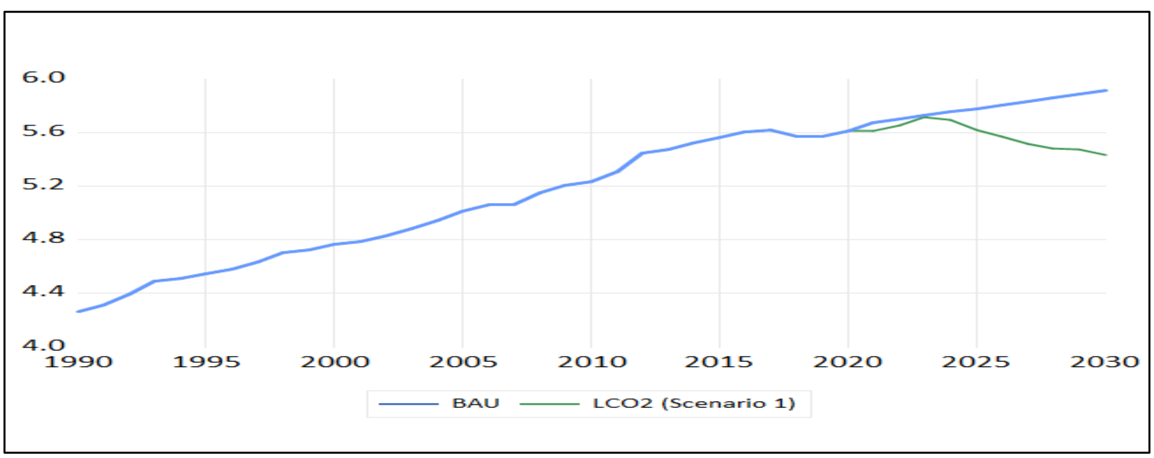

Fig. (1): CO_2 emissions (MT) forecasts under environmental scenarios
Source: Based on VECM model estimation

According to the baseline scenario, Saudi Arabian authorities will not implement any environmental policies to lower CO_2 emissions. As a result, carbon dioxide emissions from electricity generation will rise further under this BAU scenario, meaning that CO_2 emissions will persist increasing to 2030. Under scenario 1, Saudi Arabia's policymakers will apply a low carbon strategy through reducing electricity generation from traditional sources by 50% and replacing them with renewable sources to abate CO_2 emissions from 2021-2030. The scenario results indicated that Saudi Arabia's CO_2 emissions will be decreasing starting from 2021 (See Fig. 1).

4.3 Green growth indicators analysis:

Saudi Green Initiative (SGI) is leading several ambitious programs aimed at cutting emissions. 1) Hastening the national circular carbon economy initiative to cut, reuse, recycle, and remove CO_2 emissions. 2) Investing in renewable energy to help Saudi Arabia transition to a more sustainable energy mix. By 2030, Saudi Arabia aims to generate 50% of its electricity from renewable sources. 3) Leading the globe in the production and export of clean hydrogen, thereby spearheading a new sustainable energy source. 4) Improving Saudi Arabia's energy efficiency program (SEEPP) in order to increase energy efficiency. 5) Changing waste management: starting a large-scale initiative to change waste management in Riyadh (Saudi Green Initiatives, 2024). The following discussion examines the extent to which Saudi Arabia has successfully progressed toward green growth, using OECD indicators as a framework for evaluating its initiatives.

(1) **The environmental and resource productivity of the economy indicator**: Saudi Arabia improved 12 places in the energy transition pillar in the world and holds the top place in the renewable energy growth indicator, due to Saudi's plan to increase the share of renewable energy in its electrical generating to 50% by 2030 (Ministry of Energy, 2022). In terms of reducing the carbon intensity of economic activities, Saudi Arabia has initiatives in carbon capture, utilization, and storage (CCUS) (ARAMCO, 2024). Also, Saudi Arabia makes efforts in waste management to enhance waste collection, recycling, and disposal thus reducing its environmental impact.

(2) **The natural asset base indicator**: Saudi Arabia to improve its natural capital is planting 10 billion trees and allocating 30% of its land and sea areas for preservation. Natural resources will preserve and improve under some initiatives, such as the Saudi Green Initiative (SGI) (Green Initiatives, 2024). Also, preserving natural resources and reducing environmental degradation through minimising waste sent to landfills through recycling and waste-to-energy projects. Also, initiatives such as CCUS mitigate environmental degradation and preserve natural resources.

(3) The environmental dimension of quality of life indicator: Saudi Arabia future cities with a focus on green technologies and sustainability, aim to raise living standards and enhance the environment: NEOM city intends to include green flying taxis (Syme, 2024). In addition, Saudi Arabia's deployment of over 10 million smart electricity meters allows consumers to monitor and manage their energy consumption more effectively, with cost savings, which in turn reduces energy-related environmental issues (Saudi energy consulting, n.d). Carbon credit exchange platform (Public Investment Fund, 2024) and effective waste management and fuel-efficient vehicles, all are reducing pollution and health risks which in turn enhance life quality and lead to a more sustainable environment.

(4) Economic opportunities and policy responses indicator: Saudi advanced 10 places in the Green Future Index 2022, reflecting its commitment to green growth policies. Focusing on sectors such as renewable energy, tourism, and mining, in addition to investments in recycling, projects a transition to a circular economy. Also, the initiative of fuel efficiency fees promoting fuel-efficient vehicles creates economic opportunities, which in turn supports industries related to vehicle efficiency (Saudi Energy Efficiency Center, 2023). Investments in CCUS technologies create new jobs and encourage innovation. These strategies and initiatives reflect policy responses to accomplish sustainable development.

(5) The socio-economic context and the characteristics indicator: To reduce reliance on fossil fuels, Saudi Arabia is focusing on economic diversification and sustainable development, which reflects on the development and growth of the country, through expanding into renewable energy, tourism, technology, and mining. This expansion of sustainable industries addresses high unemployment and creating jobs and supports population growth and employment. Also, the Saudi government's focus on urban development through smart city and implementing green projects, such as NEOM city, aims to set new standards for sustainability and improve living standards.
In sum, Table7 reveals initiatives that support several main areas within the OECD framework.

Table (7): Saudi Arabia's green growth initiatives versus OECD indicators

	Main indicators	Saudi Action
1	The environmental and resource productivity of the economy	The Saudi plan to increase the share of renewable energy in its electricity generation to 50% by 2030
		Saudi Arabia's efforts to enhance waste collection, recycling, and disposal
		Saudi Arabia has an initiative in carbon capture, utilization, and storage
2	The natural asset base	The Saudi and Middle East Green Initiatives
		Minimizing waste sent to landfills
		CCUS programs will protect natural resources
3	The environmental dimension of quality of life	NEOM city aims to raise living standards
		10 million smart electricity meters will reduce energy-related environmental issues
		Carbon credit exchange platform
		Effective waste management and initiative of fuel-efficient vehicles enhance life quality
4	Economic opportunities and policy responses	Focusing on sectors such as renewable energy, tourism, and mining create jobs
		Fuel-efficient fees and CCUS create jobs and reflect policy responses
5	The socio-economic context and the characteristics	Generating jobs and urban development by diversifying economy, sustainable industries, and smart cities

Source: Author's summary based on studies listed above.

5. Results discussion:

According to the VECM analysis, there are long-run relationships among our variables, meaning they influence CO_2 emissions. The results reveal that electricity generation contributes positively to CO_2 emissions. The fact that oil dominates the Saudi economy and may take a long time to shift is one explanation for the outcome. Furthermore, the rapid growth of industries and urbanisation causes more electricity generation. Also, findings demonstrated that the GDP and population growth are important contributors to the rise in CO_2 emissions. Although there was a national plan to diversify the income base, the oil sector's contributions to GDP growth from 1990 to 2020 made this unsurprising. Therefore, the key to reducing carbon emissions is transition to a green economy through raising energy efficiency and diversification of energy sources. Over time, Saudi Arabia's efforts to improve energy efficiency and the country's environmental plan will contribute to a decrease in the country's emissions growth. Saudi policymakers ought to focus more on increasing energy efficiency and educating the public about the need to use electricity more rationally.

For the two scenarios results: under a baseline scenario (BAU), CO_2 emissions will continue to increase. The ambitious scenario which is built based on the energy efficiency program that intends to generate 50% of power from renewable resources, indicates that Saudi Arabia's CO_2 emissions will decrease to 5.43 MT by 2030 compared with BAU which reaches 5.91 MT by 2030. Saudi Arabia can thus reduce CO_2 emissions based on adoption of the abatement scenario. This could occur as a result of Saudi Arabia's energy efficiency initiatives, like the Saudi Green Initiative, and its renewable energy projects. Nonetheless, improving energy efficiency in the electrical sector is a crucial component of Saudi Arabia's CO_2 emission reduction plan. However, Saudi authorities must create a plan that outlines each sector's accountability for lowering energy use.

By reviewing Saudi's green growth activities and programs, we found that these efforts demonstrate Saudi Arabia's alignment with OECD green growth indicators. The country is showing a commitment to preserving the environmental quality through innovative environmental and economic strategies. This reflects Saudi Arabia's commitment to sustainable development as outlined in its Vision 2030 and the Saudi Green Initiative.

6. Conclusion and Policy Implications:

This study evaluated green growth indicators for Saudi Arabia versus OECD green growth indicators from 1990 to 2020 using three techniques. First, the VECM approach was employed to estimate the long-run relationship between CO_2 emissions and economic growth. VECM results indicated carbon emissions are influenced by the GDP and electricity generation in Saudi Arabia. Then, two environmental scenarios were constructed using the estimated coefficients of the VECM model: the baseline scenario result showed that carbon emissions from 1990 to 2020 will continue rising to 2030. While scenario 1 assumes that Saudi Arabia's policymakers will apply a low carbon strategy through reducing electricity generation by 50% to reduce CO_2 emissions, the results implied that Saudi Arabia's carbon emissions will be decreasing starting from 2021 up to 2030. Finally, reviewing Saudi Arabia's green growth initiatives and programs showed the country's alignment with OECD green growth indicators. Through innovative economic and environmental initiatives, the country is demonstrating its dedication to maintaining the quality of the environment and sustainable development as stated in the Saudi Green Initiative and Vision 2030.

Despite efforts by Saudi Arabia to improve energy efficiency and a national environmental policy contributing to a decrease in the region's emissions growth, if the country needs to achieve net zero and ensure a sustainable future, implementing a number of policies will be required, such as: (1) Update its NDC continuously. (2) Accelerate the implementation of renewable energy projects significantly (Climate Action Tracker, 2023). (3) Even with the lowest emissions scenario, more work is required to reach net zero by 2060.

This includes investing in carbon removal technology and implementing policies like carbon pricing (Darandary et al., 2024). (4) There are several areas that should move forward exclusively from an energy policy perspective for advancing the green energy transition, like strategies for regional and cross-sectoral collaboration, technological innovation, adoption of international models and research, resource conservation, environmental protection and climate change, human capital development and public engagement (Islam & Ali, 2024). By adding another country or variables with longer-run datasets, the current study could be repeated. Future research could also examine other crucial sectors, like transportation and waste sectors that affect green growth.

Author's Declaration
Conflicts of Interest: None
We hereby confirm that all the figures and tables in the manuscript are mine and ours. Any figures and images which are not mine, have been permitted to be reproduced and attached to the manuscript.

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