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Implications of Energy Consumption by Sector on Carbon Emissions in Saudi Arabia

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ABSTRACT

The increasing global focus on sustainable development has attracted significant attention towards environmental issues. A crucial aspect of this emphasis is the aim to decrease energy consumption in order to minimize damage to the environment. However, discussions surrounding this subject have raised concerns. Sustainable development has gained considerable recognition among economists and policymakers due to its potential impact on productivity. Previous research primarily concentrated on overall energy consumption rather than analyzing specific sectors' energy usage and its effects on CO_2 emissions. Particularly, there has been a lack of extensive research on the relationship between energy usage in sectors such as agriculture and transportation, and the resulting emission of CO_2. Therefore, this study seeks to examine the impact of energy usage in Saudi Arabia's transportation, industrial, and agricultural sectors on CO_2 emissions from 1979 to 2022. To analyze this correlation, the study utilizes the Autoregressive Distributed Lag (ARDL) technique. The findings indicate that the transportation sector has a greater influence on CO_2 emissions compared to the industrial sector. Conversely, energy usage in the agricultural sector is found to contribute to a reduction in CO_2 emissions. Informed by these findings, policymakers can implement policy interventions and measures to address the negative health effects resulting from environmental degradation. By targeting sectors identified as major contributors to environmental problems, strategies can be implemented to mitigate pollution, decrease exposure to harmful substances, and promote sustainable practices.

Keywords: Energy Consumption, Saudi Economy, CO_2 Emission, Transportation Sector, Industrial Sector, Agricultural Sector
JEL Classifications: C13, C22, E21, Q40, Q50

1. INTRODUCTION

The burning of fossil fuels for energy remains the primary contributor to global greenhouse gas emissions, accounting for approximately three-quarters of the total. While renewable energy sources like solar and wind power are being increasingly utilized, the global energy mix continues to rely heavily on gas, oil, and coal. In fact, a significant majority (84%) of our energy generation is derived from fossil fuels.

Furthermore, each year, the global consumption of fossil fuels keeps to increase. Over the past decade, There has been an increase in total production from 118,315 to 141,685 TWh (terawatt-hours). This highlights the ongoing reliance on fossil fuels and the challenges faced in transitioning to more sustainable alternatives. Oil production contributes to various types of pollution, inclusive air, and water pollution. These can potentially have long-term impacts on the environment. Additionally, there is strong evidence to suggest that oil production contributes significantly to the emission of greenhouse gases. One of the primary GHGs associated with oil production is carbon dioxide (CO_2), which plays a notable part in climate change. CO_2 emissions make up a considerable proportion of GHG emissions and contribute to the overall increase in global temperatures (United States Environmental Protection Agency 1990-2022). Whereas pursuing economic growth is a vital objective for any economy, it is crucial not to overlook its environmental consequences. Balancing economic development with environmental sustainability is crucial for addressing the negative impacts of oil production and promoting a more sustainable future. Despite the challenges associated with being one of the largest oil-exporting countries, Saudi Arabia is dedicated to actively participating in towards the objectives outlined in the Paris Agreement and promoting environmental sustainability. The Vision 2030 plan, which outlines the country's planned goals for national industrial development and transformation encompass targets for mitigating soil, water, and air pollution. The aim is to create a healthier and more fulfilling life for its citizens (Mahmood et al., 2020). Saudi Arabia recognizes the importance of avoiding the "resource curse" phenomenon and strives to maintain a balance between economic growth and a sustainable environment. This task is particularly challenging considering that sectors such as transportation, industry, and agriculture contribute significantly to income generation and GDP growth. Industrialization often requires extensive use of natural resources. However, Saudi Arabia remains committed to finding innovative solutions that allow for economic growth while minimizing negative environmental impacts. This demonstrates their dedication to addressing the challenges of sustainable development in a country heavily reliant on oil exports.

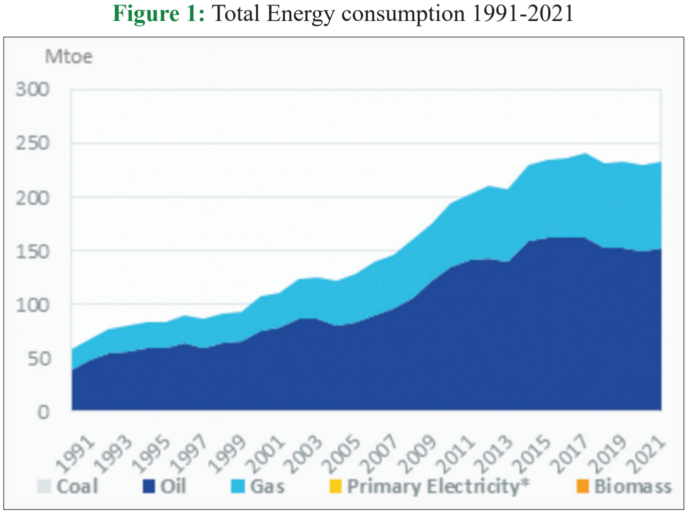
Figure 1, shows an upward trend of energy consumption in Saudi Arabia for 30 years, from 1991 to 2021, the per capita consumption is significantly high, reaching 6.6 toe in 2021. The total energy consumption has ceased its growth trend since 2015 and has gradually declined at a rate of 1.4% per year, reaching approximately 232 Mtoe in 2021.

Over the past few decades, there has been a significant and rapid growth in Saudi Arabia's CO_2 emissions (Enerdata 2022). Figure 2 illustrates the trajectory of these emissions, which make up only a small portion of the Kingdom's overall emissions. The figure demonstrates a generally upward trend, although the growth rate of emissions has varied during different periods.

2. LITERATURE REVIEW

Numerous studies in the literature have extensively examined the influence of utilization of energy and progress of the economy on

Figure 1: Total Energy consumption 1991-2021



Source: Enerdata 2022

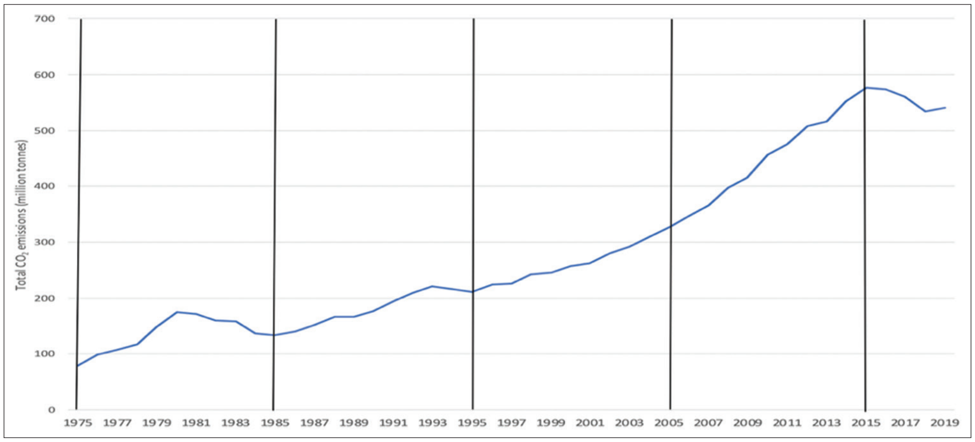
CO_2 emissions. Khan et al. argue that both economic expansion and energy use have detrimental effects on the environment. Radmehr et al. (2021). Karaaslan and Camkaya investigate the causal relationships between utilization of energy, economic development, and CO_2 emissions in their respective studies.

In the study conducted by Muhammad (2019), the Generalized Method of Moments (GMM) technique is employed to explore potential connections between progress of the economy, utilization of energy, and CO_2 emissions in the European Union (EU) region from 1995 to 2014. The findings reveal bidirectional associations between expansion of the economy and CO_2 emissions, as well as between the utilization of renewable energy and expansion of the economy. Applying the same methodology and analyzing data from 2001 to 2017, Muhammad made the discovery that utilization of energy and expansion of the economy have negative implications for the environment in developed nations as well as in the Middle East and North Africa (MENA) region. The study revealed that utilization of energy contributes to environmental degradation, while economic development holds the potential to alleviate environmental damage in developing nations. In their study, Ardakani and Seyedaliakbar (2019) delved into the interconnections between energy utilization, expansion of the economy, and CO_2 emissions within the MENA region from 1995 to 2014. Their findings unveiled the presence of the environmental Kuznets curve (EKC) phenomenon in Oman, Qatar, and Saudi Arabia. This signifies that as GDP levels rise, it can potentially serve as a safeguard against environmental degradation in the later stages. This conclusion is substantiated by prior research conducted by Ozgur et al. (2022). Li and Haneklaus (2022). Furthermore, they observed a U-shaped relationship between per capita gross domestic product (GDP) and CO_2 emissions in Algeria and Bahrain, indicating that continued GDP growth exacerbates environmental degradation in the later stages.

In their respective studies, Ozgur et al. (2022), Karaaslan and Camkaya (2022), as well as Cai et al. utilized the (ARDL) method. Cai et al., in particular, focused on examining the influence of economic development and clean energy utilization on CO_2 emissions in G7 countries. The findings of the study were diverse, indicating a unidirectional connection between utilization of energy and expansion of the economy in Canada, Germany, and the US. Additionally, a unidirectional relationship between CO_2 emissions and utilization of energy was observed in Germany, while a unidirectional association between clean utilization of energy and CO_2 emissions was specific in the US.

Pejović et al. (2021) found conflicting results when examining the connections between expansion of the economy, CO_2 emissions, and utilization of energy in the 27 EU countries and the Western Balkans. Their use of panel vector autoregression (PVAR) and GMM methods uncovered several associations: (1) a two-way relationship between expansion of the economy and CO_2 emissions, (2) a negative two-way relationship between CO_2 emissions and utilization of energy, (3) a non negative connection from expansion of the economy to CO_2 emissions, and (4) a non negative relation from CO_2 emissions to expansion of the economy. A study conducted by Ozgur et al. (2022) aimed to investigate the

Figure 2: Total CO_2 emissions (Mt) from 1975 to 2019



Source: Enerdata 2022.

presence of the environmental Kuznets curve (EKC) in India from 1970 to 2016. The researchers utilized the ARDL technique and discovered that nuclear energy has the potential to decrease CO_2 emissions. The results in India provided support for the existence of the EKC, indicating that beyond a certain threshold, an increase in GDP could result in a reduction in environmental harm.

A study conducted by Wang et al. (2022) aimed to explore the relationship between financial development, renewable utilization of energy, and CO_2 emissions in 11 countries. The researchers analyzed data from 1990 to 2015 and utilized the Driscoll-Kraay and Dumitrescu-Hurlin methodologies. The results emphasized the importance of financial development in determining the influence of renewable utilization of energy on CO_2 emissions. Furthermore, the study uncovered interconnected relationships among financial development, renewable energy usage, and CO_2 emissions. A study conducted by Li and Haneklaus (2022) aimed to investigate the relationship between the utilization of clean energy, expansion of the economy, trade openness, urbanization, and CO_2 emissions in the G7 nations. The researchers employed the ARDL technique and analyzed data from 1979 to 2019, covering a span of 40 years. The results of the study provided evidence for the presence of the environmental Kuznets curve (EKC).

Moreover, the findings demonstrated that an increase in the adoption of renewable energy sources can result in a decrease in CO_2 emissions, both in the short-term and long-term. Furthermore, the study uncovered that variables such as trade openness and urbanization can contribute to environmental deterioration. Karaaslan and Camkaya (2022) conducted a research study to investigate the potential influence of expansion of the economy, health expenditure, and the utilization of nexhaustible and non-replenishable energy on environmental degradation in Turkey. The researchers utilized both the ARDL technique and the Toda-Yamamoto approach to investigate the causal relationship between the variables. The study examined data from 1980 to 2016. The results indicated that expansion of the economy and the consumption of non-replenishable energy sources lead to an increase in CO_2 emissions. In contrast, expenditures on healthcare and the utilization of inexhaustible energy sources were found to be associated with a reduction in CO_2 emissions.

Chandran and Tang conducted a study in which they discovered that income levels and utilization of energy in the transportation sector have a significant long-term impact on CO_2 emissions in Malaysia, Indonesia, and Thailand. The authors utilized data out of 1971-2008 and performed a multivariate co-integration analysis on a selected group of ASEAN members. The results highlighted the prominent role of transportation as a contributing factor to CO_2 emissions. In contrast, Shaari et al. (2022). and Demena, et al. (2020) Employed the ARDL approach to investigate the impact of utilization of energy in the agricultural sector. The findings of their study indicated that the utilization of energy in agriculture contributes to a decrease in environmental degradation in Malaysia.

In summary, existing literature has mainly focused on overall utilization of energy without considering specific sectors. However, the impact of utilization of energy varies across different sectors. Therefore, a failure to address sector-specific utilization of energy may result in misguided policies that could have adverse effects on productivity.

3. RESEARCH METHODOLOGY

3.1. Data

The information utilized in our study ranges from 1979 to 2022, focusing on the Saudi kingdom economy. We obtained secondary data from the World Bank for our analysis. The variables we incorporated in our study are listed in Table 1.

In Table 2, the statistical description of variable is presented. The author applied the logarithm to (L CO_2, LAG, LTR, LIN, LEX, LIM, LY, and LP) to assess the similarity of the values of these variables. The remaining variables were primarily calculated using percentages or per capita (Gujarati 2009). The entire variable have standard deviations close to zero, suggesting that the data points are closely grouped around the means.

3.2. Econometric Model

The study utilized the econometric methodology to test hypotheses by applying the ARDL model. This model is a recent dynamic approach that considers the element of time in order to identify short- and long-term relationships among variables. Equation 1, outlines how the connection between CO_2 emissions, energy consumption in the transportation sector, energy consumption in the industrial sector, energy consumption in the agriculture sector, exports, imports, economic growth and population growth can be defined.

$$CO_2=\alpha+\beta 1AG+\beta 2TR+\beta 3IN+\beta 4EX+\beta 5IM+\beta 6Y+\beta 7P+\mu t \quad (1)$$

In the analysis of time-series data, it is recommended to convert Equation 1, into logarithms. This conversion helps in examining the percentage in environmental degradation that occurs due to a percentage change in energy consumption. Additionally, a national logarithmic transformation is conducted to tackle any potential non-linear relationships between the dependent and independent variables. As a result, the new equation can be expressed as follows:

$$LN\ CO_2=\alpha+Ln\beta 1AG+Ln\beta 2TR+Ln\beta 3IN+Ln\beta 4EX+Ln\beta 5IM+Ln\beta 6Y+Ln\beta 7P+\mu t \quad (2)$$

Where by, LN CO_2 represents the national logarithm of CO_2 emissions, LNAG represents the natural logarithm of energy consumption in the agricultural sector, LNRT represents the natural logarithm of energy consumption in the transportation sector, LNI represents the natural logarithm of energy consumption in the industrial sector, LNX represents the natural logarithm of export, LNM represents the natural logarithm of import, LNY represents the natural logarithm of GDP, LNP represents the natural logarithm of population growth. The anticipated indications for 1, 2, and 3 rely on the progress made in these three sectors. It is predicted that 4 and 5 will show a negative correlation with CO_2 emissions. In the case of 6, the expected indication will demonstrate either the presence of the pollution haven hypothesis with a negative indication or the halo effect hypothesis with a positive indication. Finally, both 7 and 8 are expected positive indications.

In this research, we utilized the Autoregressive Distributed-Lag (ARDL) model, which has gained popularity as a dynamic approach that incorporates the element of time. The objective was to examine the short and long run relationship among variables and determine the speed at which the system converges to equilibrium. I conducted an analysis of the long run relationships between variables using time series data. The ARDL model comprises two components. Firstly, the Autoregressive (AR) component, which relies on lagged values of the dependent variable, incorporating it as a lagged independent variable. Secondly, the distributed lagged (DL) component, which indicates that the dependent variable is influenced by changes in the independent variables and their lagged values.

$$\begin{aligned} dLnCO2_{2t} &= \alpha_0+\alpha_1 LnCO_{2t-1}+\alpha_2 LnAG_{t-1} \\ &+\alpha_3 LnTR_{t-1}+\alpha_4 LnIN_{t-1}+\alpha_5 LnEX_{t-1} \\ &+\alpha_6 LnIM_{t-1}+\alpha_7 LnY_{t-1}+\alpha_8 LnP_{t-1}+ \\ &\sum\nolimits_{j=1}^{p}\beta_{1j}\Delta LCO_{2t-j}+\sum\nolimits_{j=0}^{q}\beta_{2j}\Delta LAG_{t-j}+ \\ &\sum\nolimits_{j=0}^{n}\beta_{3j}\Delta LnTR_{t-j}+\sum\nolimits_{j=0}^{r}\beta_{4j}\Delta InIN_{t-j} \\ &+\sum\nolimits_{j=0}^{m}\beta_{5j}\Delta LnEX_{t-j}+\sum\nolimits_{j=0}^{k}\beta_{6j}\Delta LnIM_{t-j} \\ &+\sum\nolimits_{j=0}^{e}\beta_{7j}\Delta LnY_{t-j}+\sum\nolimits_{j=0}^{f}\beta_{8j}\Delta LnP_{t-j}\mu_{it} \end{aligned} \quad (3)$$

Table 1: Variables' definition and description

Variable	Notation	Description	Unit
Energy consumption in agriculture sector	AG	The total energy demand in the agriculture sector at its final stage	Tons of oil equivalent
Energy consumption in transportation sector	TR	The overall energy demand at the end, specifically within the transportation industry	Tons of oil equivalent
Energy consumption in industrial sector	IN	The overall energy demand at the end of the process in the industrial sector	Tons of oil equivalent
Export	EX	The percentage of goods and services exported in relation to the Gross Domestic Product (GDP)	%
Import	IM	The proportion of imports of goods and services in relation to Gross Domestic Product (GDP)	%
Economic growth	Y	Gross Domestic Product (GDP) adjusted for inflation.	%
Population growth	P	Total population growth	%
CO_2 emissions	CO_2	Carbon dioxide emissions encompass the carbon dioxide generated while energy is being consumed.	Metric tons per capita

Table 2: Statistical description of variables

	L CO_2	L AG	L TR	L IN	L EX	L IM	L Y	L P
Mean	5.382	6.239	9.547	9.325	4.1082	4.003	8.1082	0.603
Median	5.540	6.471	9.720	9.443	4.4961	4.151	8.496	0.651
Maximum	5.878	6.970	11.346	10.67	4.8321	4.724	9.232	1.524
Minimum	4.344	3.192	8.292	6.142	4.095	3.863	7.995	0.863
SD	0.671	0.942	0.279	0.312	0.2321	0.295	0.632	0.475
Observations	43	43	43	43	43	43	43	43

Where (Δ) refers to the first difference operator, p, q, r, n, m, k, e, and f indicate lags, (α_1 to α_8) refers to long-run parameters, ($_0$) refers to short-run parameters, (β_1 to β_8) refers to the intercept, and (μ) refers to the error term.

4. FINDINGS

For our analysis in this study, we are using secondary data on macroeconomic variables. Therefore, it is essential to perform a unit root test to determine the stability of the data. For this analysis, we are utilizing the augmented Dickey-Fuller approach, which has been extensively used and proven effective in previous research.

Economic analysis techniques are frequently used to investigate if there are periodic fluctuations in the average and spread of time-series information. The unit root test enables us to assess the null hypothesis, indicating that the data is not stationary, in comparison to the alternative hypothesis, which implies that the data is stationary.

Table 3 shows the results of the unit root test conducted using the ADF method to assess the stability of all variables. After considering the intercept and absence of trend, the analysis reveals that LnAG, LnEX, LnY, LnIM, and LnP have unit roots and are therefore not stationary at the current level. Conversely, the remaining variables (Ln CO_2, LnAG, and LnTR) do not have unit roots and are deemed stable at the current level.

All variables become stable when they are subjected to differencing once. When an intercept and trend are included, the results indicate that only LnY and LnP have unit roots and are not stationary at the initial level. On the contrary, Ln CO_2, LnAG, LnEX, LnIM, and LnTR do not have unit roots and are stationary at the initial level. However, all variables exhibit stationarity when the differences are calculated. In conclusion, the variables used in this study have different degrees of integration-some are integrated of order 1 (I(1)), while others are integrated of order 0 (I(0))-which suggests that the ARDL technique can be applied.

We performed the ARDL bounds testing technique and the results are shown in Table 4. The F-statistic of 7.0911 surpasses the critical value of 4.21, which means we reject the null hypothesis that there is no co-integration. This finding suggests that we can proceed with estimating the long-run and short-run effects. Additionally, we used the Akaike Information Criterion (AIC) to automatically determine the best lag for our analysis.

4.1. Short Run Estimation Results

The analyzed data from Tables 5 and 6 reveal the findings regarding the short run and long run relationship. Table 5 indicates that the variables LnAG, LnTR, LnIN, and LnY have a significant impact on CO_2 in Saudi Arabia in the short run. Additionally, the results from the error correction model (C) in the table demonstrate that the error correction term (C) is highly significant at a significance level of 5%., and it has a negative sign as expected. This implies that there is a short run equilibrium relationship, or cointegration, among the variables in the model, with a value of 2.8. Moreover, this suggests that approximately 2.8 within 1 year, bringing the system back towards the short run equilibrium, correct deviations from the equilibrium. Finally, the coefficient for ECT is −0.2257 and significant, affirming the presence of short-run relationships between energy consumption by sector, export, import, economic growth, population growth, and CO_2 emissions.

4.2. Long Run Estimation Results

The estimates of the long run show that there is a statistically significant and positive economic relationship between both CO_2 levels and energy consumption by sector. This implies that there is a positive relationship in the long run. Specifically, for every one unit increase in energy consumption by the transportation sector, CO_2 levels increase by 0.255 units. Similarly, for every one unit increase in energy consumption by the industry sector, CO_2 levels increase by 0.242 units.

The results of diagnostic tests reported in Table 7 were based on various tests, such as the Jarque-Bera test, the Breusch-Godfrey series correlation test, the heteroskedasticity test, and Ramsey's stability test. All of these tests showed that the F-statistics were not statistically significant. However, these results indicate that the model used does not have any diagnostic problems. Furthermore, the variables of the study, which include energy consumption in the agricultural sector, energy consumption in the transportation sector, energy consumption in the industrial sector, export, import,

Table 3: ADF test and PP test results

Variables	Intercept		Intercept with Trend	
	Level	First Difference	level	First Difference
Ln CO_2	−5.3804***	−5.4300***	0.2344	0.0000***
LnAG	−2.0449	−4.6965***	0.4258	0.0002***
LnEX	−0.9726	−3.5190**	0.0121**	0.0000***
LnY	−1.0627	−1.4204***	0.5635	0.0001***
LnIM	−0.1733	−2.3548***	0.7589	0.0011***
LnTR	−2.1287*	−0.4083**	0.8986	0.0000***
LnP	−1.5649*	−3.0570**	0.0376**	0.0000***
LnIN	3.0226*	5.7332***	0.0641**	0.0000***

Notes: *** and ** denote significance at the 10%, and 5% levels, respectively.

Table 4: Bounds test result

F-statistic		7.0911***
Critical value	Lower bound	Upper bound
10%	2.05	3.19
5%	2.87	3.73
1%	3.01	4.21

*** denotes significance at 1%

Table 5: Short-run estimation results

Variable	Coefficient	SE	T-statistic	Prob
LnAG	−0.0515*	0.0066*	−1.0866**	0.0028
LnEX	0.0575*	0.0187*	0.0553*	0.0050
LnY	0.221167	0.0231	3.2532	0.0040
LnIM	−0.0208	0.0691	−2.3473*	0.0860
LnTR	0.2005*	0.0219*	1.0338	0.0091
LnP	−0.0757	0.034485	−0.1959	0.0318
LnIN	0.0026	0.001644	−1.6327	0.0075
C	−2.8515**	0.0602**	−4.7606**	0.0000
ECT	−0.2257***	0.0398***	−5.0843***	0.0000

***,**and *denote significance at 1%, 5% and 10% respectively

GDP growth, and population growth, also do not suffer from any diagnostic problems as shown in Table 7.

To ensure the stability of the model, we have used the Cumulative Sum (CUSUM) graph and the Cumulative Sum of Squares (CUSUMSQ) graph (Figure 3 below). Both diagrams in the figure show that all the plotted points are within the red bounds. This confirms the stability of the model used.

5. DISCUSSION OF THE FINDINGS

The results of this study indicate that increased energy usage in the agricultural sector can have negative effects on the environment. It is worth noting that energy consumption in the agricultural sector is relatively low, particularly in rural areas where traditional production methods are still widely used. This practice may contribute to a reduction in CO_2 emissions. Compared to other sectors, agriculture has the smallest share of total energy consumption, especially when it comes to non-renewable sources like oil. Therefore, introducing technologies that rely on non-renewable energy in this sector could potentially harm the environment. Additionally, this study highlights the potential environmental risks associated with higher energy consumption in the industrial sector. This sector accounts for the second-largest share of total energy consumption and demonstrates an increasing reliance on non-renewable sources such as oil and coal. Consequently, this trend contributes to higher CO_2 emissions in Saudi Arabia. Given these findings, it is crucial to prioritize environmental considerations in the development of this sector.

Table 6: Long-run estimation results

Variable	Coefficient	SE	T-statistic	Prob
LnAG	−0.0346	0.029837	−34.67733	0.0000
LnEX	−0.297741	0.015404	−19.32833	0.0000
LnY	2.476733	0.090698	27.30756	0.0000
LnIM	0.579563	0.016479	35.16976	0.0000
LnTR	0.255272	0.009204	27.73612	0.0000
LnP	0.055870	0.012639	4.420278	0.0000
LnIN	0.242386	0.038474	6.300074	0.0000
C	−0.002504	0.000760	−3.296092	0.0017

***, **and *denote significance at 1%, 5% and 10% respectively

Table 7: Diagnostic tests results

F-statistic=5.9146		
Statistical tests	**F-statistics**	**Probability**
Jarque-Bera	0.079	0.673
Breush Godfrey collecting series	0.165	0.795
Heteroskedastisity test	1.781	0.102
Reset Ramsey Stability	1.435	0.1687

In order to mitigate CO_2 emissions, it is crucial to address energy consumption in the transportation sector. Multiple studies, including research by Chandran and Tang and Nasreen et al. (2020), have demonstrated a positive correlation between energy usage in this sector and CO_2 emissions. In Saudi Arabia, the transportation sector consumes the highest proportion of total energy, surpassing even the industrial sector. As a result, its impact on CO_2 emissions is greater than that of the industrial sector. This phenomenon can be attributed to various factors, as explained by Yuaningsih et al. (2021). One key factor is the increasing demand for transportation services driven by rising income levels and rapid economic development. These findings are consistent with the conclusions drawn by other researchers such as Shaari et al. (2022), and Ridzuan et al. (2022). in their studies on Saudi Arabia.

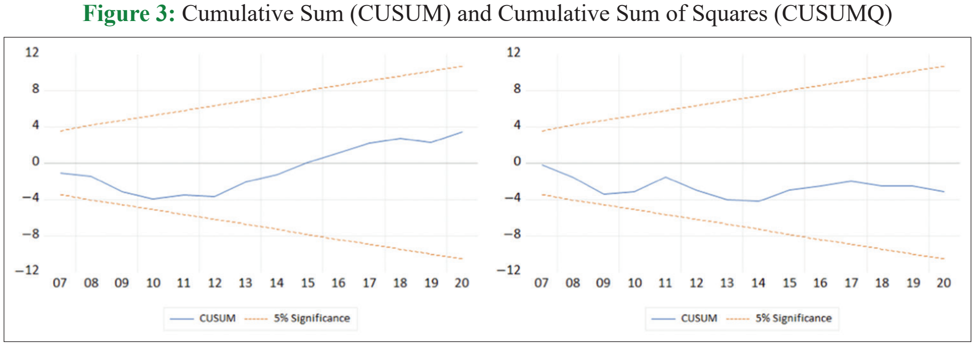
The process of economic growth is a significant driver of environmental degradation, as it involves increased reliance on non-renewable energy sources that release higher levels of CO_2 into the atmosphere. In Saudi Arabia, the use of oil, coal, and gas to fuel economic activities has resulted in a consistent rise in CO_2 emissions. As a developing country, Saudi Arabia prioritizes economic growth over environmental conservation, which contradicts the findings of Rahman et al. who suggest that higher economic growth should lead to reduced CO_2 emissions in newly industrialized nations.

In addition to this, exports also contribute to environmental degradation, as highlighted by Wang et al. (2018). Saudi Arabia's export industry heavily relies on electrical and electronic goods, which can generate CO_2 emissions during production processes. Furthermore, this sector consumes various non-renewable energy sources like coal and oil, further contributing to CO_2 emissions.

6. CONCLUSIONS

This study investigates the relationship between sector-specific energy consumption and CO_2 emissions in Saudi Arabia from 1979 to 2022. The ARDL approach is utilized to analyze the data, and the findings shed light on the impact of energy consumption in different sectors. The results demonstrate that energy consumption in the transportation and industrial sectors, as well as exports and economic expansion, have positive effects on CO_2 emissions. This implies that higher energy consumption

Figure 3: Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMQ)



in these sectors contributes to increased CO_2 emissions. On the other hand, energy consumption in the agriculture sector is found to have a significant negative impact on CO_2 emissions. Therefore, an increase in energy use in agriculture does not harm the environment. Interestingly, population growth and imports do not exhibit a significant influence on CO_2 emissions according to this study's findings.

In light of the research revealing the negative environmental consequences of energy consumption in the transportation and industrial sectors, it is imperative for policymakers to develop effective policies. Saudi Arabia's continued reliance on non-renewable energy sources like coal and oil calls for urgent action. Given that agriculture has minimal impact on the environment, implementing environmental policies specific to this sector may not be necessary. However, greater attention should be directed towards addressing issues in the industrial and transportation sectors. It is noteworthy that the transportation sector has a more significant influence on CO_2 emissions compared to the industrial sector.

In order to mitigate environmental degradation, it is crucial to enhance the effectiveness of existing government measures aimed at diversifying fuels, particularly in the transportation and industrial sectors. Despite the implementation of these policies, non-renewable energy sources still prevail in these sectors across Saudi Arabia. Therefore, a transition towards greater utilization of renewable energy sources such as solar, biodiesel, and hydropower is necessary. To encourage consumers to adopt electric vehicles, it is essential to ensure reasonable pricing for such vehicles. Furthermore, firms within these sectors that contribute significantly to CO_2 emissions should be subjected to carbon taxes and pricing mechanisms. This approach aligns with the support of many economists who believe that implementing such policies can reduce CO_2 emissions while generating revenue for the government.

Although higher economic growth and exports have led to increased CO_2 emissions, it does not mean that reducing these emissions to mitigate environmental degradation is impossible. In fact, there are viable solutions that can be considered, such as the implementation of carbon capture and storage (CCS) technology. CCS technology involves capturing carbon dioxide emissions from industrial processes or power generation and storing them deep underground in geological formations. By adopting this technology, it is possible to significantly reduce environmental degradation caused by CO_2 emissions. Therefore, instead of accepting the notion that reducing emissions is unattainable, exploring options like CCS technology can pave the way towards a more sustainable future.

While this study has provided valuable insights, it is important to acknowledge its limitations. Several potential variables, such as corruption and financial development, were not included in this analysis. Incorporating these variables in future studies could enhance the findings and contribute to the formulation of more effective policies. Moreover, it is important to acknowledge that this study only concentrates on Saudi Arabia by utilizing time-series data analysis. In order to obtain a wider comprehension of the influence of energy consumption on CO_2 emissions, forthcoming research should contemplate utilizing panel data analysis encompassing numerous countries. By broadening the range of analysis and taking into account additional variables, subsequent studies can offer a more all-inclusive understanding of the correlation between energy consumption and CO_2 emissions, thereby aiding the development of well-informed global policies. This research was funded by the Deanship of Scientific Research at KFU: GRANT5752.

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