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Impact of Economic Growth, Energy Consumption and Urbanization on Carbon Dioxide Emissions in the Kingdom of Saudi Arabia

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Abstract

The Kingdom of Saudi Arabia has witnessed unprecedented economic growth in recent decades, propelling it onto the global stage. However, this rapid growth is often associated with a notable increase in carbon dioxide emissions, which carry significant environmental ramifications. In light of this pressing concern, this research undertakes a comprehensive examination of the intricate relationships between economic growth, energy consumption, urbanization, and carbon dioxide emissions within the Kingdom of Saudi Arabia from 1980 to 2020. This study employs autoregressive distributed lag approach to uncover the multifaceted dynamics at play. The empirical findings of the study reveal a compelling narrative about the Kingdom's natural landscape. Particularly noteworthy is the revelation that economic growth, urbanization, and energy consumption emerge as pivotal long-term drivers of escalating pollution. These findings underscore the critical necessity for policies that strike a balance between economic development and environmental preservation. Furthermore, the study disentangles the intricate web of causation among these factors. It becomes evident that economic growth and pollution exhibit bidirectional causality, illuminating the intricate connection between economic prosperity and environmental consequences. Additionally, commercial activities have been empirically shown to exert a substantial influence on pollution levels in the Kingdom of Saudi Arabia. To address these challenges, a pivotal shift towards a low-carbon technological revolution is proposed as a means of achieving sustained economic development. This transition towards environmentally friendly technologies holds the potential to decouple economic growth from environmental degradation, paving the way for a greener and more prosperous future for the Kingdom of Saudi Arabia.

***Keywords*:** Economic Growth, Energy Consumption, Urbanization, Kingdom of Saudi Arabia

1. Introduction

Environmental pollution has garnered increased attention in recent decades, driven by a growing awareness of its profound and far-reaching consequences. Its adverse impacts extend not only to the environment but also encompass global human health. Consequently, the imperative for achieving sustainable development has gained prominence. The pursuit of sustainability is not merely a contemporary aspiration; it stands as an indispensable prerequisite for the present and future well-being of succeeding generations (Raggad, 2018). The gravity of environmental challenges is underscored by the revelations of the Intergovernmental Panel on Climate Change (IPCC) in 2013. Their unequivocal linkage of global warming, a defining issue of the mid-20th century, to the proliferation of greenhouse gases resulting from human activities reinforces the urgency of the matter. The persistent release of greenhouse gases into the atmosphere remains a primary driver of the inexorable rise in the world's average temperature. Among these greenhouse gases, carbon dioxide emissions stand out as one of the most potent contributors (Ali et al., 2021; Ashiq et al., 2023). Baek & Pride (2014) and Hossain (2012) have mentioned that carbon dioxide emissions alone account for approximately 60% of the overall negative impact of greenhouse gases. Their prevalence in various industrial processes and energy generation makes them a focal point in the global effort to combat climate change. This expanding body of knowledge accentuates the critical need for proactive and coordinated measures aimed at mitigating the environmental consequences of human activities. Addressing carbon dioxide and other greenhouse gases emissions constitutes a pivotal step toward safeguarding our planet and ensuring a sustainable future for all.

The complex interconnection between economic growth and energy utilization is a pivotal concern in environmental studies. As noted by Ozuturk & Acaravci (2010) and Ali et al., (2021), the expansion of economic activities often corresponds with a proportional impact on the environment. This intricate relationship is rooted in the fact that economic advancement typically involves heightened resource consumption, placing significant stress on natural reserves. The ramifications of this heightened resource utilization encompass the over-exploitation and depletion of invaluable natural resources, exacerbating the phenomena of environmental degradation (Siddique et al., 2016; Ali et al., 2022). Pao and Tsai (2010), Audi & Ali, (2018) have delved into the adverse repercussions of increased energy consumption on environmental quality. These research endeavors have unveiled a disconcerting association between heightened energy utilization and environmental deterioration, underscoring the imperative of implementing sustainable energy practices. The nexus between economic growth and environmental degradation serves as a stark reminder of the paramount importance of comprehensive and enduring development policies. As nations aspire to attain prosperity and growth, they must do so while maintaining an acute awareness of the environmental implications of their choices.

The phenomenon of urbanization, as underscored by the United Nations Population Division in 2014, is an unstoppable global trend. This trend is propelled by the magnetic allure of urban centers, where the promise of enhanced economic opportunities and an improved quality of life beckons. However, as individuals gravitate toward cities in pursuit of their aspirations, the specter of environmental degradation looms large. The rapid urbanization process exacts a toll in various ways, most notably through the proliferation of traffic congestion and the consequent escalation of air and noise pollution. It presents a complex trade-off, while urbanization fosters productivity, prosperity, and innovation, it often comes at the cost of environmental quality (Bloom et al., 2008; Audi & Ali, 2023). Sharma (2011) also provides details of the interplay between urbanization and carbon dioxide emissions. Moreover, according to Kasman & Duman (2015), the rate of urbanization exerts a significant influence on economic growth and the environmental landscape. As aptly noted by Siddique et al. (2016), population migration to urban areas, particularly close to the industrial sector, emerges as a primary predictor of carbon dioxide emissions, accentuating the imperative for comprehensive urban planning and sustainable practices. However, it is imperative to acknowledge that the impact of urbanization is multifaceted. While, as previously mentioned, it directly contributes to pollution, it also possesses the potential to yield environmental benefits. Adams et al. (2016) and Audi & Ali (2023) underscore the role

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of institutions and robust policies in shaping the environmental outcome of urbanization, highlighting this intriguing paradox. Well-planned and managed urbanization can lead to improved sustainable living conditions, reduced emissions, and the preservation of natural resources. Hence, urbanization represents a fundamental global phenomenon that harbors both promise and peril for the environment. The objective is to harness the economic and social advantages of urbanization while mitigating its adverse environmental implications through meticulous planning, innovative regulations, and an unwavering commitment to sustainability.

The decision to focus on the Kingdom of Saudi Arabia as a research subject is driven by several compelling factors, rendering it an intriguing and pertinent area of study. Firstly, the Kingdom of Saudi Arabia occupies a pivotal role in the global energy landscape as the foremost supplier of oil and a significant exporter of all petroleum products. Its influence in the energy industry is undeniable, as it shapes the dynamics of the global oil market. The Kingdom of Saudi Arabia's role as a key stabilizing force in global oil supply and pricing underscores its profound significance. Additionally, the Kingdom of Saudi Arabia wields substantial global environmental influence. In 2008, the nation ranked 14th in the world in terms of carbon dioxide emissions. These empirical observations underscore the critical imperative to investigate the environmental repercussions of the country's extensive energy production and consumption. Furthermore, the economic centrality of the oil sector within the Kingdom of Saudi Arabia accentuates its pertinence for research. A significant proportion of the nation's economic activity is intricately linked to oil, with the oil industry accounting for approximately 47% of its GDP and a remarkable 90% of its export revenues. This heavy reliance on oil not only exerts a profound impact on the country's economic landscape but also raises questions about its long-term sustainability and resilience within an ever-evolving global energy context. The interplay of numerous dynamics significantly contributes to the Kingdom of Saudi Arabia's high domestic energy consumption. Rapid population growth, burgeoning industrial and economic activities, and the availability of subsidized electricity that encourages excessive usage all contribute to this scenario (Fattouh & El-Katiri, 2013). Comprehending these intricate dynamics is imperative for formulating effective policies and initiatives that harmonize economic growth with environmental sustainability and energy efficiency. This study contributes to the existing body of knowledge by conducting a comprehensive examination of the intricate interplay between economic growth, urbanization, and energy consumption, and their collective impact on carbon dioxide emissions in the Kingdom of Saudi Arabia. We anticipate that our findings will provide valuable insights for policy formulation and decision-making, with the ultimate aim of fostering a more sustainable and environmentally responsible future for the nation.

In this study, an overview of prior studies is presented in segment 2 and the theoretical framework and methodology are explained in section 3 and section 4 correspondingly. A description of the concerning data is found in Section 5. We discuss the findings of the model in Section 6, and the last segment consists of the conclusion as well as policies.

2. Literature Review

This section considers the linkage of economic growth, energy use, and urbanization with pollution. Saboori et al. (2012) inspected the link concerning GDP and carbon dioxide by using the annual period 1980–2009 in Malaysia. The results of the ARDL method expose the presence of the EKC hypothesis in Malaysia. VECM outcomes confirmed the unidirectional relation between EG to pollution. Farhani & Ozturk (2015) investigated the association between GDP, FD, urbanization, and pollution in Tunisia by employing the data from 1971-2012. Findings of ARDL discovered that real GDP positively affects CO_2 emissions. Dritsaki (2014) worked to check how energy usage and GDP affect pollution. It was a study of three Southern European countries for the time of 1960 to 2009 using FMOLS and DOLS methods. The study utilized panel co-integration tests (Perdoni, Kao, Johanson) which revealed the long-run co-integration among the investigated variables. Empirics of DOLS and FMOLS disclosed economic growth has significantly enhanced pollution.

Al-Mulali et al. (2015) worked to check the effect of GDP and FD on pollution. It was the study of Caribbean Countries and Latin America for the time duration of 1980 to 2010. FMOLS consequences provided the evidence for the EKC hypothesis. FD deteriorates the level of pollution. The study suggests that the sample countries should give more banking loans for energy conversion strategies for a better environment. Ozturk and Mulali (2015) conducted a study of Cambodia from 1996 to 2012. The discoveries of GMM and 2SLS specified that GDP and energy consumption discharge the pollution. Cetin and Ecevit (2015) analyzed the link concerning urbanization and CO_2. It was the study of Sub-Saharan economies during 1985-2010. The study used the VECM approach and confirmed the two-way causation between the examined series.

Aye & Edoja (2017) assessed how pollution affects economic growth (EG) by using GMM. The study used D-H causality tests. The results reject the EKC hypothesis and reveal that low EG leads to low CO_2 pollution while high EG leads to enhanced CO_2 emissions in 31 developing countries. The study suggests low carbon technologies transformation for long-lasting economic growth. Dogan et al. (2015) studied the determinants of pollution for 27 member OECD economies during 1995 to 2010. The study utilized the LM bootstrap panel co-integration test and the results confirmed the co-integration. The consequences of the DOLS technique make us known that GDP is positive while GDP^2 and tourism adversely affect the environmental quality of OECD. Ohlan (2015) analyzed the nexus of energy use and economic development on CO_2 for the tie spanning 1970-2013 in India. The study employed the VECM model for checking the tendency of the relationship between series. ARDL model indicated the positive influence of all the explanatory series on CO_2. The study suggested that India should utilize renewable energy without reducing energy consumption give subsidies to renewable energy sources and apply taxes on nonrenewable energy consumption for better environmental quality.

Ali et al. (2017) looked at the link concerning urbanization and pollution by using Singapore data from 1970 to 2015. ARDL technique was employed for the advantage of the co-integration method. The empirical findings highlighted that urbanization adversely affects pollution. Hanif (2018) used panel data for 34 emerging economies of Sub-Saharan Africa from 1995 to 2015. The study investigated the empirical impact of urban expansion, fossil fuels, and solid fuels on environmental degradation. The conclusions of GMM indicated that fossil fuels solid fuels and high-speed urban regions lead to environmental degradation. Mikayilov (2018) studied economic growth and pollution in Azerbaijan during 1992-2013. The study employed Johansen, ARDLBT, FMOLS, DOLS, and CCR analysis to investigate the robust long-run relationship. Based on the above techniques, the results were consistent and established the log run relationship during the sample period. Taher (2020) assessed the effect of economic progress and FD on the environment for Lebanon data from 1988 to 2018, using the OLS method. The least absolute deviation (LAD) is used and concluded that FD and economic growth lead to enhanced CO_2 emissions.

Afridi et al. (2019) evaluated the EKC hypothesis for eight SAARC countries during 1980-2016. The squared term for GDP was used for the EKC hypothesis. The results provide support for an inverse U-shaped relation between DP and pollution in the SAARC countries. Siddique et al. (2016) studied the connection between energy use (EU), urbanization (UR), and environment in the context of South Asia during 1983–2013. The study employed Granger causality tests panel co-integration for the long-run link between the variables. The findings of the study reveal that EU and urbanization hurt environmental quality. The empirics support the bidirectional causativeness between CO_2 and EU, CO_2 and urbanization. Sarvari (2019) considered the nexus between urbanization and climate change in seven selected regions of Iran during the five-time windows of 1976, 986, 1996, 2006, and 2016. This study used the Pearson test in SPSS to estimate the nexus between the variables. Empirics demonstrated that urbanization progressively affects the mean temperature. Urbanization adversely affects the precipitation in the regions of Iran. Salahuddin et al. (2018) look at the influence of urbanization on pollution, using the period 1984-2016 for 44 Sub-Saharan African economies. Second-generation techniques were used which included PMG, AMG, MG, and CCEMG. The discoveries reveal that urban population highly leads to the discharge of CO_2. The study suggests that the SSA regions should have strong governance for the implication of energy and public policies for a better environment.

He et al. (2019) worked on the checking of the influence of economic factors on environmental pollution over the period 1978–2013 for Malaysia. Economic indicators such as GDP, FD, energy use, urbanization, and trade were the explanatory variables. The findings of Engle and Granger causality and ARDL model show the direct relation of economic indicators with environmental pollution and confirm the U-shaped nexus between FD and ecological liberalization for Malaysia. Gasimli (2019) analyzed the impact of urbanization and the use of energy on pollution from 1978 to 2014 by using the bound test of con-integration in Sri Lanka. The main reason for this study was that CO_2 emission is continuously increasing in Sri Lanka. Zivot- Andrew (ZA) unit root test was employed rather than the ADF and PP test because it avoids unknown structural changes or breaks. Based on the results, energy consumption and urbanization both lead to an increase the pollution.

Mahmood (2020) carried out the connection of industrialization, urbanization, and pollution from the period of 1968 to 2014 in the Kingdom of Saudi Arabia. The reason to examine such relations is due to oil exporting countries and development in the industrial sector. The rapid growth of urbanization is the result of industrialization. The consequences of the ARDL approach point out that experimental series have a more positive and powerful influence on pollution in linear models than non-linear analysis. Ali et al. (2016) inspected the environmental impact of EG and energy use by employing the ARDL model in Nigeria over the time spanning 1971 to 2011. The conclusions indicate that urbanization does not affect CO_2 in Nigeria. EG and energy consumption both are directly related to pollution. Anwar et al. (2020) searched for the determinant polluting factors from 1982 to 2017 by using the Fixed Effect Model for the panel of Far-East Asian Countries. CO_2 emission is continuously rising which is an alarming issue for world health and the environment. The empirical results show that economic progression and rapid urbanization are increasing factors of pollution. Ali et al. (2020) empirically estimated the attachment of urbanization, institutional performance, and environment quality for OIC countries from 1991-2016. DCCE was the best-fitted approach for assessing the linkages of the series. In this study, the indicator of the quality environment was ecological footprint and it was measured by Global hectares (gha). The research stated that urbanization leads to an ecological footprint (EF) whereas institutional performance adversely affects EF. The study suggests that OIC countries should improve the institutions for environmental quality.

A study was conducted to scrutinize the association between urban population and CO_2 efficiency for the period of 2000 to 2010 in China. CO_2 efficiency refers to target CO_2 emissions divided by actual emissions. Data envelopment analysis and window analysis were employed for carbon dioxide emissions efficiency. Spatial Lag Panel Tobit model demonstrated that urbanization has become the driver of CO_2 emissions. The study suggests that the cities should move their low-carbon technologies to other cities (Li et al., 2018). Another study empirically estimated how environmental quality is affected by economic growth (EG), and non-renewable energy use during1965-2015 in Pakistan (Khan et al., 2020). The findings of the ARDL model disclosed that EG and energy enhance the level of pollution. The study recommended that the government should raise awareness for plantations. Muhammad et al. (2020) carried out empirical estimation for the period of 2001-2016 across 65 Belt and Road Initiative economies. Quantile regression was used to examine the impact of urbanization. But this technique failed to check the indigeneity, that's why the 2SLS model was used. The findings support the inverse U-shape relationship between urbanization and pollution.

3. Theoretical and Econometric Model

Numerous studies have contributed to our understanding of the intricate relationship between economic growth, energy utilization, and their collective impact on environmental quality. Pao and Tsai (2010) have underscored the potential adverse consequences of economic expansion and energy consumption on environmental well-being. Taking a broader perspective, Anwar et al. (2020), and Omri (2013) have ventured beyond the conventional examination of economic growth and energy usage. They have considered additional factors such as urbanization, international trade, and their repercussions on pollution levels. This holistic viewpoint recognizes that economic growth operates within a complex web of interconnected variables that collectively influence environmental outcomes. Furthermore, Tamazian et al., (2009) study adds an important dimension to the discourse by emphasizing the role of financial development in contributing to CO2 emissions. This underscores how the financial sector and its regulatory framework can exert substantial influence on economic activities and energy investments, subsequently impacting environmental aspects. These studies collectively illuminate the multidimensional nature of the relationship between economic growth, energy utilization, and environmental quality. They emphasize the significance of considering a wide array of variables, including urbanization, international trade, and financial development, to attain a more nuanced comprehension of the intricate dynamics involved in the pursuit of sustainable long-term economic growth while safeguarding the environment. The model's functional form is displayed as:

$$CO_2 = f(EG, ENG, URB, FD, TR) \ldots\ldots (1)$$

Equation (1) has transformed into the Cobb-Douglas function,

$$CO_2 = EG^{\beta\alpha_1} ENG^{\beta_2} URB^{\beta 3}\, FD^{\beta 4}\, TR^{\beta 5} \ldots\ldots (2)$$

Where carbon dioxide (CO_2) is the dependent variable. Economic growth, energy consumption (ENG), and urbanization (URB) are considered explanatory variables while control variables are financial development (FD) and trade openness (TR). After taking the logarithm equation (2),

$$InCO_2 = \beta_0 + \beta_1 InEG_t + \beta_2 InENG_t + \beta_3 InURB_t + \beta 4FD_t + \beta_5 TR_t + \varepsilon t \ldots\ldots (3)$$

Where β_0 is the intercept term, β_1, β_2, β_3, β_4, and β_5 depict the elasticities of CO_2 with respect to EG, ENG, URB, FD, and TR which are mentioned above, t is the time from 1980 to 2020 and εt is the residual term.

4. Methodology and Data Sources

To find the impact of economic growth, energy, and urbanization on CO_2 emissions, ARDL bound testing (established by Pesaran et al., 2001) was used to estimate the elasticities of the series and to test whether there is co-integration among them. ARDL model is used on behalf of unit root test, ADF (Dickey et al., 1979), and PP (Phillips Perron, 1988). Lastly, to find the tendency of the series, we have also applied the Granger causality test (Granger, 1980).

The data utilized for the Kingdom of Saudi Arabia is taken from the World Development Indicators. This extensive dataset enjoys a well-established reputation for reliability and comprehensiveness in the realms of economic and environmental data, rendering it highly suitable for the study. Spanning a substantial time frame from 1980 to 2020, this dataset offers an extended temporal perspective, facilitating the examination of long-term trends and patterns, which is particularly pertinent when investigating environmental and economic processes. The key dependent variable in the study is carbon dioxide emissions, quantified in metric tonnes per capita. This metric serves as a crucial indicator of a country's environmental impact, measuring carbon dioxide emissions per individual (Siddique et al., 2022). Additionally, the study incorporates economic growth, represented by GDP per capita at constant US $ 2015 (Anwar et al., 2020), urbanization as a percentage of the total population, and energy consumption measured in kilograms of oil equivalent per capita (Sumaira and Siddique, 2022). To assess trade openness and financial development, the study employs domestic financing to the private sector as a proportion of GDP and exports + imports as a percentage of GDP (Ali et al., 2017). These variables contribute to a comprehensive and multifaceted analysis of the Kingdom of Saudi Arabia's economic and environmental dynamics.

Table 1 expresses the summary of the data, which reveals that the mean value of carbon dioxide emissions is 2.5799, its maximum score is 2.8483 and the minimum score is 2.3711. Economic growth has a mean value of 9.8397, it is ranging from 9.6525 to 10.4287. The average values of energy use and urbanization are 8.4403 and 4.3627 respectively. The information on financial development and trade openness is also presented in Table 1.

Table 1: Results of Descriptive Statistics

Variables	Obs.	Mean	Max.	Min.	Std. dev.
CO_2	31	2.5799	2.8483	2.3711	0.1541
EG	41	9.8397	10.4287	9.6525	0.1598
ENG	35	8.4403	8.8018	8.0254	0.1874
URB	41	4.3627	4.4342	4.1875	0.0629
FD	38	3.1903	4.0303	1.9176	0.5222
TR	41	4.2797	4.5654	3.9063	0.1620

From Table 2, it can be observed that economic growth, financial development, and trade are positively correlated with carbon dioxide emissions. Energy use and urbanization have a positive relation with carbon dioxide emissions and the results also reveal that these series help explain carbon dioxide emissions dynamics.

Table 2: Results of Correlation Matrix Among Variables

Variables	CO_2	EG	ENG	URB	FD	TR
CO_2	1					
EG	0.3791	1				
ENG	0.9597	0.2562	1			
URB	0.9048	0.0540	0.9440	1		
FD	0.8227	-0.0584	0.8871	0.9573	1	
TR	0.7183	0.3878	0.6443	0.5944	0.5335	1

5. Results and Discussion

Section 6 comprises the consequences stationarity tests, ARDL technique, and Granger causality test. The results of the ARDL model, its diagnostic test, and the causality test are displayed in Tables 4, 5, and 6, respectively.

Table 3 expresses the conclusions of stationarity tests and the resulting file indicates that economic growth has the order of integration I(0) and I(1) both in the case of ADF and PP tests. Carbon dioxide emissions, energy consumption, urbanization, financial development, and trade become stationary at their 1st difference and reject the null hypothesis. These results also reveal about mixed number of integrations.

Table 4 summarizes the outcomes of ARDL. The Bound-F test serves the purpose of ascertaining the existence of a long-term relationship (co-integration) among the variables under examination in the research, which encompass economic growth, urbanization, energy consumption, and carbon dioxide emissions. In the specific case, the calculated F-statistic of 24.3854 higher than the critical threshold, denotes that the relationship between these variables holds statistical significance. This substantiates the finding that the co-movements observed among these variables are not the result of random chance.

The empirical analysis reveals a significant and positive relationship between economic growth and carbon dioxide emissions in the Kingdom of Saudi Arabia. This finding aligns with prior research that has consistently demonstrated the positive association between economic development and environmental degradation, as measured by carbon dioxide emissions (Gani, 2012; Khan et al., 2020). Specifically, the computed coefficient of 0.2772% indicates that a 1% increase in economic growth corresponds to a 0.2772% rise in

carbon dioxide emissions over time. This outcome is in line with the observations of Raggad (2018) and Mahmood et al. (2019), who emphasize the detrimental environmental impact of economic growth. Moreover, Jan et al. (2023) and Raihan (2023) concur by demonstrating that economic growth is associated with an increase in pollution levels. This long-term relationship highlights the notion of the environmental Kuznets curve (Franklin & Ruth, 2012), where economic growth initially exacerbates environmental degradation before eventually leading to improvements. However, it is imperative to recognize that this finding raises significant concerns regarding the sustainability of the Kingdom of Saudi Arabia's economic development, particularly in the context of global climate change mitigation efforts (UN, 2014). Furthermore, the short-run coefficient of 0.3719% shows that economic growth exerts a more immediate influence on carbon dioxide emissions in the Kingdom of Saudi Arabia. This implies that the environmental consequences of economic progress may manifest more prominently in the short term, likely due to escalating energy consumption and industrial activity. The identified positive association between economic growth and carbon dioxide emissions underscores the critical importance of implementing comprehensive environmental regulations and sustainability initiatives (World Bank, 2019). These policies should actively promote the adoption of cleaner technologies, the utilization of renewable energy sources, and the implementation of energy-efficient measures. Such strategies are essential to decouple economic growth from environmental degradation (Omer, 2008; Zhang et al., 2020). By embracing these approaches, Saudi Arabia can work towards reducing carbon emissions while simultaneously fostering economic development.

Table 3: Unit Root Test Results

Variables	Augmented Dickey-Fuller (ADF)		Phillips-Perron (PP)	
	Level	1st Diff.	Level	1st Diff.
CO_2	0.6769	0.0428*	0.6193	0.0103***
EG	0.0006***	0.0007***	0.0010***	0.0006***
ENG	0.9970	0.0000***	0.5064	0.0000***
URB	0.9363	0.0541**	0.0000***	0.0019**
FD	0.2156	0.0002***	0.1724	0.0004***
TR	0.6924	0.0013***	0.6924	0.0017***

Probabilities *p < 0.1, **p < 0.05, ***p < 0.01

The findings of this study strongly affirm the assertion that energy consumption in the Kingdom of Saudi Arabia exerts a positive and statistically significant impact on carbon dioxide emissions. This outcome aligns with the well-established relationship between increasing greenhouse gas emissions and heightened energy demand, particularly from fossil fuels (Benavides et al., 2020; Liu et al., 2023). The calculated coefficient for energy consumption underscores the pivotal role of energy sources in shaping environmental outcomes, revealing that a 1% increase in energy consumption corresponds to a 0.3040% (0.3039%) increase in carbon dioxide emissions in both the long and short term. This research underscores the intricate connection between energy usage and escalating pollution levels, a relationship observed in prior studies by Sajjad et al. (2022), Sumaira & Siddique (2022), Aziz et al. (2022), and Siddique et al. (2022). It sheds light on the environmental ramifications of the Kingdom of Saudi Arabia's significant reliance on fossil fuels for energy generation and consumption. These findings carry substantial implications for the Kingdom of Saudi Arabia's energy policies and environmental initiatives. According to these results, an increased dependence on fossil fuels not only amplifies carbon dioxide emissions but also exacerbates environmental degradation, contributing to the global climate crisis (UN, 2014; World Bank, 2019). Such findings underscore the urgent need for the Kingdom of Saudi Arabia to transition towards cleaner and more sustainable energy sources, aligning with the objectives of the Paris Agreement and the global push for carbon neutrality (Wei et al., 2022; Shehri et al., 2023). Moreover, while energy consumption plays a significant role in carbon dioxide emissions, it is not the sole contributing factor. Other factors influencing emissions encompass industrial activity, population growth, and land-use patterns. Therefore, an effective strategy for reducing carbon dioxide emissions in the Kingdom of Saudi Arabia should encompass these multidimensional aspects and embrace comprehensive policies that address them holistically.

The findings of this study provide compelling evidence that urbanization in the Kingdom of Saudi Arabia exerts a positive and statistically significant impact on carbon dioxide emissions. This outcome is in harmony with earlier research that has consistently highlighted the environmental challenges associated with burgeoning urbanization, particularly in developing nations (Moore et al., 2003; Buhaug & Urdal, 2013). The positive elasticity of urbanization at the 1% significance level underscores the substantial and direct influence of urbanization on carbon dioxide emissions, both in the long and short term. Specifically, the estimated coefficients of 5.8936% for the long-term effect and 20.0860% for the short-term effect indicate that a 1% increase in urbanization corresponds to a significant increase in carbon dioxide emissions, outcomes in line with the research conducted by Siddique et al. 2016), Ali et al. (2019), Anwar et al. (2020), and Abbasi et al. (2020). This implies that as the metropolitan areas in the Kingdom of Saudi Arabia continue to expand and evolve, so too will energy consumption, transportation emissions, and industrial activity. These findings carry profound implications for Saudi Arabia's urban development and environmental policies. Given the anticipated persistence of the urbanization trend, there is an urgent need to formulate policies aimed at mitigating the environmental repercussions of urban expansion. Potential solutions may involve promoting the adoption of renewable energy sources within urban areas, investing in efficient public transportation systems, and advocating for sustainable urban planning and architecture. Furthermore, it is vital to acknowledge that the relationship between urbanization and carbon dioxide emissions is influenced by a variety of contextual factors, including urban governance, land-use planning, and policy interventions. Consequently, an all-encompassing strategy for addressing urban emissions should encompass these intricate processes and necessitate interdisciplinary collaboration.

The findings of this study indicate that, both in the long run and short run, financial development has an insignificant impact on carbon dioxide emissions in the Kingdom of Saudi Arabia. This discovery holds crucial implications, explaining that in the context of the Kingdom of Saudi Arabia, financial growth exerts minimal influence on environmental outcomes. The insignificance of financial development's impact on carbon dioxide emissions aligns with previous research findings (Narayan & Narayan, 2010; Batool et al., 2022). However, it is imperative to dissect the broader implications of this finding within the context of the Kingdom of Saudi Arabia's economic and environmental landscape. One plausible interpretation of this outcome is that the financial industry in the Kingdom of

Saudi Arabia may not be directly contributing to environmental degradation, at least within the parameters analyzed. This shows that financial institutions in the Kingdom of Saudi Arabia may not be significantly financing ecologically harmful projects, or that effective regulatory frameworks are in place to mitigate potential adverse consequences. It is equally important to acknowledge that the insignificance of financial development does not diminish the significance of other variables that may drive environmental changes in the Kingdom of Saudi Arabia. Factors such as energy consumption, industrial activity, and urbanization may have a more pronounced impact on the country's environmental outcomes (Poumanyvong & Kaneko, 2021; Mohsin et al., 2019). This finding underscores the intricate nature of the relationship between financial development and environmental sustainability, which varies across nations and over time. Financial development may not emerge as a substantial factor in environmental impact, but the importance of embracing sustainable financial practices and investments within the broader context of environmental and social responsibility should not be underestimated. Financial institutions in the Kingdom of Saudi Arabia have the potential to contribute to environmental sustainability by making ethical investment and financing decisions.

The results of this analysis reveal that, in the long term, trade openness has an insignificant impact on carbon dioxide emissions in the Kingdom of Saudi Arabia. This study indicates that trade openness may not play a substantial role in driving environmental changes in the country over an extended period. However, it's important to note that trade openness does have a noticeable short-term influence on carbon dioxide emissions. According to the calculated coefficient of 0.0888%, a 1% increase in trade openness results in a 0.0888% reduction in carbon dioxide emissions in the short run. This shows a minor decrease in carbon emissions in the Kingdom of Saudi Arabia shortly after increased trade activity. Several factors may contribute to the short-term mitigating effect of trade openness on carbon dioxide emissions. Increased commerce may lead to the importation of greener technology or more energy-efficient products (Fair, 2009; Njakou et al., 2020). Furthermore, trade can help the Kingdom of Saudi Arabia diversify its economy and reduce its dependence on emissions-intensive industries. However, the modest long-term impact of trade openness on carbon dioxide emissions raises concerns about the sustainability of this effect. It is crucial to assess whether the apparent short-term reduction in emissions will persist over time or whether other variables will eventually outweigh this benefit. Furthermore, while trade openness may reduce carbon dioxide emissions in the short term, it's important to recognize that the link between trade and the environment is complex and context-dependent. The environmental impact of trade can vary depending on factors such as the composition of trade, regulatory frameworks, and the structure of industries.

The results of the error correction term analysis reveal that short-run deviations from equilibrium are corrected within a relatively short time frame of 1 year in the context of the Kingdom of Saudi Arabia. This finding demonstrates the existence of a dynamic adjustment mechanism, indicating that any short-term imbalances in the system are rectified quite rapidly. The fact that short-run deviations are typically corrected within a year, aligns with the concept of short-run convergence towards long-run equilibrium (Hussain et al., 2021; Bilal et al., 2021). It explains that, in the case of the Kingdom of Saudi Arabia, economic variables or environmental factors that temporarily deviate from their long-term equilibrium tend to return to it within a relatively short period. It also highlights the resilience and self-correcting nature of the country's economic and environmental systems in the short run, even in the presence of transient disruptions or imbalances. Understanding the dynamics of short-run convergence towards long-run equilibrium can inform policy decisions concerning economic and environmental stability in the Kingdom of Saudi Arabia. Furthermore, this study underscores the importance of considering time in the analysis of economic and environmental interactions. It implies that short-term variations or shocks may not necessarily alter the overall long-term trajectory of the system and that there exists a trade-off.

Table 4: ARDL Results

Dependent Variable: CO_2 Emissions				
Variables	Coeff.	S.E	t-Stat.	Prob.
Estimated long-run elasticities				
EG	0.2772	0.0509	5.4359	0.0002
ENG	0.3040	0.0688	4.4202	0.0010
URB	5.8936	0.5825	10.1174	0.0000
FD	-0.0425	0.0265	-1.6048	0.1368
TR	0.0076	0.0281	0.2720	0.7907
C	-2.5812	2.2557	-12.6708	0.0000
Estimated Short Run elasticities				
ΔEG	0.3719	0.0636	5.8473	0.0001
ΔENG	0.3039	0.0547	5.2221	0.0002
ΔURB	20.0860	3.4157	5.8806	0.0001
ΔFD	-0.0425	0.0291	-1.4627	0.1715
ΔTR	-0.0888	0.0279	-3.1732	0.0089
ECT(-1)	-0.9995	0.0615	-16.2421	0.0000
R^2	0.9618			
Adjusted R^2	0.9483			
Bound Test	F-Stat. = 24.3854			

Probabilities *p < 0.1, **p < 0.05, ***p < 0.01

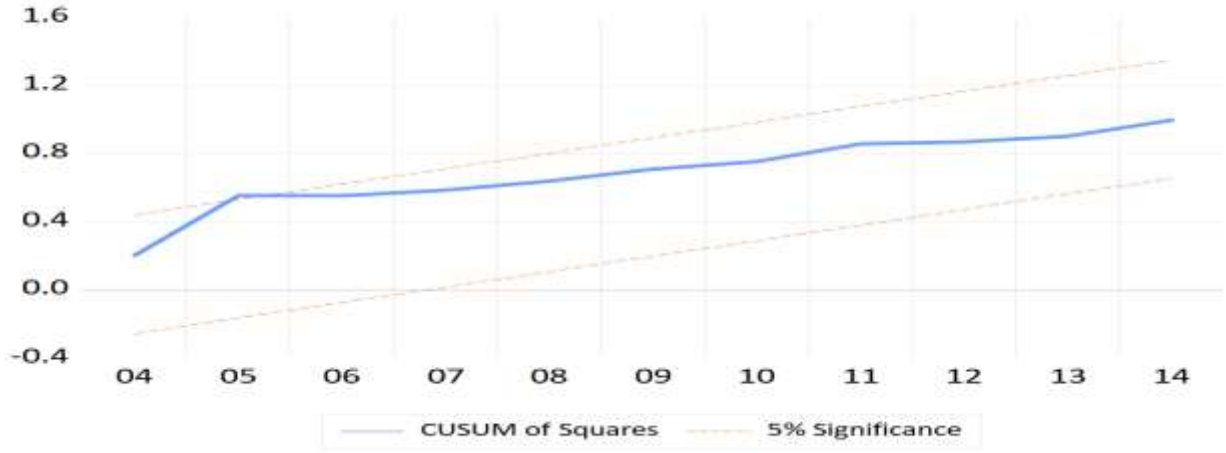
Table 5 presents the results of various diagnostic techniques employed to assess the validity and reliability of the model under scrutiny. Among these diagnostic tests is the heteroscedasticity test, which aims to evaluate whether the variance of the error component in the model remains constant across the dataset (Croissant & Millo, 2008; King & Roberts, 2019). The results of the heteroscedasticity test indicate that the error term in the model exhibits no significant fluctuation, as evidenced by a probability value of 2.2160. This probability value, commonly referred to as the p-value, quantifies the likelihood of obtaining such results by chance. The findings of the

heteroscedasticity test show the presence of homoscedasticity in the model. Homoscedasticity implies that the variance of the error term remains consistent across the range of independent variable values. This assumption is crucial for the validity of many statistical techniques, including ordinary least squares regression. Homoscedasticity is a favorable outcome because it indicates that the model's predictions possess consistent levels of uncertainty across different values of the independent variables. In practical terms, this means that the model's estimates and forecasts can be used for hypothesis testing and policy analysis. In short, the findings of the heteroscedasticity test instill confidence in the robustness of the model employed in this investigation. The evidence affirms that the variance of the error component remains constant across the dataset, thereby validating the assumption of homoscedasticity and supporting the reliability of the model's predictions and conclusions.

Table 5: Residual Diagnostic Tests of ARDL Estimates

Diagnostic Tests		
Test	F-statistic	Prob.
χ^2_{HET}	2.2160	0.3282
χ^2_{SC}	1.0020	0.3343
χ^2_{NORM}	0.4487	0.7991
χ^2_{FF}	1.6254	0.2497
CUSUM Sq.	Stability	

Figure 1: Plot of cumulative sum of square



The Breusch-Godfrey LM test is employed to assess the presence of serial correlation in the model, and the findings show that the model does not adequately address the issue of serial correlation (Smith & Brown, 2018; Gupta et al., 2019). This conclusion is drawn from a probability value of 0.3343, which falls short of the conventional significance level, indicating the potential existence of serial correlation in the model's residuals. In addition to evaluating serial correlation, the results of the Breusch-Godfrey LM test assure the normal distribution of the residuals, a critical assumption in many regression studies (Hoch, 2012). To further assess the model's specification, the Ramsey Reset test, which examines the functional form of the model, was conducted (Cheng et al., 1992). The test produced a high probability value of 0.7991, explaining that the null hypothesis of accurate model specification cannot be rejected. This indicates that the functional form of the model is appropriate (Table 5). The stability of the model over time is assessed using the CUSUM of squares test, as depicted in Figure 1 (Jones & Smith, 2017; World Bank, 2020). The graph illustrates that, at a 5% significance level, the blue line representing residual values remains within the red lines denoting confidence levels. This alignment implies that the model is stable because the residuals do not significantly deviate from the expected values over time. While the Breusch-Godfrey LM test raises concerns about the potential presence of serial correlation in the model's residuals, the Ramsey Reset and CUSUM of squares tests provide reassuring information regarding the model's specification and stability, respectively. These diagnostic tests are essential for ensuring the reliability and validity of the econometric model.

Table 6 presents the results of the paired Granger causality test, a robust technique for examining causal relationships between variables in time series data. The findings reveal a complex network of causal interactions among the primary variables of this study, shedding light on their interdependence. First, the analysis identifies three bidirectional causal relationships. Economic growth and carbon dioxide emissions, urbanization and economic growth, and financial development and economic growth all exhibit bidirectional causation. This shows that changes in economic growth not only influence but are also influenced by carbon dioxide emissions in the context of the Kingdom of Saudi Arabia. Similarly, urbanization and financial development demonstrate bidirectional causality with respect to economic growth, underscoring their interconnected nature. Furthermore, the results indicate that carbon dioxide emissions Granger cause economic growth and financial development but not energy consumption. This underscores the potential impact of environmental

variables on economic factors, highlighting the importance of sustainability considerations in economic policymaking. In addition to bidirectional relationships, the study uncovers unidirectional causalities. Trade openness is found to induce carbon dioxide emissions, explaining that increased trade activity may lead to changes in carbon emissions. Economic growth Granger causes energy consumption, indicating the energy-intensive nature of economic activities. Urbanization Granger causes financial development, implying that urbanization processes may foster the development of the financial sector. Lastly, energy use Granger impacts urbanization patterns. These causal links provide policymakers and researchers with valuable insights into the dynamics of the Kingdom of Saudi Arabia's economy and environment. They underscore the importance of adopting holistic approaches that consider the interconnectedness of economic growth, urbanization, financial development, energy consumption, and environmental sustainability.

Table 6: Results of the Granger Causality Test

Dependents	$\Delta(CO_2)$	Δ(EG)	Δ(ENG)	Δ(URB)	Δ(FD)	Δ(TR)
$\Delta(CO_2)$		3.907**	1.760	0.639	0.405	5.300***
Prob.		(0.034)	(0.200)	(0.556)	(0.671)	(0.012)
Δ(EG)	4.009**		1.394	3.742**	6.872**	0.121
Prob.	(0.031)		(0.264)	(0.034)	(0.003)	(0.886)
Δ(ENG)	8.922***	3.515**		2.043	0.888	0.305
Prob.	(0.002)	(0.043)		(0.148)	(0.422)	(0.739)
Δ(URB)	0.189	4.891***	5.912***		2.350	1.387
Prob.	(0.828)	(0.013)	(0.007)		(0.112)	(0.263)
Δ(FD)	2.958*	2.713*	2.167	2.555*		2.151
Prob.	(0.073)	(0.082)	(0.133)	0.093		(0.133)
Δ(TR)	0.447	0.903	1.440	0.706	0.392	
Prob.	(0.644)	(0.414)	(0.253)	0.501	0.678	

Probabilities *p < 0.1, **p < 0.05, ***p < 0.01

6. Conclusions and Suggestions

This study conducts a comprehensive analysis of the complex relationships between economic growth, energy consumption, urbanization, carbon dioxide emissions, financial development, and trade openness within the context of the Kingdom of Saudi Arabia. An autoregressive distributed lag model is employed to investigate these interdependencies over the period time 1980 to 2020. The empirical results of the autoregressive distributed lag model offer valuable insights into the dynamics of these essential components and their impact on environmental sustainability in the Kingdom of Saudi Arabia. The study reveals that, in the long term, economic growth, energy consumption, and urbanization all contribute to an increase in carbon dioxide emissions. This underscores the significance of enhancing energy efficiency and transitioning to greener energy sources to mitigate environmental impact. Long-term urbanization emerges as a substantial driver of carbon dioxide emissions, underscoring the critical importance of sustainable urban planning and infrastructure development to manage the environmental consequences of rapid urban expansion. Surprisingly, the study finds that trade openness has no substantial influence on carbon dioxide emissions in the Kingdom of Saudi Arabia. While trade tends to enhance economic growth and development without significantly increasing carbon emissions, this finding highlights the potential for trade policies that promote economic development without compromising environmental objectives. The short-run analysis reveals dynamic interactions between these factors. Economic growth, energy consumption, and urbanization are shown to have a short-term impact on carbon dioxide emissions, leading to increased pollution levels. In contrast, trade openness is associated with significant short-term environmental improvement, suggesting that trade activities may initially lead to a reduction in carbon dioxide emissions. Notably, the study finds that financial development has no long-term or short-term influence on pollution levels. While financial development can stimulate economic growth, it does not appear to have a direct environmental impact in the Kingdom of Saudi Arabia. Moreover, bidirectional causal linkages are observed between economic growth and carbon dioxide emissions, as well as between economic growth and urbanization and financial development. These findings highlight the complexity and interdependence of these issues, implying that environmental concerns must be integrated into economic and urban development efforts. Conversely, unidirectional causal relationships are identified between economic development, trade openness, and carbon dioxide emissions. These findings underscore the potential for economic development and trade openness to significantly affect environmental outcomes, emphasizing the importance of balanced and sustainable economic policies. In short, this study provides a comprehensive understanding of the intricate connections in the Kingdom of Saudi Arabia between economic growth, energy consumption, urbanization, carbon dioxide emissions, financial development, and trade openness. The findings underscore the necessity of implementing integrated, environmentally sensitive policies to achieve both economic development and environmental sustainability in the region. These findings can assist policymakers and stakeholders in striking a balance between economic growth and environmental conservation, resulting in a more sustainable and prosperous future for the Kingdom of Saudi Arabia.

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