The Role of Economic and Environmental Variables in Green Growth: Evidence from Saudi Arabia

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ABSTRACT

Saudi Arabia, as one of the world's leading oil producers, faces critical challenges in transitioning to sustainable economic growth. The heavy reliance on oil exports, coupled with rapid urbanization and environmental degradation, underscores the urgent need for green growth strategies tailored to the Kingdom's unique socioeconomic and environmental context. This study aims to investigate the factors influencing the Green Growth Index (GGI), which measures sustainable economic growth, and analyze the short-term and long-term relationships between key variables such as environmental technology diffusion, carbon emissions, financial development, GDP per capita, and urbanization. The research employs the Autoregressive Distributed Lag (ARDL) model to assess the effects of various explanatory variables on the GGI, considering both immediate and delayed impacts. The model also incorporates an Error Correction Model (ECM) to evaluate the short-term dynamics and long-term equilibrium adjustments. It is found that the diffusion of environmental technologies and urbanization positively influence GGI in the short term, while CO_2 emissions are also linked to growth in the short run. However, financial development negatively impacts green growth in the long term, and GDP per capita has no significant effect. The ECM indicates that urbanization and emissions are major short-term drivers, while other factors show minimal short-run influence. This paper provides new insights into the dynamics of green growth by highlighting the roles of urbanization, environmental technologies, and emissions, offering valuable policy implications for sustainable development. The findings contribute to the understanding of the complex relationships that shape green growth in both the short and long term.

Keywords-green growth; environment-related technologies; CO_2; financial development; GDP per capita; urbanization; ARDL model; Saudi Arabia

I. INTRODUCTION

Sustainable economic growth, or green growth, is increasing in importance as nations balance economic development with environmental preservation [1]. The Green Growth Index (GGI) helps measure this balance by assessing economic, environmental, and social factors [2]. As environmental concerns like climate change and pollution rise, understanding green growth drivers becomes crucial, especially for resource-dependent nations [3]. Saudi Arabia, a major oil producer, faces challenges in transitioning to a low-carbon economy. The country is addressing this through its Vision 2030 initiative, aiming to diversify its economy, reduce oil dependence, and promote sustainability [4]. Key programs, such as the Saudi Green Initiative and the Middle East Green Initiative, focus on reducing carbon emissions, combating desertification, and promoting clean energy [5]. However, rapid urbanization, population growth, and industrial impacts present ongoing challenges [6].

Technological innovation in clean production and resource efficiency plays a critical role in green growth, though its ability to mitigate urbanization and industrial pressures is uncertain [7]. Additionally, managing carbon emissions and aligning financial development with sustainability goals are crucial for long-term progress [8]. Urbanization offers both opportunities for innovation and risks of increased environmental degradation if not managed properly [9].

Technological advancements, particularly in the fields of renewable energy and eco-friendly solutions, play a crucial role in decoupling economic growth from environmental degradation. Empirical studies have highlighted that technological innovation is a key driver of green growth. Innovations in areas such as renewable energy, energy efficiency, and waste management have proven to be instrumental in achieving this balance. Authors in [10] found that upgrading the technology innovation value chain is essential for promoting green transformation and sustainable development. Their research indicates that technological progress not only facilitates environmental benefits but also creates economic opportunities by fostering new industries and improving productivity in green sectors. Similarly, authors in [11] found that technologies developed for the production and processing of goods in OECD Asian countries have significantly contributed to green growth. Their study underscores how these technologies have enabled increased production efficiency and reduced environmental impact.

The relationship between CO_2 emissions and green growth is multifaceted, presenting both challenges and opportunities. While CO_2 emissions contribute to climate change, they also drive innovation in green technologies and sustainable solutions. Elevated emissions prompt investments in technologies like carbon capture and storage 12] and encourage economic growth that can fund green initiatives. The Environmental Kuznets Curve suggests that emissions initially rise with industrialization but decline at higher income levels due to green technologies and regulations [13]. Market mechanisms like carbon markets and emission trading systems, such as the EU Emissions Trading System, encourage businesses to adopt eco-friendly practices [14]. Rising CO_2 levels also lead to stronger climate policies and international agreements like the Paris Accord, aligning nations with sustainable development goals [15]. Increased awareness of CO_2 impacts further drives consumer demand for sustainable products, prompting industries like automotive to innovate with electric vehicles [16].

Empirical research underscores the pivotal role of financial development in promoting green growth. Authors in [17] highlight that financial development positively influences renewable energy consumption, while economic growth tends to negatively impact it. Authors in [18] found that although economic growth and energy intensity increase CO_2 emissions, financial development helps mitigate these emissions by facilitating energy-efficient technologies. The study in [19] further explores the asymmetric effects of financial development on environmental quality in Pakistan, showing that while bank-based financial development may hinder the environment, regulations can counteract these negative effects. Authors in [20] suggest that financial systems foster both economic growth and the financing of sustainable technologies, contributing to overall environmental sustainability. Collectively, these studies emphasize that the type of financial development and the regulatory framework are crucial in determining its impact on green growth.

GDP per capita is widely considered a key determinant of green growth, with many studies supporting its positive correlation with sustainable economic development. Authors in [21] found that economic development positively influences green growth, although the impact varies between developed and developing countries. In developed nations, higher GDP per capita often facilitates greater investment in green technologies, while in developing countries, the relationship may be influenced by different structural and institutional factors. In [22], a long-run positive relationship between economic growth and a sustainable environment in Azerbaijan is confirmed, suggesting that as economic development progresses, it supports environmental sustainability. Similarly, authors in [23] show that economic growth helps sustain the environment by reducing carbon emissions, highlighting how increased economic prosperity can enable the adoption of cleaner technologies and energy-efficient practices. Overall, these studies suggest that, in many contexts, higher GDP per capita can contribute to both economic and environmental sustainability.

Urbanization has been shown to have both positive and negative effects on green growth. On one hand, it drives innovation and offers opportunities for the development of more sustainable infrastructure. On the other hand, it can lead to challenges such as increased pollution and resource consumption. The impact of urbanization on green growth largely depends on factors like environmental policies, industrial structure, and the level of economic development [24, 25]. Authors in [26] explored the relationship between urbanization and urban green development in the Yangtze River Economic Belt, revealing a "U" shaped curve. In this model, urbanization initially hampers green development due to increased environmental pressures but eventually promotes it as sustainable practices and technologies are integrated into urban growth over time.

Most green growth studies emphasize global frameworks, often lacking applicability to resource-dependent economies like Saudi Arabia (KSA). Despite initiatives such as Vision 2030 and the Saudi Green Initiative, limited research explores how these strategies address challenges like carbon reduction, desertification, and oil dependency [27, 28]. This study fills the gap by adapting global green growth concepts to Saudi Arabia's specific context, contributing to the understanding of sustainable transitions in similar economies. The results of this study aim to provide actionable insights for policymakers in KSA, offering a clear understanding of the relationships between key factors and the GGI. These findings are expected to inform strategies for achieving Vision 2030's sustainability objectives and contribute to the broader discourse on sustainable development in resource-rich economies. The research addresses a critical gap in the literature by focusing on the specific challenges and opportunities faced by KSA in its transition toward green growth.

This study employs the Autoregressive Distributed Lag (ARDL) model to analyze the impact of several variables on KSA's Green Growth Index, capturing both short-term dynamics and long-term adjustments. By incorporating the Error Correction Model (ECM), the analysis provides deeper insights into how quickly deviations from sustainable growth are corrected and the relative importance of each variable in driving green growth.

II. METHODOLOGY

The methodology for analyzing time-series data involves sequential steps to explore the data, test assumptions, build models, and ensure robustness.

Step 1: Unit Root Testing for Stationarity: Stationarity is a key assumption in time series analysis. Unit root tests, including the tests in [29], are conducted to determine whether variables are stationary. If the level form of a variable is non-stationary, the test is repeated on its first difference. This ensures that all variables meet the stationarity requirements.

Step 2: ARDL Model Estimation: Once stationarity is confirmed, ARDL models [30] are estimated. The following ARDL model was constructed:

$$Y_t = \alpha + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \varepsilon_t \quad (1)$$

where, Y_t is the dependent variable, X_t represents the independent variables, α is the intercept, β_i and γ_j are the coefficients of the lagged dependent and independent variables, p and q are the number of lags, and ε_t is the error term.

$$GGI_t = \alpha + \sum_{i=1}^{p} \beta_i GGI_{t-i} + \sum_{j=0}^{q} \gamma_j DET_{t-j} + \sum_{j=0}^{q} \gamma_j CO2_{t-j} + \sum_{j=0}^{q} \gamma_j FDI_{t-j} + \sum_{j=0}^{q} \gamma_j GDPC_{t-j} + \sum_{j=0}^{q} \gamma_j URBP_{t-j} + \varepsilon_t \quad (2)$$

Models with varying lag structures are estimated, and their fit is compared using criteria such as the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The model with the lowest AIC or BIC is selected as the best fit.

Step 3: Diagnostic Checks: Diagnostics are essential for ensuring the validity of the ARDL model. Residuals are analyzed for autocorrelation by the test analysed in [31]. Heteroscedasticity is assessed using tests such as White's test [32]. The test in [33] is used to assess whether a dataset follows a normal distribution. These diagnostic tests confirm the reliability of the model estimates.

Step 4: Bounds Test for Long-Run Relationship: The Bounds test determines whether a long-run relationship exists among the variables. If a long-run relationship is confirmed, the residuals from the ARDL model are used to create an ECM.

Step 5: ECM: The ECM helps to study the short-run adjustments towards the long-term equilibrium, capturing how shocks to the system are corrected over time. The general form of the ECM is:

$$Y_t = \mu + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \lambda ECT_{t-1} + \varepsilon_t \quad (3)$$

where ECM_{t-1} is the Error Correction Term, which represents the deviation from the long-run equilibrium relationship in the previous period:

$$ECT_{t-1} = Y_{t-1} - \emptyset X_{t-1} \quad (4)$$

where $\emptyset$ is the long-run relationship between Y and X, λ is the adjustment coefficient that tells us how quickly the system corrects deviations from equilibrium, and ε_t is the error term for the ECM, accounting for any other short-term shocks.

Step 6: Stability Analysis: Stability of the estimated model is crucial for robust inference. Stability tests such as CUSUM and CUSUMSQ are conducted [34]. These tests graphically analyze the cumulative sum of residuals and squared residuals against critical boundaries.

III. DATA

This study utilizes time-series data for KSA from 1990 to 2023, providing a comprehensive view of technological, economic, and environmental dynamics over more than three decades. The variables are transformed into natural logarithm form. The variables represent diverse domains, including technological indicators (GGI), economic factors (Financial Development Index and GDP per capita), and environmental measures (CO_2 emissions and Urbanization rates). Table I presents the data description.

TABLE I. DATA DESCRIPTION

Variable	Abbrev.	Source
Green Growth Index (total patents -all technologies)	GGI	OECD
Diffusion of environment-related technologies (percentage of inventions)	DET	OECD
Carbon dioxide emissions per capita	CO2	Worldbank
Financial Development Index	FDI	Worldbank
GDP per capita (constant 2015 US$)	GDPC	Worldbank
Urban population (% of total population)	URBP	Worldbank

The GGI reflects innovation across all technological sectors [35, 36]. The percentage of inventions related to environment technologies (DET), measures the diffusion of sustainable innovations. Carbon dioxide emissions per capita (CO2) indicate the environmental impact of a country's economic and industrial activities. The FDI assesses the growth of the financial sector, while GDPC provides a measure of economic prosperity, adjusted for inflation. Finally, URBP reflects the proportion of a country's population living in urban areas, which can influence the adoption of technology and environmental strategies. These variables collectively offer insights into how innovation, economic development, urbanization, and environmental sustainability are interconnected.

The descriptive statistics in Table II show stable trends across various indicators. The GGI averages 3.43, with moderate variability, while the diffusion of environment-related technologies has a mean of -3.42, indicating low diffusion. CO_2 values have a mean of 2.65, reflecting stable emissions. The financial development index averages -0.96, suggesting moderate development and GDP per capita is stable with a mean of 9.83. Urban population also remains stable at a mean of 4.40%. These statistics highlight consistent economic and environmental patterns in KSA, with variability mainly in innovation-related measures.

TABLE II. DESCRIPTIVE STATISTICS

Abrev.	Obs.	Mean	Std. Dev.	Min	Max
GGI	32	3.4300	1.4200	0.0000	5.4700
DET	32	-3.4200	0.6200	-4.4600	-2.2200
CO2	33	2.6500	0.1800	2.3600	2.9300
FDI	32	-0.9600	0.1900	-1.3100	-0.6500
GDPC	34	9.8300	0.0800	9.6600	9.9700
URBP	34	4.4000	0.0300	4.3400	4.4400

The unit root tests (Table III) assess the stationarity of the variables in the dataset.

TABLE III. DICKEY-FULLER TEST RESULTS

Variable	Test Statistic	Variable in 1st difference	Test Statistic
GGI	-2.3890	ΔGGI	-5.3970***
DET	-2.8590*	ΔDET	-5.4680***
CO2	-1.3090	ΔCO2	-4.7510***
FDI	-1.3520	ΔFDI	-5.2390***
GDPC	-1.2060	ΔGDPC	-5.6250***
URBP	-4.3490***	ΔURBP	-5.6670***

***, **, and * imply the significance at 1%, 5%, and 10% level, respectively

The results from the Dickey-Fuller tests indicate that the variables, GGI, DET, CO_2, FDI, and GDPC, are non-stationary at the level. However, the URBP is stationary at level. After applying the first difference, all variables become stationary. To select the appropriate model, we compared the results of ARDL models with different lag structures (Table IV). Model 1 with lag 1 performs better based on both AIC and BIC values, which suggests it is more efficient.

TABLE IV. MODEL SELECTION

	Model 1 Lag 1	Model 2 Lag 2
AIC	15.1555	16.4761
BIC	31.9699	41.0874

IV. EMPIRICAL FINDINGS

The ARDL model indicates how different variables, including their lags, influence the dependent variable over time. The results of the ARDL regression are provided in Table V.

TABLE V. ARDL MODEL RESULTS

Variable	Lag	Coefficient	Standard Error
Δggi	L1	0.2636	0.1768
Δdet	L0	0.2198**	0.1021
	L1	0.0910	0.1039
Δco2	L0	7.1697***	2.1519
	L1	0.9870	2.2946
Δfdi	L0	-0.4884	0.6041
	L1	-1.8547***	0.6446
Δgdpc	L0	-2.7010	1.6801
	L1	-0.4012	1.6568
urbp	L0	197.1953**	76.8125
	L1	-155.2962**	74.6625
_cons	_cons	-182.0886***	42.8156
R squared	0.9691	F-statistic	51.2700***

*** and ** imply the significance at 1% and 5% level, respectively

The model demonstrates strong explanatory power, it accounts for almost 97% of the variance in the GGI. The F-statistic is also quite significant, further supporting the model's reliability.

The GGI, which measures the sustainable growth in an economy, is influenced by several key factors. One significant factor is the current level of environmental technology adoption that has a positive and significant effect on the GGI. This suggests that the spread and implementation of eco-friendly technologies contribute positively to green growth. However, the past values of this variable do not show a significant impact, indicating that the effect of technology diffusion on green growth is primarily immediate rather than delayed.

Another important factor is CO_2 emissions. The coefficient for Lag 0 is highly significant, indicating that higher CO_2 emissions in the short term are positively related to the GGI. This is an interesting finding because it suggests that, at least in the short term, emissions might be associated with economic activities that could drive growth, potentially due to industrial activities. However, the Lag 1 coefficient is not significant, implying that the effect of emissions on green growth might diminish over time.

The FDI also plays a role in shaping the GGI. The coefficient for FDI is negative at Lag 1 and statistically significant, suggesting that past financial development may have a negative long-term impact on green growth. This could reflect the idea that rapid financial development might lead to economic activities that prioritize growth over sustainability in the long term.

GDPC appears to have little influence on green growth. Neither the short-term nor the long-term effects of GDPC on the GGI are statistically significant. This indicates that changes in economic output per person do not have a direct influence on green growth in this model, suggesting that green growth is driven more by technological and environmental factors than by the overall economic output.

URBP shows a significant positive relationship with the GGI in the short term, suggesting that urbanization is positively associated with green growth. This is likely due to the concentration of resources and technologies in urban areas. However, in the long term, URBP has a significant negative effect, indicating that the benefits of urbanization on green growth may diminish or even turn negative over time. This could be due to challenges such as urban sprawl, pollution, or unsustainable urban development.

To validate the ARDL regression results, it is essential to ensure that the residual diagnostics meet the necessary assumptions for a reliable and robust model. The results (Table VI) suggest that the residuals do not exhibit serial correlation. To test if the variance of residuals is constant across observations, we performed the White test for heteroscedasticity (Table VII). The results indicate that we fail to reject the null hypothesis of homoskedasticity. Shapiro-Wilk was conducted to check if the data (residuals) are normally distributed (Table VIII). The results suggest that the residuals are normally distributed.

TABLE VI. CHECK FOR AUTOCORRELATION

Variable	Coefficient	Standard Error	P-value
residuals (L1)	0.0207	0.1990	0.9180
_cons	-0.0015	0.0345	0.9660

TABLE VII. CHECK FOR HETEROSCEDASTICITY

White's test		
	Chi squared	**P-value**
Ho: Homoskedasticity	0.9300	0.6282

TABLE VIII. CHECK FOR NORMALITY

Statistic	W Statistic	Z Value	p-value
Value	0.9686	-0.0540	0.5216

These results validate the use of inferential statistics, ensuring the reliability and accuracy of the model's estimates.

The Bounds Test is used to determine whether a cointegration exists among the variables. The results reveal that there is strong evidence of a long-run relationship among the variables (F-statistic = 75.0500 with p-value = 0). This result supports moving forward to estimate the long-run coefficients and error correction terms (Table IX). The results of the Error Correction Model (ECM) estimation reveal key insights into the short-run dynamics of the dependent variable concerning the explanatory variables. The R squared value indicates that approximately 94.35% of the variation in GGI is explained by the model, highlighting a strong fit. The F-statistic is significant, confirming the joint significance of the explanatory variables.

TABLE IX. EMC REGRESSION

Variable	Coefficient	Std. Error	t-Statistic
Δdet	0.1662	0.1108	1.5000
Δco2	4.2010*	2.3243	1.8100
Δfdi	−0.4300	0.7098	−0.6100
Δgdpc	−1.2529	1.8864	−0.6600
urbp	49.3870***	2.8205	17.5100
ecm	0.3525	0.2165	1.6300
_cons	−213.6014***	12.4161	−17.2000
R squared	0.9435	F-statistic	64.0400***

*** and * imply the significance at 1% and 10% level, respectively

Among the variables, URBP has a highly significant positive impact on GGI, suggesting a robust relationship. This implies that urbanization substantially contributes to changes in the dependent variable. CO2 show a positive and moderately significant impact, suggesting that environmental factors influence GGI in the short run. Other variables, such as FDI and GDPC are not statistically significant, indicating that their short-run effects on GGI are minimal within the model. The error correction term (ecm) suggests that deviations from the long-run equilibrium are corrected at a rate of 35.25% per period, though the correction speed is not statistically significant. Overall, the model underscores urbanization and carbon dioxide emissions as notable drivers of GGI in the short run.

Figure 1 displays the cumulative sum of residuals and squared residuals, respectively, along with boundaries. The results indicate that the test statistic stays within the boundaries, indicating that the model does not experience any significant structural breaks over the sample period. The model is considered stable, and the coefficients do not change significantly over time.

We performes ARMA (Autoregressive Distributed Lag) to validate the results of the ARDL-ECM model (Table X). The ARMA and ARDL-ECM models provide similar insights, with CO_2 emissions and urbanization showing significant effects on the GGI. However, the effects of FDI and GDPC are not significant in either model. Urbanization appears to be one of the strongest predictors of green growth, as indicated by the large positive coefficients for both models.

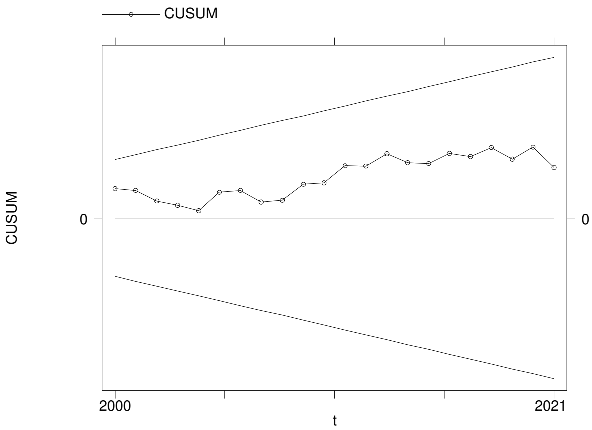

Fig. 1. CUSUM and CUSUMSQ graphs.

TABLE X. ARMA REGRESSION

Component	Coefficient	Standard Error
Dependent Variable (Δggi)		
Δdet	0.1339	0.1254
Δco2	4.8091**	2.2192
Δfdi	0.0484	0.7202
Δgdpc	-2.2273	2.0311
urbp	50.4443***	3.7304
_cons	-218.269***	16.3764
ARMA Coefficients		
AR(1) (L1.)	0.2856	0.3011
Variance		
/sigma	0.2835***	0.0510

*** and * imply the significance at 1% and 10% level, respectively

The results from both models are consistent, suggesting robustness in the analysis, reinforcing the idea that CO_2 emissions and urbanization play significant roles in determining Green Growth.

V. DISCUSSION

One of the key findings is the positive and significant impact of the diffusion of environment-related technologies on green growth in the short term. The adoption of these technologies contributes directly to sustainable development by improving energy efficiency, reducing emissions, and fostering innovation in green sectors. This result aligns with [17, 25], who emphasized the immediate benefits of such technologies. The lack of significant effects from past adoption suggests that these benefits do not exhibit delayed impacts, highlighting the urgency of accelerating technology diffusion for immediate gains in green growth.

The relationship between CO_2 emissions and the GGI provides an interesting perspective [37]. In the short term, the positive association suggests that emissions, often a byproduct of industrial activity and economic growth, might temporarily support green growth. However, this finding challenges the conventional view that emissions are purely detrimental to environmental sustainability. Authors in [22] observed similar patterns, where industrial expansion contributed to short-term economic growth despite the environmental costs. In the long term, the absence of a significant effect underscores that the environmental damage from emissions eventually outweighs their short-term benefits. These results emphasize the need to decouple economic growth from emissions, as highlighted by [24], to ensure sustainable development.

Financial development presents a contrasting dynamic. While it is generally perceived as a driver of economic growth, the analysis indicates a negative long-term relationship with green growth [38, 39]. This suggests that rapid financial development might prioritize economic expansion at the expense of environmental sustainability, consistent with findings by [20]. To mitigate such adverse effects, financial systems must be aligned with green investment strategies, integrating sustainability goals into economic planning and development policies.

GDPC does not show a significant impact on green growth in either the short or the long term. This result challenges the traditional assumption that higher income levels automatically translate into better environmental outcomes. Authors in [18] similarly found that economic growth alone is insufficient to drive green growth, emphasizing the need for targeted strategies focused on technological advancements and efficient resource use rather than relying solely on economic output.

Urban population dynamics exhibit a dual effect on green growth. In the short term, urbanization positively influences sustainability by providing the infrastructure, resources, and innovations necessary for green practices. However, over the long term, urban sprawl, pollution, and resource depletion counteract these benefits, leading to a negative relationship with green growth [39]. Authors in [26] observed that urbanization initially supports but eventually hinders sustainability if not managed effectively. This underscores the critical role of urban planning in mitigating the environmental challenges of uncontrolled urban expansion, as also noted by [24].

The findings highlight the complexity of factors influencing green growth. In the short term, technological advancements, urbanization, and even emissions contribute positively, while financial development poses challenges in the long term.

For KSA, the findings emphasize balancing short-term industrial gains with long-term sustainability through Vision 2030 initiatives such as green financing, urban planning, and renewable energy. Globally, the study highlights universal challenges like urbanization's dual impact, the trade-offs of financial development, and the critical role of green technologies in decoupling growth from emissions.

VI. CONCLUSION

This study offers a comprehensive analysis of the dynamics influencing the Green Growth Index (GGI), focusing on the interaction between technological innovation, environmental sustainability, and economic factors. Employing ARDL and ECM models, it reveals that while the diffusion of environment-related technologies and urbanization foster green growth in the short term, their long-term effects are more intricate. Urbanization and CO_2 emissions emerge as immediate drivers of green growth, highlighting the challenges of balancing economic activity with environmental sustainability. Notably, financial development, despite its role in economic growth, presents long-term challenges for green growth, with a negative association over time. The study also finds that GDP per capita has no significant impact on green growth, emphasizing the need to prioritize technological and environmental considerations over economic output alone.

For Saudi Arabia, these findings are particularly relevant, given its rapid urbanization and ambitious Vision 2030 agenda, which aims to diversify the economy and promote sustainability. The research underscores that while urbanization and environmentally friendly technologies drive short-term green growth, long-term success depends on managing carbon emissions, financial systems, and urbanization trends effectively. Vision 2030 provides a strategic framework for addressing these challenges through initiatives in renewable energy and green infrastructure, offering Saudi Arabia an opportunity to harmonize economic transformation with environmental goals. Ultimately, this research contributes valuable insights into sustainable development, guiding policymakers toward informed strategies that balance economic growth and environmental sustainability.

The study's results are limited by the availability of data and the model's focus on specific variables. Further research could explore other potential factors influencing GGI and refine the model for different countries or regions.

REFERENCES

[1] *Towards Green Growth*. Paris, France: OECD Publishing, 2011.

[2] "Green Growth Index," *Green Growth Index*. https://greengrowthindex.gggi.org/.

[3] "Saudi Vision 2030." https://www.vision2030.gov.sa/.

[4] Saudi Green Initiative. (2023). *About the Saudi Green Initiative*. Retrieved from https://www.sgi.gov.sa/about-sgi/

[5] "UN-Habitat - A Better Urban Future." UN-Habitat, https://unhabitat.org/.

[6] U. N. Environment, "UNEP - UN Environment Programme." https://www.unep.org/node.

[7] WorldBank, "World Bank Group - International Development, Poverty and Sustainability." https://www.worldbank.org/ext/en/home.

[8] "Welcome to the United Nations." http://www.un.org.

[9] M. Cheng, J. Wang, S. Yang, and Q. Li, "The driving effect of technological innovation on green development: From the perspective of efficiency," *Energy Policy*, vol. 188, May 2024, Art. no. 114089, https://doi.org/10.1016/j.enpol.2024.114089.

[10] C. N. Mensah *et al.*, "Technological innovation and green growth in the Organization for Economic Cooperation and Development economies," *Journal of Cleaner Production*, vol. 240, Dec. 2019, Art. no. 118204, https://doi.org/10.1016/j.jclepro.2019.118204.

[11] S. Akther, M. R. Sultanuzzaman, Y. Zhang, F. Almutlaq, and M. E. Huq, "Exploring the influence of green growth and energy sources on 'carbon-dioxide emissions': implications for climate change mitigation," *Frontiers in Environmental Science*, vol. 12, Oct. 2024, Art. no. 1443915, https://doi.org/10.3389/fenvs.2024.1443915.

[12] P. Mitic, A. Fedajev, M. Radulescu, and A. Rehman, "The relationship between CO2 emissions, economic growth, available energy, and employment in SEE countries," *Environmental Science and Pollution Research*, vol. 30, no. 6, pp. 16140–16155, Feb. 2023, https://doi.org/10.1007/s11356-022-23356-3.

[13] Y. Sun *et al.*, "Green Growth, Economic Development, and Carbon Dioxide Emissions: An Evaluation Based on Cointegration and Vector Error Correction Models," *Energies*, vol. 15, no. 10, Jan. 2022, Art. no. 3767, https://doi.org/10.3390/en15103767.

[14] L. Balza, L. Heras-Recuero, D. Matias, and A. Yepez-Garcia, "Green or Growth? Understanding the Relationship between Economic Growth and CO2 Emissions," Inter-American Development Bank, New York, NY, USA, Technical Report IDB-TN-2930, May 2024.

[15] Z. Huang, "Does green investment reduce carbon emissions? New evidence from partially linear functional-coefficient models," *Heliyon*, vol. 9, no. 9, Sep. 2023, Art. no. e19838, https://doi.org/10.1016/j.heliyon.2023.e19838.

[16] J. Wang, S. Zhang, and Q. Zhang, "The relationship of renewable energy consumption to financial development and economic growth in China," *Renewable Energy*, vol. 170, pp. 897–904, Jun. 2021, https://doi.org/10.1016/j.renene.2021.02.038.

[17] M. Shahbaz, F. A. Jam, S. Bibi, and N. Loganathan, "Multivariate Granger causality between CO2 emissions, energy intensity and economic growth in Portugal: evidence from cointegration and causality analysis," *Technological and Economic Development of Economy*, vol. 22, no. 1, pp. 47–74, Jan. 2016, https://doi.org/10.3846/20294913.2014.989932.

[18] M. Shahbaz, S. J. H. Shahzad, N. Ahmad, and S. Alam, "Financial development and environmental quality: The way forward," *Energy Policy*, vol. 98, pp. 353–364, Nov. 2016, https://doi.org/10.1016/j.enpol.2016.09.002.

[19] T. Beck and R. Levine, "Stock markets, banks, and growth: Panel evidence," *Journal of Banking & Finance*, vol. 28, no. 3, pp. 423–442, Mar. 2004, https://doi.org/10.1016/S0378-4266(02)00408-9.

[20] V. Tawiah, A. Zakari, and F. F. Adedoyin, "Determinants of green growth in developed and developing countries," *Environmental Science and Pollution Research*, vol. 28, no. 29, pp. 39227–39242, Aug. 2021, https://doi.org/10.1007/s11356-021-13429-0.

[21] J. I. Mikayilov, M. Galeotti, and F. J. Hasanov, "The impact of economic growth on CO2 emissions in Azerbaijan," *Journal of Cleaner Production*, vol. 197, pp. 1558–1572, Oct. 2018, https://doi.org/10.1016/j.jclepro.2018.06.269.

[22] M. S. Alam and N. Kabir, "Economic growth and environmental sustainability: empirical evidence from East and South-East Asia," *International Journal of Economics and Finance*, vol. 5, no. 2, pp. 86–97, Jan. 2013, https://doi.org/10.5539/ijef.v5n2p1.

[23] A. Kwilinski, O. Lyulyov, and T. Pimonenko, "The Effects of Urbanisation on Green Growth within Sustainable Development Goals," *Land*, vol. 12, no. 2, Feb. 2023, Art. no. 511, https://doi.org/10.3390/land12020511.

[24] W. Yang, Q. Chen, Q. Guo, and X. Huang, "Towards Sustainable Development: How Digitalization, Technological Innovation, and Green Economic Development Interact with Each Other," *International Journal of Environmental Research and Public Health*, vol. 19, no. 19, Jan. 2022, Art. no. 12273, https://doi.org/10.3390/ijerph191912273.

[25] Y. Pan, T. Teng, S. Wang, and T. Wang, "Impact and mechanism of urbanization on urban green development in the Yangtze River Economic Belt," *Ecological Indicators*, vol. 158, Jan. 2024, Art. no. 111612, https://doi.org/10.1016/j.ecolind.2024.111612.

[26] M. Al-Fayez and A. Al-Shehri, "Vision 2030 and the future of green growth in Saudi Arabia: Challenges and opportunities," *Middle East Development Review*, vol. 22, no. 2, pp. 110-124, 2024.

[27] R. Waheed, "Energy Challenges, Green Growth, Blue Indicators, and Sustainable Economic Growth: A Study of Saudi Arabia," *Evaluation Review*, vol. 47, no. 6, pp. 983–1024, Dec. 2023, https://doi.org/10.1177/0193841X221134653.

[28] D. A. Dickey and W. A. Fuller, "Distribution of the Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association*, vol. 74, no. 366a, pp. 427–431, Jun. 1979, https://doi.org/10.1080/01621459.1979.10482531.

[29] M. H. Pesaran, Y. Shin, and R. J. Smith, "Bounds testing approaches to the analysis of level relationships," *Journal of Applied Econometrics*, vol. 16, no. 3, pp. 289–326, 2001, https://doi.org/10.1002/jae.616.

[30] J. Durbin, J. DURBIN, and G. S. Watson, "Testing for serial correlation in least squares regression," *Biometrika*, vol. 37, no. 3–4, pp. 409–428, Dec. 1950, https://doi.org/10.1093/biomet/37.3-4.409.

[31] H. White, "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity," *Econometrica*, vol. 48, no. 4, pp. 817–838, 1980, https://doi.org/10.2307/1912934.

[32] S. S. Shapiro and M. B. Wilk, "An analysis of variance test for normality (complete samples)," *Biometrika*, vol. 52, no. 3–4, pp. 591–611, Dec. 1965, https://doi.org/10.1093/biomet/52.3-4.591.

[33] R. L. Brown, J. Durbin, and J. M. Evans, "Techniques for Testing the Constancy of Regression Relationships Over Time," *Journal of the Royal Statistical Society: Series B (Methodological)*, vol. 37, no. 2, pp. 149–163, Jan. 1975, https://doi.org/10.1111/j.2517-6161.1975.tb01532.x.

[34] S. A. Sarkodie, P. A. Owusu, and J. Taden, "Comprehensive green growth indicators across countries and territories," *Scientific Data*, vol. 10, no. 1, Jun. 2023, Art. no. 413, https://doi.org/10.1038/s41597-023-02319-4.

[35] K. S. Herman, Y. J. Kim, S. Shayegh, and J. Xiang, "A critical review of green growth indicators in G7 economies from 1990 to 2019," *Sustainability Science*, vol. 18, no. 6, pp. 2589–2604, Nov. 2023, https://doi.org/10.1007/s11625-023-01397-y.

[36] J. J. Ferreira, J. M. Lopes, S. Gomes, and C. Dias, "Diverging or converging to a green world? Impact of green growth measures on countries' economic performance," *Environment, Development and Sustainability*, Feb. 2023, https://doi.org/10.1007/s10668-023-02991-x.

[37] R. L. Ibrahim, A. Alomair, and A. S. Al Naim, "How Financial Development Is Driving the Growth and Environmental Dimensions of Sustainable Development in Africa: Heterogeneous Analyses," *Sustainability*, vol. 16, no. 21, Jan. 2024, Art. no. 9284, https://doi.org/10.3390/su16219284.

[38] M. K. Anser *et al.*, "Financial development, oil resources, and environmental degradation in pandemic recession: to go down in flames," *Environmental Science and Pollution Research*, vol. 28, no. 43, pp. 61554–61567, Nov. 2021, https://doi.org/10.1007/s11356-021-15067-y.

[39] J. Vogel and J. Hickel, "Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO2–GDP decoupling in high-income countries," *The LANCET*, vol. 7, no. 9, pp. e759–e769, Sep. 2023, https://doi.org/10.1016/S2542-5196(23)00174-2.