

# **Fossil fuel subsidy swaps: A path towards accelerating the renewable energy transition in Saudi Arabia**

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## **Abstract**

The present paper endeavors to provide a more nuanced assessment of the impact of fossil fuel subsidies on renewable energy generation in Saudi Arabia, which chiefly aims to generate 50% of energy from renewables by 2030 under the banner of Vision 2030 but is ranked the world's fourth-largest fossil fuel subsidizer. It does so by using the ARDL model over the period 1995–2023, which brings together the two waves of energy price reforms implemented in 2016 and 2018. The importance of this study lies principally in determining the percentage of improvement in renewable energy production as a result of reducing fossil fuel subsidies in view of the potential of renewable energy to unlock domestic fossil fuels used to generate energy and export them instead or convert them into value-added products by downstream industry in addition to meeting the many and varied local energy needs. The current undertaking has unearthed that a decrease of 1% in fossil fuel subsidies would increase renewable energy production by 7.98% and 10.61% in Saudi Arabia in the short and long run, respectively. These findings could prove substantially important to policymakers and stakeholders who want to boost the benefits of fossil fuel subsidy removal and direct the revenues thereof to jump-start the renewable energy industry. The Saudi government should by no means slack off on its endeavors to phase out inept fossil fuel subsidies, especially in boom years and times of oil price hikes. What underpins this conviction is that the continuous commitment to removing these subsidies sends a patently strong signal to the market and investors that the government is genuinely committed to moving steadily towards cleaner and more sustainable energy sources.

**Keywords:** Renewable energy; Fossil fuel subsidies; Saudi Arabia; ARDL approach.

**JEL Classification Numbers:** C50, H20, O53, Q42.

## 1. Introduction

It is universally known that Saudi Arabia plays a diversity of crucially important roles in the global oil market; the oil reserves it owns are estimated at nearly 267.2 billion barrels (the equivalent of roughly 16% of the world's proven petroleum reserves). It produces 9.61 million barrels of oil per day (OPEC, 2024). According to Moody's Analytics (2024), the oil sector represents nearly 87% of budget revenues, 42% of GDP, and 90% of export earnings. As far as consumption is concerned, Saudi Arabia is the largest consumer of petroleum products in the entire Middle East region, with 3.59 million barrels of oil per day (British Petroleum (BP), 2022). This makes it ahead of countries with larger populations and economies, such as Canada and Germany. This lavish consumption can be rightly ascribed to the decline in energy prices fueled by the rise in fossil fuel subsidies. Fuel prices in Saudi Arabia are amongst the lowest in the entire world: Gasoline, for example, costs only 62 cents per liter, while its global price is \$2.54 per liter (Bloomberg, 2024). This relatively huge gap between domestic and international prices represents foregone revenue and could be viewed as an implicit subsidy (Aldubyan and Gasim, 2021). Hartley and Medlock III (2008) report that Saudi citizens believe they deserve low energy prices as a way to take advantage of their country's fossil fuel wealth. On account of the high, subsidy-driven energy consumption, population growth, as well as extreme weather conditions, Saudi Arabia faces severe challenges bearing predominantly upon energy use inefficiency, energy waste, and the inability to achieve financial sustainability. These factors combined have made it utterly important for the country to adopt more stringent and serious steps with regard to energy subsidy reform and the urgent restructuring of the energy sector in its entirety (Sarrakh et al., 2020; Al-Saidi, 2022).

Owing to the urgent need to plug budget loopholes engendered by the alarming decline in global oil prices at the end of 2014 and the associated necessity to borrow money for the first time through the international bond market in 2016, the Saudi government launched three waves of energy price reforms in 2016, 2018, and 2024 to deal with the loss of revenue from oil sales. In an attempt to alleviate the negative impact of rising energy costs on low- and middle-income households, the government launched the Citizen's Account in conjunction with the second wave of energy price reforms. This account serves to provide monthly cash transfers to all eligible low- and middle-income households using revenues generated from higher energy prices (Bradshaw et al., 2019; Aldubyan and Gasim, 2021). The existing strong resistance to the utter elimination of these subsidies stems essentially from a lack of strong political will. Political leaders dread that the outright removal of subsidies could have the risk of potential regressive effects on low- and middle-income households as well as large companies whose activities depend on fossil resources (Hassan et al., 2024). Despite these consecutive waves of reforms, there remains still room for further reform efforts that will encourage the uptake of renewable energy, which can be deemed as the only solution to meet the additional energy demand without penalizing the well-being of the environment (Fattouh et al., 2018). It is a widely known fact that renewable energy in Saudi Arabia has not been able to adequately compete with subsidized fossil fuels (Farnoosh et al., 2014; Parajuli et al., 2015; Walters, 2017; Matar and Anwer, 2017; Matar and Shabaneh, 2020).

Fossil fuel subsidies are, in effect, viewed as a significant burden on Saudi Arabia's coffers. They have risen from \$47.02 billion in 2021 to \$76.94 billion in 2022, with the latter figure exceeding \$60.7 billion the Saudi government spent on health in the self-same fiscal year (IEA, 2023; Saudi Ministry of Health, 2024). This economically perverse mammoth subsidy could engender wasteful consumption of fossil fuels, which would stand as a massive financial burden, discourage the development and use of renewable energy, and exacerbate environmental degradation (Sovacool, 2017). The role of fossil fuel subsidies in discouraging the development and deployment of renewable energy has been proven by a number of studies, such as Arias and van Beers (2013), Besada and Olender (2015), Aryanpur et al. (2022), Antimiani et al. (2023), Zhang and Chiu (2023), and Hosan et al. (2023).

Saudi Arabia has only a relatively limited experience in the sphere of renewable energy technologies (Alsulami et al., 2024). In spite of the fact that the Kingdom has massive potential for solar (Farnoosh et al., 2014) and wind resources (Alyousef and Stevens, 2011), it produced 67% of its electricity from natural gas, 33% from oil, and only 0.2% from renewable energy sources in 2022 (U.S. Energy Information Administration, 2023). This is deemed a low percentage and a far cry from its ambitious goal of generating 50% of energy from renewables by 2030 (Al-Saidi, 2022). However, the important steps that the Kingdom is taking towards adopting renewable energy sources under the wider banner of Saudi Vision 2030, which was launched on April 25, 2016, can by no means be overrated. In 2017, the Kingdom launched the National Renewable Energy Program (NREP), which chiefly aims to incorporate 50% renewable technologies and 50% natural gas into the country's power system by 2030 (Matar et al., 2024; Hassan and El-Amin, 2024). The Kingdom also announced in 2021 the Green Saudi Arabia and Green Middle East initiatives, which together cover a massive program to plant 50 billion trees and eliminate 130 million tons of carbon emissions (Al-Saidi, 2022).

The environmental impact of fossil fuel subsidy reform in Saudi Arabia has been the subject matter of a plethora of research works, such as Sarrakh et al. (2020), Alshammari (2021), Naef (2024), and Matar et al. (2024). By contrast, a range of studies, such as Sarrakh et al. (2020), Bah and Saari (2020), Aldubyan and Gasim (2021), Gasim and Matar (2023), and Gasim et al. (2023), had an altogether different thematic scope as they were predominantly interested in estimating the size of energy subsidies along with identifying the outcome of their elimination on the livelihood of poor families and the welfare in Saudi Arabia. Some studies preferred to unearth the factors that Saudis take into account when moving towards the use of renewable energy, such as Mosly and Makki (2018), Almulhim and Al Yousif (2023), and Alsulami et al. (2024). What is worthy of mention at this juncture is that even the studies that have attempted to investigate the relationship between fossil fuel subsidies and the development and use of renewable energy in Saudi Arabia, such as Farnoosh et al. (2014), Parajuli et al. (2015), Matar et al. (2016, 2017), Matar and Anwer (2017), and Matar and Shabaneh (2020), with which ours shares the same scope, are outdated and did not take into consideration the second wave of energy price reform enacted in 2018.

This is principally why the present research paper aims to fill the knowledge gap left by previous studies by endeavoring to provide a more nuanced assessment of the impact of fossil fuel subsidies on renewable energy generation in Saudi Arabia using the ARDL model during

the period from 1995 to 2023. We deliberately targeted this period as such because it brings together the two waves of energy price reforms implemented in 2016 and 2018. This, we believe, will make the analysis far more useful for tailoring effective energy policies to accelerate the smooth transition to renewable energy and boost energy security and economic stability as a whole.

The importance of this research paper also lies in determining the percentage of improvement in renewable energy production as a result of reducing fossil fuel subsidies in view of the potential of renewable energy to unlock domestic fossil fuels used to generate energy and export them instead or convert them into value-added products by downstream industry in addition to meeting the many and varied local energy needs. Needless to say, if renewable energy sources are not adequately developed in Saudi Arabia, the rapid increase in domestic energy demand could potentially ultimately exhaust all fossil fuels allocated for export in the future. This will entail a negative impact on the country's budget and the living conditions of its citizens, who are accustomed to well-being and prosperity. Saudi Arabia may, as a result, even lose its strategic role in OPEC and the global oil market and no longer have enormous political benefits. These potential repercussions are much more perilous than the non-economic justifications that are being clung to, such as prestige and modernity images attached to the development of large-scale renewable energy projects and nuclear energy in the NEOM project, including "The Line" city. Unlike previous studies that overlooked important structural breaks, our study aims to pinpoint structural changes in the econometric relationship between variables by relying on the Zivot-Andrews test, which can accurately detect a structural break point.

In order to achieve the aforementioned aims, the rest of this paper is structured as follows: Section 2 reviews the relevant literature. Section 3 sheds light on the trends in fossil fuel subsidies and renewable energy generation in Saudi Arabia. Section 4 introduces the data and presents the econometric methodology in detail. Section 5 reports and discusses the estimation results. Section 6 concludes with some recommendations.

## **2. Literature Review**

The low cost of fossil fuels, by dint of subsidies, incentivizes consumers to consume more energy in utterly inefficient ways and, by the same token, encourages waste, thus hindering all manner of efforts put into reducing overall energy consumption and transitioning to a low-carbon energy system. On the one hand, fossil fuel subsidies are viewed by governments as pro-poor citizen schemes as they enable energy to be made more affordable for low-income households. This indubitably clearly contributes to lessening energy poverty and improving living conditions for less privileged households. After all, oil-rich governments opt for fossil fuel subsidies essentially because they seek to improve the social welfare of the country, support local industries, enhance their international competitiveness, and gain citizens' support for a range of subtly intertwined political considerations. All these factors stood as virtually impenetrable barriers to the process of eliminating fossil fuel subsidies (Alderman, 2002). On the other hand, these subsidies usually trigger off major instances of resource misallocation and are often the biggest cause behind the creation of long-term economic inefficiencies. They also contribute to massively undermining the competitiveness of renewable energy sources and stand as sturdy political and financial barriers to the adoption of RE technologies. Additionally,

they delay the transition to a sustainable energy system (Rogelj et al., 2016). Reforming fossil fuel subsidies would, therefore, generate additional badly needed financial resources for the public budget. These could be later invested in renewable energy or used as adjunct or primary compensatory measures for those energy-intensive sectors whose competitiveness potential depends heavily upon those subsidies (Monasterolo and Raberto, 2019). Antimiani et al. (2023) disclosed that the utter elimination of all the existing facets of fossil fuels and the allocation of the resulting revenues by virtue of deploying an innovation fund can unquestionably give a strong boost to renewable energy and achieve environmental targets at much lower costs.

Fossil fuel subsidies can target either energy consumption or energy production. Consumption subsidies denote that the price paid by consumers is less than the cost of supply. Governments of low-income and emerging countries usually opt for this type of subsidy to reduce households' energy bills. These subsidies, however, tend to benefit wealthier households and have less impact on energy poverty. Del Granado and Coady (2012) emphasized that fuel subsidies are an unduly expensive approach to protecting the poor. The co-authors went on to argue that such subsidies' benefits are largely leaked to the highest-earning groups, with the top income quintile capturing six times more subsidies than the bottom income quintile. They also unearthed that cutting down on fuel subsidies by \$0.25 per liter results in a 5% decrease in income for all groups as a result of the indirect impact on the prices of other goods and services that families habitually consume. Therefore, a number of studies have put forward that, for optimal outcomes, the reduction of fossil fuel subsidies ought to be accompanied by cash transfers to compensate poor and middle-income households (Koplow and Dernbach, 2001; Coady et al., 2010, 2015; Del Granado and Coady, 2012; Jiang and Lin, 2014). With regard to the other type of subsidy, production subsidies, by acting on supply-side production, contribute to keeping the price of fossil fuel extraction and energy production below the market price. This will result in increased profitability for mining and utility companies (Coady et al., 2017; Soile and Mu, 2015). Naef (2024) added on this front that when fossil fuel subsidies are removed, fossil fuel companies can reconvert into other renewable energy-related businesses.

Zimmer et al. (2021) enumerated a number of other reasons for the persistence of fossil fuel subsidies and the difficulty associated with their elimination. They mentioned the lack of public information about the size, distribution, and effects of subsidies, weak institutions' inability to better target those subsidies, and the lack of confidence in the government's ability to use the fiscal revenues generated from energy subsidy removal (especially in corruption-prone countries). They also referred to concerns about the detrimental impact these removals have on the poor and inflation. Countries that have attempted to abruptly eliminate fossil fuel subsidies have faced large popular protests, as happened in Mexico in 2017 and in Ecuador in 2019. Such forms of popular unrest are not confined to less developed countries. Even in France, a developed country, a fuel tax increase sparked the Yellow Vest movement. When such situations arise, governments often tend to take a step back rather than pursue reform efforts.

Among the most significant recent studies that addressed in some satisfactory depth the relationship between fossil fuel subsidies and the development and use of renewable energies in Saudi Arabia, it is worth mentioning the study carried out by Parajuli et al. (2015), which confirmed, amongst an array of other things, that fossil fuel subsidies are among the most

demanding challenges facing Saudi Arabia in implementing more environmentally friendly solutions based on the use of renewable energy technologies.

A number of other studies, namely those of Matar et al. (2016, 2017), Matar and Anwer (2017), and Matar and Shabaneh (2020), agree that plans to reform fuel prices in Saudi Arabia will enable the burning of petroleum products to be replaced with alternative energy technologies. In an undertaking whose scope partly matches those of the previously mentioned studies, Groissböck and Pickl (2018) disclosed that a fuel price equivalent to 60% of the international wholesale fuel price would result in approximately 50% of the total power capacity generated from entirely renewable technologies by 2030 in Saudi Arabia. Farnoosh et al. (2014) underscored that if the Kingdom succeeded in shifting from an energy mix based on 100% fossil fuels to a mix where the share of renewable energy sources is 30%, it would be empowered to gain an annual cost reduction of up to 3% during the period between 2020 and 2030.

It is worthy of mention that some studies have a completely different scope, as they opted for attempting to get to the bottom of the factors that condition the Saudis' decision with regard to the use of renewable energies. By way of illustration, Almulhim and Al Yousif (2023) concluded that the "economic criterion" is the most important criterion that matters most to Saudis when attempting to move towards renewable energy. It is accompanied by a number of other secondary ones, namely the 'environmental criterion', 'social criterion', and 'risk criterion'. Towards the end of their paper, they made a significant recommendation based on the need for the government and policymakers in Saudi Arabia to take into account economic, environmental, and social criteria far more carefully when choosing the most relevant scenario for investment in renewable energy. Mosly and Makki (2018) investigated social responses to the purchase and use of renewable energy in Saudi Arabia. They found out that the most influential factor that governs decisions to adopt RE is economic. Similarly, they concluded that people in the 18-29 age range were more willing to adopt alternative energy sources, such as renewable energy, early on. This interesting result was interpreted by the level of awareness of this group compared to other groups. Alsulami et al. (2024) investigated the factors that may encourage or hinder the adoption of renewable energy among Saudi consumers, especially in light of the Saudi government's plans to generate 50% of electricity from renewable energy sources by 2030. They concluded that the paucity of knowledge with regard to renewable energy among Saudi consumers constitutes a major hurdle to adopting this sustainable energy. This is prone to frustrate the Saudi government's efforts to encourage the implementation of renewable energy schemes locally.

A number of other studies have had a set of different aims as they laid emphasis upon estimating the size of energy subsidies, the enormity of the impact their elimination will have on poor households, and the size of the gains achieved through energy price reforms in Saudi Arabia. According to Sarrakh et al. (2020), the value of energy subsidies in Saudi Arabia amounted to \$80 billion in 2012, the equivalent of 11% of the country's GDP. They concluded that the total removal of energy subsidies in the absence of social safety nets would negatively affect the economy of Saudi Arabia by increasing energy prices. The outright removal of subsidies, accompanied by a targeted cash transfer to shield the social and health sectors, would have a positive impact on the country's economy. They, therefore, stressed how important it is for

the Saudi government to reform current subsidy programs to ensure a sustainable future for Saudi citizens. Gasim and Matar (2023) revealed that energy subsidies peaked at \$85 billion in 2012 in Saudi Arabia, then decreased to \$39 billion in 2016 as an immediate outcome of implementing the first wave of energy price reform in 2016, then rose to \$47 billion in 2018 after the second wave of reforms; this was put down to some recovery in global oil prices. Bah and Saari (2020) reported that a 90% increase in energy prices worsens the financial burden on the poorest households by 12.6%, compared to 5.14% for the richest households in Saudi Arabia. The co-researchers also confirmed that the citizen account system, which is a comprehensive compensation scheme allocated to low- to middle-income households, adequately shields these household categories against energy price reforms. It, however, does not protect high-income groups. Aldubyan and Gasim (2021) concluded that energy price reforms related to gasoline and residential electricity delivered total welfare gains of 8.8 and 3.8 billion SAR, respectively, in 2018. The co-authors have also found out that these reforms led to significant increases in government revenues in 2018, totaling roughly 32.8 billion SAR. The researchers went on to report that part of this increase in government revenues was put into financing the Citizens' Account. Stated more clearly, about 19.4 billion SAR was used to comprehensively compensate lower- to middle-income households. This denotes that the Saudi government has been left with a net gain of 13.4 billion SAR. For obtaining comprehensive as well as accurate price and income elasticity estimates, Gasim et al. (2023) have modeled energy demand across five end-use sectors and 15 energy producers in Saudi Arabia. They subsequently conducted a welfare analysis of the energy price reforms implemented in 2016 and 2018. The gleaned findings reveal that the 2016 reform delivered a total annual welfare gain of US\$11.6 billion in 2016, while annual welfare gains rose to US\$17 billion in 2018, specifically after the 2018 reform.

### **3. Trends in fossil fuel subsidies and renewable energy generation in Saudi Arabia**

The Kingdom of Saudi Arabia, whose economy depends extensively on fossil fuels, is regarded as one of the world's largest producers and exporters of oil and gas. Energy prices in the Kingdom are still among the lowest in the world on account of the abundance of oil resources and the low cost of local production. Gasoline is deemed the most subsidized oil product in the Kingdom. Bloomberg (2024) reports that fuel prices in Saudi Arabia are amongst the lowest in the entire world. Gasoline, for example, costs only 62 cents per liter, while its global price is \$2.54 per liter. This large support for gasoline can be ascribable to the lack of public transportation and the country's geographical expansion, in addition to the fact that Saudi citizens believe that they have the right to obtain low energy prices in a country where the government controls the production of fossil fuels (Sarrakh et al., 2020). It is utterly undeniable that fossil fuel subsidies impose a significant burden on Saudi Arabia's coffers. They have gone up from \$47.02 billion in 2021 to \$76.94 billion in 2022, with the latter figure exceeding \$60.7 billion the Saudi government allocated to healthcare expenses in the self-same fiscal year (IEA, 2023; Saudi Ministry of Health, 2024). This unduly generous subsidy encourages wasteful fossil fuel consumption, which constitutes a significant financial burden, discourages the development and use of renewable energy, and, worse still, inevitably causes large-scale environmental degradation (Sovacool, 2017).

Saudi Arabia has been known for decades for laying mega obstacles for climate change agreements and for dominating the positions of the oil-exporting countries that dread the negative spillovers of the energy transition on their carbon industries (Depledge, 2008). The Kingdom had built strong fiscal buffers during the boom years of 2011–2014 and was hugely confident in its ability to readily cope with falling oil prices for a longer period of time (IMF, 2016). In 2016, however, it was compelled to borrow money for the first time through the international bond market (Bradshaw et al. 2019). This forced the country to realize the urgent need to diversify its economic base and energy mix following the repercussions of falling global oil prices at the end of 2014. The sustained period of low oil prices gave rise to an urgent need to plug the existing budgetary holes. The Kingdom has, consequently, begun to implement austerity measures, including fuel subsidy reduction, and explore different energy policy paths in order to pave the way for a cleaner and more sustainable future under the wider banner of Saudi Vision 2030, which was launched on April 25, 2016. It is worth emphasizing that this comprehensive and ambitious blueprint for social and economic reform seeks to diversify the Saudi economy, reduce its dependence on fossil fuels, advance renewable energy resources, and make the Saudi energy system far more productive and more dependent on sustainable energy sources (Khan et al., 2023). Relatively recently, the Kingdom has become acutely aware that the development and use of renewable energy will significantly augment the economic efficiency of using local resources and will free up barrels of oil used to generate electricity that is initially sold at a low, subsidized local price and export them instead at high international prices; the additional revenues thereof can be transferred to Saudi citizens (Blazquez and Manzano, 2017). In 2017, the Kingdom launched the National Renewable Energy Program (NREP). What principally characterizes this program is that it has set out to include 50% renewable technologies and 50% natural gas in the power system by 2030 (Matar et al., 2024). The country has likewise attempted to develop a powerful plan to generate electricity from renewable sources, such as wind and solar energy, in isolated cities (Amran et al., 2020). The Kingdom has also pledged a nationally determined contribution (NDC) to reduce its annual greenhouse gas emissions by 278 million tons of carbon dioxide annually by 2030 (Ghasim and Matar, 2023).

Saudi Arabia announced in 2021, as a part of the NEOM project, a highly ambitious plan to build a futuristic city called “The Line”. It is forecast that this city will be car-free, will contain a clean underground transportation system, and will have zero carbon emissions. This city is, likewise, expected to extend over a distance of 170 kilometers at a cost ranging between \$100 and \$200 billion. Saudi Arabia has also promoted the use of clean hydrogen and aims to be a global leader in this sector (Al-Saidi, 2022). It is worthy of mention that Saudi Arabia still faces major challenges in its transition towards green hydrogen production, such as high production costs and a lack of infrastructure. Hence, it still needs to make great strides in investing in research and development in this field (Hassan et al., 2023). In 2021, Saudi Arabia also embarked upon the ambitious Green Saudi Arabia and Green Middle East initiatives. What hallmarks these initiatives is that they encompass a massive program to plant 50 billion trees and eliminate 130 million tons of carbon emissions (Al-Saidi, 2022). Despite the glaring fact that its results may take more years to be achieved, the energy transition in Saudi Arabia is beginning to take shape. In 2022, Saudi Arabia generated 67% of its electricity from natural

gas, 33% from oil, and only 0.2% from renewable energy sources (U.S. Energy Information Administration, 2023). This is deemed an inadequately small percentage compared to the Kingdom's potential for renewable energy sources and is by no means anywhere near its ambitious goal of generating 50% of its energy from renewable energy sources by 2030 (Al-Saidi, 2022).

Reforming energy prices continues to be a major political and economic challenge for the Saudi government, which has backburnered the complete and sudden elimination of subsidies and has chosen to divide the price increase into several phases over a period of years in order to avoid popular unrest and give the economy enough time to adapt to rising energy prices (Sarrakh et al., 2020). In fact, as a result of concerns about fiscal sustainability, the Saudi government has taken some measures bearing upon energy subsidy reform, and the sharp decline in oil prices has been the optimum opportunity to do so. The Saudi government enacted three waves of energy price reforms in 2016, 2018, and 2024, successively. The first wave of energy price reform took place on January 1, 2016, and targeted all energy products. This has caused fuel, electricity, and water prices to go frighteningly up for industry and families alike. On January 1, 2018, the second wave was implemented. It focused on end-use energy consumption, especially household consumption. Ghasim et al. (2023) maintained that, aiming primarily to boost non-oil revenues, this second wave coincided with the introduction of a 5% value-added tax on all goods and services and the imposition of fees on expatriates and foreign residents. The third wave was characterized by raising the price of diesel by 53% in January 2024. Despite this, energy prices are still below international benchmarks. Therefore, the country needs to embark on further reforms (Matar et al., 2024). Before the implementation of the second wave of energy price reforms in 2018, Saudi Arabia established the Citizen's Account program, which began operating in December 2017. It is a cash transfer program that supports low- to middle-income households in an environment of high prices and compensates them for financial reforms, like subsidy reforms or the introduction of the value-added tax (VAT), through cash transfers. This rewarding program is still active to this day (Ghasim et al., 2023; Matar et al., 2024). In July 2024, the program's Director General of Communications, Abdullah Al-Hajri, stated that the total amount paid by the program to beneficiaries since its launch amounted to \$54.7 billion. He also reported that the number of beneficiaries who met the eligibility criteria amounted to a staggering total of 10.8 million (Sabq, 2024). This account is enfeebled by one major feature, namely that it grants cash transfers exclusively to Saudi citizens, while non-nationals are completely deprived of receiving any benefits (Ghasim and Matar, 2023). Despite enacting three waves of subsidy reforms, the Kingdom is still lagging far behind compared to one of its neighbors, the United Arab Emirates, which is considered an important exception by dint of its great success in abandoning the fuel subsidy policy in 2015, which allowed the country to save more than \$7 billion annually (Arzaghi and Squalli, 2023). Aldubyan and Gasim (2021) observed that the Kingdom's lack of an efficient public transportation system as well as the need for cooling in an extremely hot climate limited consumers' ability to be more responsive to price increases.

It is noteworthy that Saudi Arabia does not apply Feed-in Tariffs (FIT), which have proven to be very effective with regard to boosting renewable energy development. These tariffs do so by facilitating the attraction of more renewable energy investments, augmenting the integration of

renewable energy sources into main electricity networks, and backing up the growth of new renewable energy schemes by offering long-term acquisition arrangements for the trade of renewable energy-generated electricity (Ramli and Twaha, 2015). These tariffs depend on long-term contracts or agreements (ranging from 10 to 20 years). In point of fact, Saudi Arabia does not currently provide tax credits of any kind to offset the installation costs of renewable energy, and there are no local incentives of any kind (Ko et al., 2019).

It goes without saying that, on account of the insufficiently small spending on research and development in the field of renewable energy in Saudi Arabia, the transition to clean energy will take much longer than 2030 to be fully accomplished. According to World Bank data, the Kingdom spent only 0.46% of its GDP on research and development in 2022. This is undoubtedly an extremely small percentage compared to its huge financial capabilities. This percentage confirms that financing green energy innovations with oil money to transform the Kingdom into a regional leader in clean energy innovation is still in its infancy, as it were. It was recently proven that Saudi Arabia is striving to focus on both protecting the local oil industry and unsparingly investing in clean energy technologies. The Kingdom simultaneously announced its intention to invest more than \$266 billion in the clean energy sector from 2023 to 2030. This is rated as the largest announced investment in the Arab region as a whole, as it is the real equivalent of the annual budgets for countries in their entirety (Reuters, 2023).

## **4. Data and estimation procedures**

### **4.1. Data**

This study uses annual time series data covering the time interval 1995-2023 for Saudi Arabia. This time period has been chosen on the basis of data availability for the following variables:

**RE:** Renewable Energy is the dependent variable. It is measured in Terawatt Hours (TWh) and is based on generation from renewable sources, including wind, geothermal, solar, biomass, waste, and other renewable sources. Data have been obtained from the BP Statistical Review of World Energy.

**FFS:** Fossil fuel subsidies that are consumed directly by end-users or consumed as inputs to electricity generation. Data have been obtained from the International Energy Agency (IEA) database.

**DIV:** Economic diversification is directly represented by the export diversification index, which in turn indicates whether the export structure of each country or country grouping differs from world patterns. It takes values between 0 (a high degree of diversification) and 1 (a low degree of diversification). Data have been obtained from the UNCTAD database.

**FD:** The financial development index summarizes how developed financial institutions and financial markets are in terms of their depth (size and liquidity), access (ability of individuals and companies to access financial services), and efficiency (ability of institutions to provide financial services at low cost and with sustainable revenues and the level of activity of capital markets). Data have been obtained from the IMF's Financial Development Index database.

**INV:** Innovation is directly measured by the number of patent applications. Data have been obtained from the WIPO Statistics Database.

**INFR:** The infrastructure quality index is constructed based on the quality of roads, railroads, ports, air transport, electricity and water supplies, and telecommunications networks and is graded on a scale of 0 to 100, where 100 represents a well-developed, extensive, and efficient infrastructure. Data have been obtained from the World Economic Forum's Global Competitiveness Report.

**EF:** The economic freedom index is measured based on 12 quantitative and qualitative factors and is graded on a scale of 0 to 100, where 100 represents the maximum freedom. Data have been obtained from the Heritage Foundation.

## 4.2. Estimation procedures

### 4.2.1. Autoregressive Distributed Lag (ARDL) Bound Testing Approach

The present study aims to investigate the impact of fossil fuel subsidies on renewable energy generation in Saudi Arabia over the period 1995–2023 using the autoregressive distributed lag (ARDL) approach developed by Pesaran et al. (1996, 2001) and Pesaran and Shin (1999).

In fact, cointegration tests are used to examine the existence of a long-run relationship between a dependent variable and a set of regressors. Conventional cointegration tests introduced by Engel and Granger (1987), Johansen (1988, 1991), and Johansen and Juselius (1990) require that the set of variables be integrated of the same order. Such a fact constitutes an important limitation on these cointegration tests. Fortunately, this problem can be overcome by using the ARDL approach developed by Pesaran et al. (1996, 2001) and Pesaran and Shin (1999). The crucial advantage of this approach is that it examines the long-run relationship between variables that are stationary at different levels after confirming that none of the series are integrated of the second order (Pesaran, 2015). Another important advantage of this estimation method is that it provides robust and consistent results when dealing with small sample sizes; it also uses an unrestricted error correction model, and thus it has better statistical properties than the Engle-Granger cointegration test and provides better and more reliable results in small sample sizes than Engle-Granger and Johansen cointegration tests (Pesaran and Shin, 1999; Pesaran et al., 2001; Pesaran, 2015). In an ARDL model, all variables can enter the right-hand side of the equation with different lags (Hill et al., 2018). Additionally, the ARDL approach tackles specific estimation-related issues such as serial correlation and endogeneity (Pesaran, 2015).

Thus, this study applies the ARDL estimation technique because of its inherent benefits. Our empirical models can be described by the following equations:

$$RE = f(FFS_t, DIV_t, FD_t, DUM_t) \quad (1)$$

$$RE = f(INV_t, INFR_t, EF_t, DUM_t) \quad (2)$$

where RE, FFS, DIV, FD, INV, INFR, EF, and DUM indicate renewable energy generation, fossil fuel subsidies, economic diversification, financial development, innovation, infrastructure quality index, economic freedom, and the dummy variable, respectively. Based

on equations (1) and (2), the autoregressive distributed lag (ARDL)  $(p, q_1, q_2, q_3, q_4)$  models are specified in the following general forms:

$$\begin{aligned} \Delta RE_t = & a_0 + \sum_{i=1}^{p-1} a_{1i} \Delta RE_{t-i} + \sum_{i=0}^{q_1-1} a_{2i} \Delta FFS_{t-i} + \sum_{i=0}^{q_2-1} a_{3i} \Delta DIV_{t-i} + \sum_{i=0}^{q_3-1} a_{4i} \Delta FD_{t-i} \\ & + \sum_{i=0}^{q_4-1} a_{5i} \Delta DUM_{t-i} + b_1 RE_{t-1} + b_2 FFS_{t-1} + b_3 DIV_{t-1} + b_4 FD_{t-1} \\ & + b_5 DUM_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta RE_t = & a_0 + \sum_{i=1}^{p-1} a_{1i} \Delta RE_{t-i} + \sum_{i=0}^{q_1-1} a_{2i} \Delta INV_{t-i} + \sum_{i=0}^{q_2-1} a_{3i} \Delta INFR_{t-i} + \sum_{i=0}^{q_3-1} a_{4i} \Delta EF_{t-i} \\ & + \sum_{i=0}^{q_4-1} a_{5i} \Delta DUM_{t-i} + b_1 RE_{t-1} + b_2 INV_{t-1} + b_3 INFR_{t-1} + b_4 EF_{t-1} \\ & + b_5 DUM_{t-1} + \varepsilon_t \end{aligned} \quad (4)$$

where  $\Delta$  denotes the first difference operator,  $a_0$  is the intercept, and  $\varepsilon_t$  is the error term and is assumed to be white noise. All variables are as previously defined. The parameters  $b_1, b_2, b_3, b_4$  and  $b_5$  are long-run multipliers. Lagged values of  $\Delta RE_t$  and current and lagged values of  $\Delta FFS, \Delta DIV, \Delta FD, \Delta INV, \Delta INFR, \Delta EF$ , and  $\Delta DUM$  are used to model the short-run dynamics. The optimal lag length is selected based on the minimum Akaike information criterion (AIC).

#### 4.2.1.1. ARDL Bounds test for cointegration:

Pesaran et al. (2001) proposed a test based on the F-statistic for the joint significance of lagged-level variables in order to determine the existence of a long-run relationship among variables. This approach involves testing the null hypothesis of the absence of a cointegration relationship:  $H_0: b_1 = b_2 = b_3 = b_4 = b_5 = 0$

If the null hypothesis of no cointegration is rejected, then we must accept the alternative hypothesis of the existence of a long-run relationship:  $H_1: b_1 \neq b_2 \neq b_3 \neq b_4 \neq b_5 \neq 0$

According to Pesaran et al. (2001), the asymptotic distribution of the F-statistic is non-standard under the null hypothesis of no cointegration among the variables, regardless of whether the variables are integrated of order zero  $I(0)$  or one  $I(1)$ . As a result, the co-authors provided two sets of asymptotic critical values. One set represents the lower bound critical value and assumes that all variables are  $I(0)$ , and the other represents the upper bound critical value and assumes that all variables are  $I(1)$ . This is why this test is known as the bounds test. If the calculated F-statistic falls above the upper bound critical value, then the null hypothesis of no cointegration is rejected. In contrast, the null hypothesis is accepted if the calculated F-statistic is below the lower bound critical value. Otherwise, the results are inconclusive if the computed F-statistic lies between these two bounds.

#### 4.2.1.2. Error Correction Model (ECM)

After confirming the existence of a long-term relationship, the error correction model (ECM) can be derived straightforwardly from the ARDL model and specifically through a simple linear transformation that is able to integrate short-run dynamics with long-run equilibrium using the previously selected optimal number of lags as follows:

$$\begin{aligned} \Delta RE_t = a_0 + \sum_{i=1}^{p-1} a_{1i} \Delta RE_{t-i} + \sum_{i=0}^{q_1-1} a_{2i} \Delta FFS_{t-i} + \sum_{i=0}^{q_2-1} a_{3i} \Delta DIV_{t-i} + \sum_{i=0}^{q_3-1} a_{4i} \Delta FD_{t-i} \\ + \sum_{i=0}^{q_4-1} a_{5i} \Delta DUM_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \end{aligned} \quad (5)$$

$$\begin{aligned} \Delta RE_t = a_0 + \sum_{i=1}^{p-1} a_{1i} \Delta RE_{t-i} + \sum_{i=0}^{q_1-1} a_{2i} \Delta INV_{t-i} + \sum_{i=0}^{q_2-1} a_{3i} \Delta INFR_{t-i} + \sum_{i=0}^{q_3-1} a_{4i} \Delta EF_{t-i} \\ + \sum_{i=0}^{q_4-1} a_{5i} \Delta DUM_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \end{aligned} \quad (6)$$

where  $\Delta$  is the first difference operator,  $a_0$  is the intercept,  $a_1$ ,  $a_2$ ,  $a_3$ ,  $a_4$  and  $a_5$  are the short-run dynamic coefficients,  $\lambda$  is the coefficient of the lagged error correction term (ECT), and  $\varepsilon_t$  is the error term.  $\lambda$  determines the speed of adjustment to long-run equilibrium, and it is worthwhile to note that this coefficient must be negative and statistically significant, and its value must range from -1 to 0.

#### 4.2.2. Diagnostic and stability tests

We used different diagnostic tests to check the validity of our ARDL results, such as the Breusch-Godfrey test, also known as the Lagrange multiplier (LM) test, which was developed by Breusch (1978) and Godfrey (1978), the ARCH (autoregressive conditional heteroscedasticity) test originally proposed by Engle (1982), the Jarque-Bera test, which is one of the most popular and straightforward tests for normality, and Ramsey's Regression Equation Specification Error Test (RESET), which was proposed by Ramsey (1969) and is by far the most popular test used to verify the correctness of the model specification.

Furthermore, we used the CUSUM and CUSUMSQ tests proposed by Brown et al. (1975) to check parameter instability and test for structural change over time.

### 5. Results and discussion

#### 5.1. Unit root test results

Table 1 summarizes the results of the ADF and PP unit root tests for all variables in levels and first differences. The results show that the null hypothesis of a unit root (non-stationarity) is rejected at the level for renewable energy (RE), implying that this variable is stationary in its level form. Whereas the null hypothesis of a unit root cannot be rejected for all remaining

variables in levels; the findings reveal that these variables become stationary after taking the first differences. In the presence of a structural break in the time series, the power of these conventional unit root tests may be rather weak. Therefore, the Zivot-Andrews (ZA) unit root test with one structural break is subsequently carried out to capture one structural break in each variable.

**Table 1. Unit root tests results**

	RE	FFS	DIV	FD	INV	INFR	EF
<b>ADF</b>							
Level	-4.890630 (0.0034)***	-1.798964 (0.6781)	-2.517923 (0.3177)	-1.852281 (0.6509)	-0.833180 (0.7944)	-2.742745 (0.2295)	-1.758000 (0.6967)
1 <sup>st</sup> difference		-4.254954 (0.0036)***	-6.274875 (0.0001)***	-5.184111 (0.0015)***	-6.821826 (0.0000)***	-3.614479 (0.0498)**	-5.952124 (0.0003)***
<b>PP</b>							
Level	-4.311423 (0.0106)**	-1.983562 (0.5847)	-2.445819 (0.3501)	-1.523070 (0.5080)	-0.571102 (0.9730)	-2.628918 (0.2715)	-1.597293 (0.7673)
1 <sup>st</sup> difference		-4.063477 (0.0184)**	-6.983373 (0.0000)***	-5.388381 (0.0010)***	-7.065937 (0.0000)***	-4.930140 (0.0029)***	-6.385275 (0.0001)***

**Notes:** All unit root tests include an intercept. Probability values are reported in parentheses. (\*\*\*), (\*\*), and (\*) indicate that the estimated parameters are significant at the 1%, 5%, and 10% significance levels, respectively.

**Source:** Author's own calculations.

Table 2 shows the outcomes of the ZA unit root test with one structural break. The findings indicate that renewable energy (RE) is stationary at the level at the 1% significance level, whereas all remaining variables become stationary after taking the first differences. More importantly, the break years are determined endogenously to capture the effect of any possible structural shift over the estimation period, and they occurred for various reasons. For instance, the break in 2014 can be attributed to the 70 percent drop in oil prices from their all-time highs in 2014. Amongst the many overlapping reasons for this historic slump, one could mention the oil glut, the lower global demand for oil, particularly from China and Europe, and the expansion of U.S. shale extraction. Furthermore, the breaks in 2015 and 2016 can be explained by the fact that the 2014–2016 oil price crash dragged on and wreaked new heights of economic devastation on Saudi Arabia and its OPEC colleagues. Between 2014 and 2016, Saudi Arabia itself moved from a budget surplus to a then-record high deficit in 2015 of US\$98 billion and spent at least US\$250 billion of its foreign exchange reserves over that, which have gone forever. On the other hand, Saudi Arabia, which is universally known as the swing producer and “central bank” of the oil supply, hasn't made any moves at that time to reduce oil production to bring up prices, as the low oil prices hurt Iran and precisely Russia, which supports the Assad regime in Syria. Nevertheless, the incessant collapse in world oil prices upended the Saudi economy, put the government face-to-face with a fait accompli, and forced it to tighten its austerity belts, reevaluate its financial priorities, reconsider its diversification strategies, focus on diversifying tributaries of the non-oil economy, and implement the first wave of energy price reform in 2016. Consequently, domestic gasoline, diesel, and electricity prices increased by up to 80%. This coincided with a strong desire to give a strong boost to renewable energy. In 2016, the Kingdom launched a new economic blueprint called "Saudi Vision 2030", in which it set an ambitious target of generating 9.5 GW of electricity from renewable sources by 2030. Three

years later, in 2019, this figure was dramatically revised upwards to 58.7 GW (about 50% of its electricity from renewables) and recently raised to 130 GW by that date. Moreover, the break in 2017 is mainly due to the launch of Neom, which is a USD\$500 billion giga-project and sprawling high-tech development initiative that encapsulates innovation and grandeur in the north-west of the country. In fact, the break in 2018 is ascribed to the second wave of energy price reform Saudi Arabia initiated in 2018. Analogously, the break in 2019 can be attributed to the successful initial public offering (IPO) of the world's largest oil producer, Saudi Aramco, in 2019. Additionally, the Saudi Cabinet amended the regulations governing the Saudi Stock Exchange (Tadawul) in the same year and allowed, for the first time, overseas investors to take controlling stakes. Construction activities gained pace during 2019, with a number of infrastructure plans either announced or initiated. In 2019, Saudi Arabia announced that it would, in partnership with Virgin Hyperloop One, begin construction on the world's longest hyperloop test track, which is considered a groundbreaking sustainable solution for the future of transportation in the country. This cutting-edge technology-based project includes the construction of a research and development center and hyperloop manufacturing facility north of Jeddah. Since most structural breaks are consistent in 2016, we create a dummy variable for the year 2016. The next step is to proceed with the ARDL bounds test, which is used to examine the presence of a long-run association among variables due to its authenticity and accuracy.

**Table 2. Zivot-Andrews unit root test with a structural break**

	RE	FFS	DIV	INV	FD	INFR	EF
<b>Level</b>	-8.443714***	-2.828743	-3.639326	-0.222390	-3.401555	-2.988531	-0.982697
<b>Break Point</b>	2016	2016	2015	2017	2016	2017	2012
<b>1<sup>st</sup> difference</b>		-7.213470***	-6.695755***	-10.10536***	-6.818418***	-6.932410***	-7.363444***
<b>Break Point</b>		2018	2016	2019	2019	2019	2019

**Notes:** Zivot-Andrews test statistics are as follows: -5.57 at the 1% critical value, -5.08 at the 5% critical value, and -4.82 at the 10% critical value. (\*\*\*), (\*\*), and (\*) indicate that the estimated parameters are significant at the 1%, 5%, and 10% significance levels, respectively.

**Source:** Author's own calculations.

Table 3 illustrates the optimal lag orders chosen based on the Akaike Information Criterion (AIC) and presents the results of the ARDL Bounds test with appropriate critical values and estimated F-statistics. The findings indicate that calculated F-statistics in the two models are higher than the upper-bound critical value I(1) at the 1%, 2.5%, 5%, and 10% significance levels, confirming the rejection of the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration. The next step is to determine the long-run and short-run elasticities.

**Table 3. ARDL Bounds Test Results**

	(a): Model 1	(b): Model 2	
<b>Optimal lag Structure</b>	(1, 1, 2, 2, 1)	(1, 1, 1, 2, 1)	
<b>F-Statistics</b>	5.392631	7.485234	
<b>K</b>	4	4	
	<b>Critical values</b>	<b>Lower bounds I(0)</b>	<b>Upper bounds I(1)</b>
	10%	2.2	3.09
	5%	2.56	3.49
	2.5%	2.88	3.87
	1%	3.29	4.37

**Notes:**  $k$  is the number of independent variables. Asymptotic critical values are obtained from Table CI(iii) in Pesaran et al. (2001).

**Source:** Author's own calculations.

Table 4 shows the short-run and long-run relationships between variables in the two models. In the long run, fossil fuel subsidies (FFS) negatively and significantly affect renewable energy generation in Saudi Arabia, confirming what has been reported by Farnoosh et al. (2014), Parajuli et al. (2015), Matar et al. (2016, 2017), Matar and Anwer (2017), and Matar and Shabaneh (2020). A decrease of 1% in fossil fuel subsidies (FFS) leads to an increase of 10.61% in renewable energy generation in Saudi Arabia. This can be explained by the fact that incessant inefficient fossil fuel subsidies incentivize consumers to consume more energy in utterly inefficient ways, encourage waste, trigger off major instances of resource misallocation, draw investors and companies into fossil fuel-based industries, contribute to massively undermining the competitiveness of renewable energy sources, and, by the same token, stand as sturdy political and financial barriers to the adoption of RE technologies in the Kingdom.

According to the regression results reported in column (a), economic diversification (DIV) appears to positively and significantly affect renewable energy generation in Saudi Arabia (given the fact that a high diversification score indicates a low level of diversification); this is consistent with the results of Shahzad et al. (2021). An increase of 1% in economic diversification (DIV) sparks a 3.74% increase in renewable energy production in Saudi Arabia. In fact, when economic diversification increases, the industries require more energy for manufacturing to meet the competition encountered, thus spurring an increase in the overall energy demand. Consequently, the government might enhance renewable energy investments to cover the additional energy demand, especially under the wider banner of Saudi Vision 2030, which aims to bring the Kingdom closer to a low-carbon future.

As can be readily seen in column (a), financial development (FD) is positively and significantly linked to renewable energy generation in Saudi Arabia. This result matches well with the results of Shahbaz et al. (2021) and Khan et al. (2021). An increase of 1% in financial development (FD) generates an increase of 6.1% in renewable energy production in Saudi Arabia. High financial development provides renewable energy investors with much-needed funds and plays an undeniably crucial role in facilitating a smooth transition to renewable energy.

The coefficient of the dummy variable introduced (DUM2016) is positive and statistically significant at the 1% level of significance, implying that the first wave of energy price reform implemented in 2016 acted as a pivotal economic mechanism to incentivize renewable energy generation. Additionally, the ambitious "Saudi Vision 2030" launched in 2016, has laid the first cornerstone for accelerating the Kingdom's renewable energy transition.

In the short run, renewable energy production is negatively and significantly affected by fossil fuel subsidies (FFS) in Saudi Arabia. A decrease of 1% in fossil fuel subsidies (FFS) causes renewable energy production to increase by 7.98% in Saudi Arabia, confirming that a rapid growth in renewable energy generation in the Kingdom can be driven by a phase-out of harmful and inefficient fossil fuel subsidies. The renewable energy market will remain hindered in the short run if the energy industry continues to lean on Saudi government largesse and chase the next subsidy.

As shown in column (a), economic diversification (DIV) exerts a significant positive impact on renewable energy generation in Saudi Arabia. An increase of 1% in economic diversification (DIV) generates an increase of 1.64% in renewable energy production in Saudi Arabia. In fact, economic diversification appears to be a key factor influencing renewable energy production in the short run in the Kingdom by escalating energy demand and inducing the Saudi government to meet the growing energy needs from renewable energy sources. In Vision 2030, the government pledges to diversify the Saudi economy away from oil and simultaneously generate 50% of the country's electricity from renewables by 2030.

Column (a) indicates that financial development (FD) has a significant positive impact on renewable energy production in Saudi Arabia. An increase of 1% in financial development (FD) causes renewable energy generation to increase by 4.2% in Saudi Arabia. In the short run, the Kingdom's financial sector can step up its role in mobilizing the much-needed capital for the development of clean and renewable sources of energy and unlocking renewable energy investments.

The coefficient of the dummy variable (DUM2016) is positive and statistically significant at the 1% level of significance, indicating that the first round of energy price reform initiated in 2016 along with the Kingdom's ambitious 2030 roadmap charted a bold path towards delivering the 50% renewable energy target by 2030. The more the Kingdom commits to reforms aimed at boosting renewable energy, the brighter the short-term horizon will be.

According to the results shown in column (a), the coefficient of the error correction term (ECT) is negative and statistically significant, confirming the consistency of the ARDL model. Furthermore, the error correction term (ECT) approves the long-run relationship between renewable energy generation, fossil fuel subsidies, economic diversification, and financial development and indicates that the speed of adjustment towards long-run equilibrium is 76.6% annually in Saudi Arabia.

As shown in column (b), and precisely in the long run, innovation (INV) positively and significantly affects renewable energy generation in Saudi Arabia, confirming what has been reported by Alam and Murad (2020) and Vural (2021). An increase of 1% in innovation (INV) leads to an increase of 8.73% in renewable energy generation in Saudi Arabia. Promoting the technological arsenal necessary for renewable energy is one of the most important priorities in the long energy transition journey, given the fact that innovation and more advanced technologies are intimately associated with lower costs of renewable energy generation.

According to the regression results reported in column (b), the infrastructure quality index (INFR) appears to positively and significantly affect renewable energy generation in Saudi Arabia; this is consistent with the results of Hamed et al. (2012). An increase of 1% in the infrastructure quality index sparks a 7.85% increase in renewable energy production in Saudi Arabia. This can be explained by the fact that renewable energy investments necessarily require a well-developed, extensive, and efficient infrastructure that brings the advantages of cost savings, reduces the effect of distance between regions, and allows renewable energy entrepreneurs to work unhindered.

As can be readily seen in column (b), economic freedom (EF) is positively and significantly linked to renewable energy generation in Saudi Arabia. This result matches well with the results of Bellakhal et al. (2019). An increase of 1% in economic freedom (EF) generates an increase of 3.99% in renewable energy production in Saudi Arabia. This can be explained by the fact that more economic freedom facilitates bringing cutting-edge renewable energy technologies through trade and investment channels, thereby encouraging the uptake of renewables and sustaining their generating capacities.

In the short run, innovation (INV) has a significant positive impact on renewable energy production in Saudi Arabia. An increase of 1% in innovation (INV) causes renewable energy generation to increase by 8.48% in Saudi Arabia. If truth be told, it is impossible for renewable energy investments to come to fruition in the short term without making unprecedented efforts to induce innovation and increase R&D spending.

Column (b) indicates that renewable energy production is positively and significantly affected by the infrastructure quality index (INFR) in Saudi Arabia. An increase of 1% in the infrastructure quality index (INFR) leads to an increase of 5.55% in renewable energy generation in Saudi Arabia, confirming that rapid growth in renewable energy generation in Saudi Arabia can be unerringly achieved by optimizing energy infrastructure development.

As shown in column (b), economic freedom (EF) exerts a significant positive impact on renewable energy generation in Saudi Arabia. An increase of 1% in economic freedom (EF) generates an increase of 2.47% in renewable energy production in Saudi Arabia. In fact, economic freedom has a crucial role to play in instigating renewable energy production in the short run in the Kingdom by making technology transfer as smooth as possible and enticing renewable energy investors through much more permissive investment schemes.

According to the results shown in column (b), the coefficient of the error correction term (ECT) is negative and statistically significant, confirming the consistency of the ARDL model. Furthermore, the error correction term (ECT) approves the long-run relationship between renewable energy generation, innovation, the infrastructure quality index, and economic freedom and indicates that the speed of adjustment towards long-run equilibrium is 59.08% annually in Saudi Arabia.

A variety of diagnostic tests have been used to confirm that there are no issues of serial correlation, heteroskedasticity, or omitted variable bias in both models. The results of these diagnostic tests are shown in Table 5.

**Table 4. ARDL long-run and short-run results**

Dependent variable: (RE)	(a): Model 1	Dependent variable: (RE)	(b): Model 2
<b>Long-run coefficients</b>			
<b>FFS</b>	-10.60953 (0.0217)**	<b>INV</b>	8.735161 (0.0326)**
<b>DIV</b>	-3.745925 (0.0000)***	<b>INFR</b>	7.847565 (0.0368)**
<b>FD</b>	6.102506 (0.0249)**	<b>EF</b>	3.987779 (0.0305)**
<b>DUM2016</b>	3.253403	<b>DUM2016</b>	2.908107

	(0.0051)***		(0.0337)**
<b>Constant</b>	0.531118 (0.0271)**	<b>Constant</b>	0.379614 (0.0088)***
<b>Short-run coefficients</b>			
$\Delta$ FFS	-7.983687 (0.0000)***	$\Delta$ INV	8.483420 (0.0190)**
$\Delta$ DIV	-1.638079 (0.0000)***	$\Delta$ INFR	5.547785 (0.0259)**
$\Delta$ FD	4.205822 (0.0034)***	$\Delta$ EF	2.470946 (0.0000)***
$\Delta$ DUM2016	2.532485 (0.0000)***	$\Delta$ DUM2016	2.121494 (0.0087)***
<b>The Error Correction Term (ECT-1)</b>	-0.766045 (0.0002)***	<b>The Error Correction Term (ECT-1)</b>	-0.590821 (0.0029)***

**Notes:** Probability values are reported in parentheses. The asterisks (\*), (\*\*), and (\*\*\*) indicate that the estimated coefficients are statistically significant at the 10%, 5%, and 1% significance levels, respectively.

**In relation to economic diversification (DIV), the negative sign is interpreted here as a positive effect/impact and vice versa, since a high diversification score indicates a low level of diversification.**

**Source:** Author's own calculations.

According to the results shown in Table 5, the Breusch-Godfrey serial correlation LM test indicates that there is no serial correlation in residuals in the two models, as the p-value is greater than 0.05 in the two ARDL estimations. The results of the Jarque-Bera normality test indicate that residuals are normally distributed in the two models, as the null hypothesis of normal distribution of the residuals cannot be rejected (because all corresponding p-values are greater than 0.05). The ARCH results conclude the absence of heteroscedasticity in the residuals in the two models, as all corresponding p-values are greater than 0.05. Furthermore, the Ramsey RESET test is used to check for misspecification of the models, and it confirms that both ARDL models are correctly specified, as all corresponding p-values are greater than 0.05. In fact, both ARDL models have successfully passed all diagnostic tests.

In order to check the robustness and stability of the estimated ARDL models, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests have been used. A visual representation of CUSUM and CUSUMSQ is provided in Figure 1.

**Table 5. Diagnostic tests of ARDL models**

	<b>(a): Model 1</b>		<b>(b): Model 2</b>	
	<b>F-version</b>	$\chi^2$ <b>version</b>	<b>F-version</b>	$\chi^2$ <b>version</b>
<b>Breusch-Godfrey LM test</b>	0.417080 (0.6725)	2.360611 (0.3072)	0.575720 (0.5709)	1.455451 (0.4830)
<b>Jarque-Bera Normality test</b>	-	1.173072 (0.556251)	-	1.432979 (0.488464)
<b>Heteroscedasticity Test (ARCH)</b>	0.084842 (0.7732)	0.091319 (0.7625)	0.180321 (0.6747)	0.193352 (0.6601)
<b>Ramsey RESET test</b>	0.154040 (0.6985)	-	0.276429 (0.6043)	-

**Note:** The probability value is given in parentheses below the test statistic.

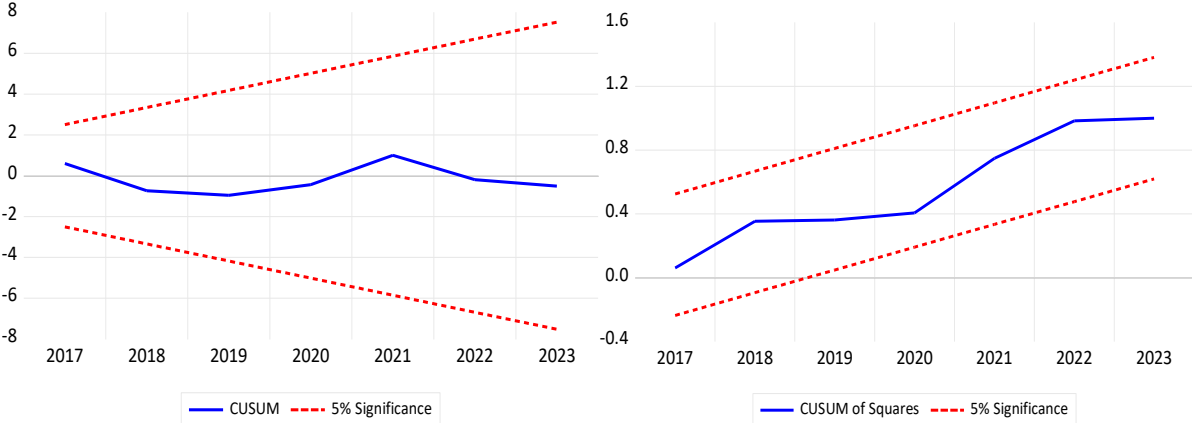
**Source:** Author's own calculations.

As shown in Figure 1, the plots of CUSUM and CUSUMSQ statistics stay within the critical bounds of the 5% significance level (represented by the pair of straight lines drawn at the 5% significance level), indicating the stability of the two models. To sum up, all these tests reflect the validity and reliability of the results, which in turn confirm that the phase-out of inept fossil

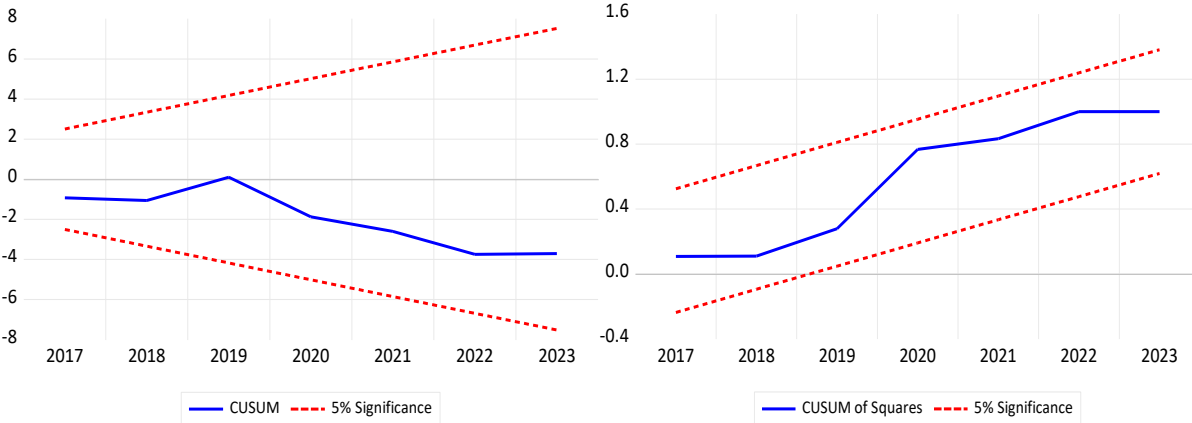
fuel subsidies, which stop being a catalyst and start becoming a crutch, can jump-start the renewable energy industry in Saudi Arabia in the short and long run.

**Figure 1. Plots of CUSUM and CUSUMSQ of recursive residuals**

**Model 1**



**Model 2**



**6. Conclusion**

This current undertaking has unearthed that eliminating inept fossil fuel subsidies has the greatest potential to significantly enhance renewable energy production as well as pave the way for a smooth transition to a sustainable energy system. After all, a decrease of 1% in fossil fuel subsidies would increase renewable energy production by 7.98% and 10.61% in Saudi Arabia in the short and long run, respectively. These findings could prove substantially important to policymakers and stakeholders who want to boost the benefits of fossil fuel subsidy removal and direct the resulting revenues to jump-start the renewable energy industry. The Saudi government should not slack off on its endeavors to phase out futile fossil fuel subsidies, especially in boom years and times of oil price hikes. What underpins this conviction is that the continuous commitment to removing these subsidies sends a patently strong signal to the market and renewable energy investors that the government is genuinely committed to moving steadily towards cleaner and more sustainable energy sources. This has the potential to entice and encourage individuals and companies towards the transition to renewable energy.

- In addition to reforming fossil fuel subsidies, measures, such as the imposition of carbon taxes, can be put in place. This can be followed by redirecting the collected funds towards supporting renewable energy technologies and energy efficiency measures, starting to implement Feed-in-Tariffs that encourage investors to get involved in renewable energy projects, and conducting tenders to obtain the lowest price for renewable energy 24/7, 365 days a year.
- Saudi Arabia ought to give a strong impetus to innovation for improving the efficiency of renewable energy sources and reducing the cost of producing and storing this energy by raising spending on research and development allocated for this to more than 1% of GDP. This will result in boosting the competitiveness of renewable energy and ensuring an uninterrupted supply of renewable energy-generated electricity.
- Saudi Arabia should enhance investment in improving public transportation, which will alleviate the adverse effects of phasing out fossil fuel subsidies on most low- and middle-income groups, regardless of whether they happen to be Saudis or expatriates. Needless to say, bringing about profitable energy subsidy reform was much easier in the United Arab Emirates by dint of the availability of public transportation alternatives.
- Saudi Arabia is in dire need, so to speak, to quadruple the promotion of education and awareness with regard to the myriad benefits renewable energy can bestow on long-term economic prosperity and the role it can play in achieving a sustainable future. This can be accomplished by launching public awareness campaigns in relation to sustainable livelihoods and low-carbon lifestyles and providing education and training for fresh university graduates and the workforce on renewable energy. The ultimate objective of these steps is to render eliminating fossil fuel subsidies and converting them to developing renewable energy sources more widely acceptable.
- Saudi Arabia must fight all manner of complacency as far as economic diversification is concerned. This is primarily because delaying economic diversification along with phasing out fossil fuel subsidies and directing the resulting revenues to develop and deploy renewable energy with the aim of supporting the state treasury by exporting more oil and gas that were being burned will increase the Kingdom's dependence on oil. Stated differently, a larger share of its GDP will thus be directly linked to oil exports and, potentially, to oil price shocks.
- It is undeniably true that the Saudi government has coupled the energy subsidy reform with the creation of the Citizen's Account program, whose chief aim has been to compensate low- to middle-income households for energy price increases through monthly cash transfers. It has, none the less, fallen woefully short of the inclusion of non-Saudi nationals in that program. This has the immediate, yet negative, impact of putting expatriates and foreign residents at a disadvantage since they are forced to pay monthly financial fees for their companions. The Saudi government must, therefore, take appropriate measures to lessen these tough challenges in order to preserve its image and its attractiveness to foreign workers on whom the Saudi economy depends. This program has yet another bad impact as it excludes the stateless Bidoons, who are displaced tribes unable to obtain Saudi citizenship. They are originally Saudis, but they are treated as foreigners. According to statistics released by the United Nations High Commissioner for Refugees, the population of these tribes combined could reach 70,000

people, while local newspapers reported that it reaches 250,000 people (The European Saudi Organization for Human Rights, 2016). This state of affairs places Saudi Arabia before the inevitable necessity of regularizing their status so that “Vision 2030” does not lose the treasured standard of comprehensiveness.

Our research faces some limitations, which may constitute a pivotal foundation for future research undertakings. First and foremost, for primarily data unavailability reasons, this study has cast light on a period that does not specifically include the third wave of subsidy reform initiated in 2024. Secondly, it goes without saying that the impact of subsidy reform is not merely confined to the environmental, social, and economic impacts, welfare, and income distribution as such; rather, it can be inextricably tied up to the Kingdom’s influence on the global oil market and the world of politics related to that. Hence, future research studies can scrutinize the impact of the magnanimous subsidy policy continuity, which is hallmarked by its potential for invigorating lavish energy consumption and depleting the oil stocks allocated for future exports, on the Kingdom’s position in OPEC+. This is regarded as a genuinely indispensable bargaining card that the Kingdom has judiciously deployed in many regional and international issues. It is, likewise, crucial for Saudi Arabia to run comprehensive nationwide poverty assessment schemes. The availability and accessibility of this information will empower future research to verify the effectiveness of energy subsidy reform in curbing poverty and ensuring that poorer segments receive an adequate share of resource revenues.

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