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Energy Transition and SDG Performance in GCC Countries: The Moderating Role of Renewable Electricity under Carbon Pressure

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ABSTRACT

This study examines the relationship between renewable electricity output and Sustainable Development Goals (SDGs) in GCC countries, while considering the moderating role of carbon dioxide emissions. The analysis employs panel data and applies the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) model to estimate both long-run and short-run relationships. The results indicate that renewable electricity output, electricity access, and renewable energy consumption positively contribute to SDG performance, whereas carbon emissions and energy intensity hinder sustainable development. The moderating analysis further shows that renewable electricity can mitigate the adverse effects of emissions. The findings highlight the importance of expanding renewable energy and improving energy efficiency to accelerate sustainable development in GCC economies.

DETAILS

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1. Introduction

Although the world has pledged to the 2030 Agenda, the achievement towards reaching the Sustainable Development Goals (SDGs) has been lopsided and limited by economic, social, and environmental demands. It has been demonstrated that merely 17% of SDG goals are on pace, and almost half of them have only partial progress, and over a third have decelerated or retrogressed since 2015 (Department of Economic and Social Affairs, 2023). The improvement is still hindered by perpetual poverty and inequality. Approximately 8.2% of the global population, or 673 million people, were hungry in 2024, and almost a third of people, almost 2.3 billion, became vulnerable to moderate or severe food insecurity (Ababa, 2025). These are amplified by climate change because increased temperatures, adverse weather patterns, and degradation of the environment are disrupting livelihoods, farming activities, and infrastructure in developing areas. There are also geopolitical wars, fiscal limitations, and increasing government debt that hamper governments from funding sustainable development policies. Subsequent global shocks since 2020, such as the COVID-19 pandemic and supply-chain disruptions, have cancelled the previous improvement in reducing health, education, and poverty (Sachs, Lafortune, & Fuller, 2024). It is questionable whether the SDGs can be achieved by 2030 without more coordination of policies, investment, and institutional capacity.

Gulf Cooperation Council (GCC) states have limited structural factors that complicate the achievement of the SDGs, even when the level of income is high and well-developed infrastructure. The economies of the region continue to be heavily reliant on hydrocarbon production, and many energy systems are dominated by fossil fuels, making it hard to mitigate carbon emissions while sustaining the growth of the economy and energy security (Mills, 2025). Ecological footprints and energy-consuming consumption patterns are also high, in addition to heightened environmental demands and reduced pace toward sustainable production/consumption targets (Al-Saidi, 2022). There are also significant challenges related to environmental conditions. GCC countries belong to the category of the most water-scarce countries in the world, and the increased demand for desalination and the rising temperatures put even further strain on the available water resources and ecosystems, impacting the achievement of SDG 6 and SDG 13 (Abdelraouf & Majed, 2025). Assessment of SDGs on a regional level has revealed that some of its goals,

such as responsible consumption and production (SDG 12), strong institutions (SDG 16), and clean water and sanitation (SDG 6), are potential problems across most of the Gulf states. The dynamics of the labor market do not allow progress either. The issues of economic diversification and job creation have been consistent, and the SDG 8 indicators differ across the GCC economies, and only several states are on the way towards meeting the 2030 goals (Abdelraouf & Majed, 2025).

According to recent literature, there are a variety of policy and technological avenues that could lead to faster development of the SDGs. There is an increasing body of literature that focuses on the expansion of renewable energy as an important strategy. Solar, wind, and hydro power systems can be developed at the same time to enhance access to energy, minimize the emission of greenhouse gases, and promote economic growth. Empirical and review literature show that the implementation of renewable energy sources is a contributing factor to SDG 7, besides guaranteeing climate mitigation, better human health, and sustainable urban centers (Almulhim & Abubakar, 2026). Technological innovation and investment in energy are also emphasized by the scholars. By investing in modern grid infrastructure, storage, and hydrogen, it is possible to speed up the decarbonization process and enhance energy-system efficiency, which will enhance the development of attacks related to climate issues (Kyei, Boateng, & Frimpong, 2025). Policy-focused studies bring to light the importance of favorable regulatory provisions such as renewable-energy subsidies, carbon prices, and infrastructure investment that may spur clean-energy emission and economic crisis mitigation (Triki, Mahmoud, Bahou, & Boudabous, 2025). Another line of literature focuses on the issue of governance and the quality of institutions. Transparent institutions, good regulation, and concerted policy frameworks are significant in enhancing effectiveness in environmental and energy policies, and weak governance has the ability to slow sustainable transitions (Naseer, Hunjra, Palma, & Bagh, 2025). Complementary studies propose multifaceted approaches to climate-development to ensure the shaping of climate policies in line with the SDG implementations, in such a way that the environmental protection, economic development, and social inclusion strengthen one another (Nilsson et al., 2024).

This study contributes to the sustainable development literature by examining the relationship between renewable electricity, carbon emissions, and SDG performance in GCC countries using the CS-ARDL approach. It provides new evidence on how renewable electricity influences sustainable development and how carbon emissions moderate this relationship. By focusing on energy-related factors within a hydrocarbon-dependent region, the study offers policy-relevant insights for advancing energy transition and sustainable development strategies in GCC economies.

This study aims to examine the impact of renewable electricity output on sustainable development goals in GCC countries. It also investigates the moderating role of carbon emissions in this relationship while considering energy access, clean cooking access, energy intensity, and renewable energy consumption as control variables to better understand sustainability dynamics.

2. Literature Review

Empirical investigations are highlighting that the availability of modern energy services has a critical engagement in promoting numerous Sustainable Development Goals because of enhanced socioeconomic wellbeing and environmental performance. Availability of electricity and clean cooking solutions has been linked with poverty levels minimization, enhanced health conditions, and provided greater educational opportunities, especially in the developing economies where energy poverty still exists (Yavuz et al., 2025). Constant electricity, empowered by dependability, allows families and companies to embrace productive technologies, provides digital services, and enhances the health care service delivery by providing a better way of refrigerating goods and access to medical equipment. The relevance of access to renewable energy in meeting SDG 7 and enhancing climate action and sustainable economic development progress can also be noticed through an increasing body of research. The empirical findings indicate that the renewable electricity production and energy efficiency benefits can help reduce greenhouse gas emissions and can benefit the long-term economic growth and bring efficiency to the environment (Candra, Chammam, Alvarez, Muda, & Aybar, 2023). Research that explores the energy-development nexuses in the world also reveals that access to energy is closely linked with various SDGs, such as SDG 1 (reduced poverty), SDG 3 (health), SDG 4 (education), and SDG 13 (climate action) (Sadath & Acharya, 2024). Recent commentaries also highlight decentralized energy systems, including off-grid solar and mini-grid technologies, as effective ways of increasing energy access in underserved areas (Bhattacharyya & Palit, 2021). These systems offer sustainable and cost-effective electricity, catalyze local entrepreneurship, and encourage inclusive development performance, which is a key contributor to sustainable development, emphasizing access to energy.

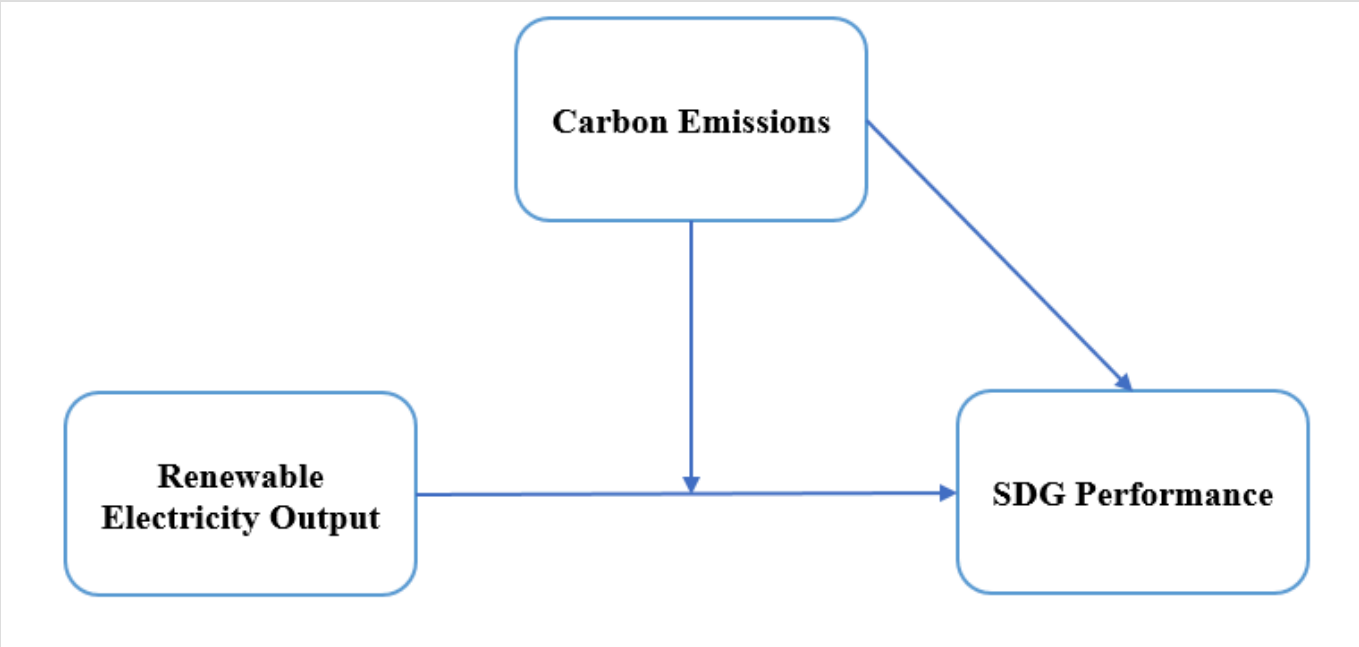

Figure 1. Theoretical Framework

There is also recent empirical literature that studies a conditional relationship between renewable electricity generation and sustainable development, with the moderating role of carbon emissions. The growth of renewable electricity resources can contribute to SDGs 7 and 13, as fossil fuels will be minimized. The success of renewable electricity is, however, mostly determined by the prevailing emission levels. In some cases, where the carbon emission is still very high because of the structure of the energy sector based on fossil fuels, the positive environmental impact of the introduction of renewable electricity can be neutralized to a certain extent (Tang, Shahla, Leyla, & Sevinj, 2023). The experience of other countries indicates that renewable energy also helps the environment to be cleaner and grow regularly, but the output depends on the level of emissions and energy system configurations. Complementary measures, which include technological innovation, energy efficiency gains, and carbon-cutting rules needed in high-emission economies, are necessary to completely convert the enlargement of renewable electricity into gains of sustainable development (Anfom et al., 2026). Therefore, recent literature is starting to give carbon emissions a more prominent role in the renewable energy-sustainability nexus as a moderator (Batra, 2023). Figure 1 displays the theoretical framework of the study.

3. Data and Methodology

3.1. Data

Table 1 presents the variables used in the study along with their definitions, measurements, and data sources. SDGs are measured using the SDG Index score, while energy-related variables include renewable electricity output, carbon emissions, electricity access, clean cooking access, energy intensity, and renewable energy consumption. Most data are obtained from the World Development Indicators database.

Table 1. Variables Description

Variables	Definition	Measurement	Sources
SDGs	Sustainable Development Goals	Overall SDG Index Score (0–100)	SDG Index
RO	Renewable Electricity Output	GWh (Annual Renewable Electricity Generation)	WDI
CO_2	Carbon Dioxide Emissions	Metric tons per capita	WDI
ACF	Access to Clean Fuels and Technologies for Cooking	Weighted average (% population access)	WDI
Elect	Access to Electricity	% of total population	WDI
EIP	Energy Intensity Level of Primary Energy	MJ/2017 USD PPP GDP	WDI
REC	Renewable Energy Consumption	Terajoules (TJ)	WDI

3.2. Model

3.2.1. Base Model

$$SDG_{i,t} = \beta_0 + \beta_1 RO_{i,t} + \beta_2 ACF_{i,t} + \beta_3 Elect_{i,t} + \beta_4 EIP_{i,t} + \beta_5 REC_{i,t} + \varepsilon_{s,t} \quad \text{eq (1)}$$

3.2.2. Moderating Model

$$SDG_{i,t} = \beta_0 + \beta_1 RO_{i,t} + \beta_2 CO_{2,i,t} + \beta_3 (RO \times CO_2)_{i,t} + \beta_4 ACF_{i,t} + \beta_5 Elect_{i,t} + \beta_6 EIP_{i,t} + \beta_7 REC_{i,t} + \varepsilon_{s,t} \quad \text{eq (2)}$$

3.3. Methodology

3.3.1. CSD ARDL

The Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) model is the new model in representing the panel estimates, which is developed to overcome the cross-sectional dependence and slope heterogeneity in panel data. The framework builds upon the conventional paradigm of ARDL because the cross-sectional averages of the dependent and independent variables are included, which is useful in addressing the issues of non-observed shared elements that impact all the nations. CS-ARDL enables scholars to estimate the short-run dynamics and long-term relationships, besides giving consistent estimates in a heterogeneous panel structure. Such a method is specifically appropriate to macro-panel research of a set of hashed together economies, including GCC countries, in which a number of economic shocks, energy markets, and policy alterations could impact several states at a time.

4. Results

4.1. Preliminary Analysis

Table 2 results indicate moderate variation in SDG performance among the GCC countries, with the mean SDG score of 59.581, with a range of 53.010 to 69.600. The output of renewable electricity displays significant dispersion, implying that there is not a uniform development in renewable energy by countries. Carbon dioxide emissions are the most volatile parameter in that they show variation in fossil fuel reliance and industrial activity in the area. The accessibility to clean cooking fuels is maintained at 100, which means that the sample was covered universally. Likewise, accessibility of electricity is almost universal without much difference. The intensity of energy has a moderate level of variation, which means that various economies vary in terms of efficiency. The level of consumption of renewable energy at a general level is rather low, which reminds us of the fact that the region still depends on traditional sources of energy.

Table 2. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
SDG	144	59.581	3.750	53.010	69.600
RO	144	0.231	0.751	0.000	4.201
CO_2	144	150.413	163.464	17.772	635.434
ACF	144	100.000	0.000	100.000	100.000
Elect	144	99.997	0.016	99.900	100.000
EIP	144	6.868	1.684	3.590	10.550
REC	144	0.065	0.173	0.000	1.000

Table 3 shows that the results of the cross-sectional dependence test are statistically significant as far as dependence between GCC countries is concerned. The Breusch Pagan LM, Pesaran scaled LM, as well as Pesaran CD have all shown significant values after the 1 percent level, which points to a good cross-section correlation. This implies that there is cross-country differentiation in economic and energy shocks, thus warranting the application of CS-ARDL methods of estimation.

Table 3. Cross-Sectional Dependence (CSD) Test

Test	Statistic	Prob.
Breusch–Pagan LM	162.384***	0.000
Pesaran Scaled LM	21.467***	0.000
Pesaran CD	−2.145***	0.000

Note: *, **, and *** denote the 10%, 5%, and 1% significance levels, respectively.

The null hypothesis of equal slopes among the countries of the GCC region is rejected in the slope homogeneity test in Table 4. The value of all statistics is significant at the 1% level, showing that the relationship between variables is not homogeneous. This implies that energy-related aspects have different effects in countries with regard to SDG performance, and hence the adoption of heterogeneous panel estimators.

Table 4. Slope Homogeneity Test

Test	Delta	P-value
Normal	8.412***	0.000
Adjusted	9.876***	0.000
HAC Approach	4.113***	0.000
Adjusted HAC	5.021***	0.000

Note: *, **, and *** denote the 10%, 5%, and 1% significance levels, respectively.

According to the results of the Westerlund panel cointegration test, which is provided in Table 5, there is a long-run equilibrium relationship between the variables in the GCC panel. Gt and Pt statistics are significant at the 1 percent level, which shows that the SDG performance is co-integrated with the energy-related variables. On the contrary, the Ga and Pa statistics are insignificant. On the whole, the substantial group statistics have a good indication of the long-run cointegration, which augurs the use of the CS-ARDL model to estimate the short and long-term relationships.

Table 5. Westerlund Panel Cointegration Test

Statistics	Value	Z-value	P-value
Gt	−6.842***	−10.917	0.000
Ga	−12.506	1.742	0.958
Pt	−12.781***	−5.893	0.000
Pa	−11.274	1.364	0.914

Note: *, **, and *** denote the 10%, 5%, and 1% significance levels, respectively.

4.2. CS-ARDL Estimation

The CS-ARDL estimation results in Table 6 reveal both long-run and short-run relationships between energy variables and SDG performance in GCC countries. In the long run, renewable electricity output (RO) has a positive and statistically significant effect on SDGs in both models, suggesting that expanding renewable electricity generation supports sustainable development outcomes in the region. This finding aligns with prior research highlighting the importance of renewable energy in advancing SDG targets related to energy access, climate mitigation, and economic sustainability (Adebayo, Uhunamure, & Shale, 2023; Apergis & Payne, 2014).

Table 6. CS-ARDL Estimation

Variables	Model 1	Model 2
Long Term		
RO	0.046** (0.021)	0.038** (0.018)
CO_2		-0.057*** (0.022)
RO×CO_2		0.029** (0.013)
ACF	0.018 (0.016)	0.012 (0.017)
Elect	0.058** (0.026)	0.061** (0.028)
EIP	-0.033* (0.019)	-0.027 (0.021)
REC	0.039*** (0.013)	0.034** (0.015)
Short Term		
RO	0.079*** (0.027)	0.073*** (0.025)
CO_2		-0.068 (0.032)
RO×CO_2		0.046 (0.021)
ACF	0.024 (0.023)	0.019 (0.024)
Elect	0.091*** (0.034)	0.095*** (0.035)
EIP	-0.049* (0.029)	-0.052* (0.030)
REC	-0.041** (0.019)	-0.046** (0.021)

Note: *, **, and *** denote the 10%, 5%, and 1% significance levels, respectively.

Carbon dioxide emissions (CO_2) show a significant negative long-run effect in the moderating model, indicating that higher emissions undermine progress toward sustainable development. This result is consistent with studies demonstrating that environmental degradation and fossil-fuel dependence hinder sustainability and SDG achievements (Shahbaz, Haouas, Sohag, & Ozturk, 2020). The positive coefficient of the interaction term (RO×CO_2) suggests that renewable electricity mitigates the adverse impact of emissions on SDGs, implying that expanding clean energy can offset environmental pressures in carbon-intensive economies.

Table 7. Robustness Check

	AMG		CCEMG	
Variables	Coefficient	Std. Error	Coefficient	Std. Error
RO	0.052**	0.024	0.047***	0.017
CO_2	-0.061***	0.027	-0.049**	0.020
RO × CO_2	0.033**	0.015	0.028***	0.011
ACF	0.016	0.020	0.013	0.018
Elect	0.069**	0.031	0.058***	0.022
EIP	-0.035*	0.023	-0.029**	0.014
REC	0.041***	0.016	0.036***	0.012

Note: *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively.

Access to electricity positively influences SDGs in both models, highlighting the developmental benefits of reliable energy infrastructure. Similar evidence has been reported in recent studies linking electricity access to improvements in welfare, productivity, and economic development (Zhang, Shi, Zhang, & Xiao, 2019). Renewable

energy consumption also shows a positive long-run impact, reinforcing the role of clean energy transitions in sustainable growth.

In the short run, renewable electricity continues to positively affect SDG performance, while energy intensity exhibits a negative effect, reflecting inefficiencies in energy use. Renewable energy consumption shows a temporary negative short-run effect, which may reflect adjustment costs associated with energy transition policies. Overall, the results confirm that expanding renewable energy and improving energy efficiency are critical for achieving sustainable development in GCC economies.

The robustness results shown in Table 7 obtained from the AMG and CCEMG estimators confirm the stability of the baseline findings. Renewable electricity output (RO) remains positive and significant in both estimators, reinforcing its important role in promoting sustainable development. Carbon dioxide emissions (CO_2) continue to exert a negative effect on SDGs, indicating that higher emissions hinder sustainability progress in GCC countries. The positive and significant interaction term (RO × CO_2) suggests that renewable electricity helps mitigate the adverse environmental effects of emissions. Access to electricity also contributes positively to SDG performance. Meanwhile, energy intensity shows a negative relationship, highlighting inefficiencies in energy use, while renewable energy consumption positively supports sustainable development.

4.3. Discussion

The results denote energy transition as the key factor in the promotion of sustainable development within GCC economies. The fact that the increased renewable electricity production has a positive effect on SDGs hints at the idea that the increased renewable capacity leads to environmental sustainability and the diversification of the economy. It applies especially to GCC countries, where the governments have initiated large-scale renewable energy programs, including the Saudi Arabia Vision 2030 and the UAE Energy Strategy 2050, to minimize the use of fossil fuels and ensure the long-term sustainability (Ubaid & Gulrez, 2025). The adverse impact of carbon dioxide emissions proves that the region′s high reliance on hydrocarbons still poses a problem to the advancement of environmental aims. Nevertheless, the fact that renewable electricity does not negatively affect emissions suggests that the growth of renewable energy can be used to reduce the environmental strains in carbon-intensive economies. Moreover, the good aspect of access to electricity indicates that the infrastructure development in the region is high, which favors economic productivity and increases welfare. The fact that there is a negative relationship between the energy intensity and the SDGs implies that sustainable growth in GCC states still requires the enhancement of energy efficiency. Figure 2 presents the summary of the results in graphical form.

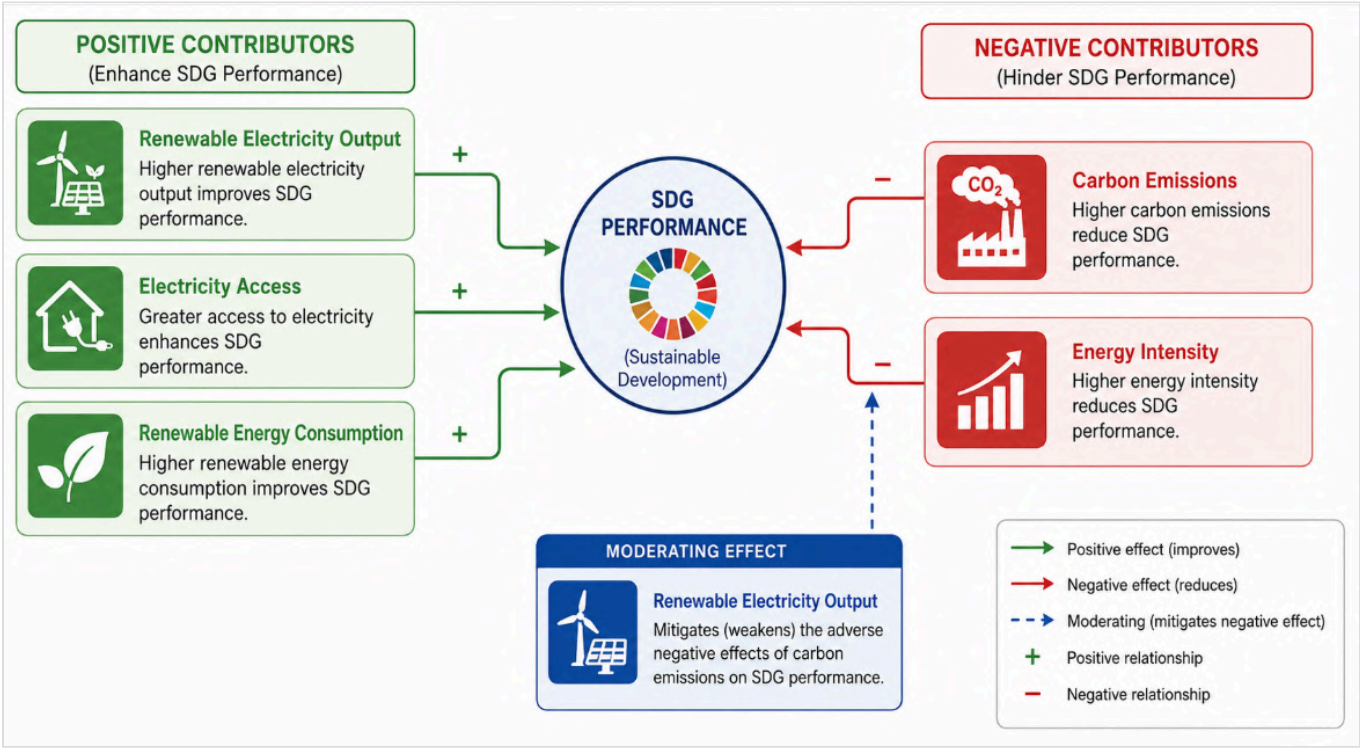

Figure 2. Result Summary

5. Conclusion

This paper analyzed how renewable energy can be applied in relation to carbon emissions and sustainable development goals in the GCC countries through the CS-ARDL framework. The findings suggest that the renewable electricity production and renewable energy consumption are a positive contribution to the SDGs performance, whereas carbon emissions and energy intensity are the obstacles to sustainable development. The relatively moderate analysis also reveals that renewable electricity could help to overcome the negative impact of carbon emissions on sustainability output. The research results underscore the need to hasten the clean energy shift in the GCC economies. In general, sustainable development needs to be achieved with the help of the expansion of renewable energy, energy efficiency, and the minimization of emissions, which are necessary measures to ensure long-term economic and environmental sustainability in the area.

The findings indicate some policy implications of the GCC countries. The governments should first increase investments in the production of renewable energy, especially solar and wind power, to decrease the use of fossil energy. The policies and incentives that promote renewable energy can be strengthened to accommodate the current energy transition policies in the region. Second, the carbon reduction policies, such as carbon pricing instruments and tighter environmental control, might lead to better sustainability results. Third, technological advancement and modernization of infrastructure are necessary to reduce the intensity of energy. Lastly, the diversification of the economy and long-term development in a sustainable way can be aided by the increased availability of reliable power and the advancement of renewable energy use, so that the national development policies of the country align with the international SDGs.

Although this research has some useful information, it has a number of limitations. To begin with, only GCC countries are analyzed, which cannot be applicable to other areas. Second, the analysis is based on aggregate indicators that are not necessarily able to reflect sector-specific changes in energy use and emissions. Third, more variables to be included, like technological innovation or institutional quality, were limited because of the availability of the data. Subsequent studies would be able to take this analysis further by including samples of countries at larger scales, sector-level statistics, or other sustainability measures. Furthermore, exploration of the interaction of renewable energy and emissions with the nonlinear or asymmetric models would yield more information depending on the economic and environmental circumstances.

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Consent to Participate

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Participation of Humans/Animals

Not Applicable