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GCC Countries' Renewable Energy Penetration and the Progress of Their Energy Sector Projects

FAHAD RADHI ALHARBI, (Graduate Student Member, IEEE), AND DENES CSALA
Department of Engineering, Lancaster University, Lancaster LA1 4YR, U.K.

Corresponding author: Fahad Radhi Alharbi (f.alharbi@lancaster.ac.uk)

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ABSTRACT The member countries of the Gulf Cooperation Council (GCC) are reliant on fossil fuels to generate electricity. Fossil fuels also represent the main source of economic income in the region. Climate change is closely associated with the use of fossil fuels, and it has become the main motivation driving the GCC countries to search for alternative solutions, such as renewable energy technologies, to eliminate their reliance on fossil fuels and the climate burden attached. The GCC countries have all adopted plans for economic development and diversification to be implemented over two decades. Such plans are strengthened by a framework for long-term planning, which includes a strategic commitment to pursue the development process in a sustainable manner. This research provides a comprehensive review and strict follow-up to shed light on the renewable energy projects implemented in the GCC region and critically discusses future prospects. The projects foreshadow the GCC countries' ability to comply with the future requirements and to spearhead the renewable energy transition towards a more sustainable and equitable future. The main findings of this research reveal that the GCC countries have achieved significant progress in the field of renewable energy deployment. The United Arab Emirates and Saudi Arabia are at the top of the list for global renewable energy projects, while Kuwait and Oman have also announced the progress of their projects and have honored their pledges. We find that Bahrain and Qatar need to exercise more transparency in regard to disclosing information about the developments of their renewable energy projects. Finally, although several promising renewable energy projects are underway or have been announced in the region, their completion should be accelerated, and more projects must be implemented to fully meet the decarbonization targets and climate constraints.

INDEX TERMS Climate change, energy transition, GCC countries, projects progress, renewable energy, transition towards sustainability.

I. INTRODUCTION

As clean energy sources, renewable energy technologies (solar and wind) have grown considerably due to climate change, global warming, and carbon dioxide (CO2) emissions. In particular, with the rapid growth of global industrial activities, climate change and global warming are the most serious environmental issues worldwide. Currently, there is a sharp increase in the CO2 levels, which aggravate environmental issues [1]–[5]. The Met Office has reported that the global rate of climate warming and atmospheric CO2 has been forecasted to show a near-record increase in 2019 [6]. The growth in the CO2 levels is driven by the continuous burning of fossil fuels [7], the expansion of heavy industries [8], and the destruction of forests due to the rapid urbanization [9], which are supported by the exceptional growth of the global population in developing countries [10]. Furthermore, the climate variation leads to warm and dry conditions in the tropics, indicating that the growth of plants that eliminate CO2 from the air is limited and the average ambient temperature is increasing, including decreased precipitation. Human activities are continuously changing the climate each year and each decade as a result of natural life processes. A previous study has reported that more than 88% of human activities cause climate change, including persistent energy generation and consumption [11]. The threats of climate change and global warming have compelled policymakers and researchers to assess the effects of the world's

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warming on the global economy and to discuss ways to eliminate greenhouse gases and CO2 emissions to mitigate global warming [3]. The countries of the Organization for Economic Co-operation and Development (OECD) strive to reduce greenhouse gas emissions, due to their stationary nature, and to comply with the international norms on environmental risks [12]. Thirty-four democratic countries of the OECD work to address the environmental challenges of globalization, corporate governance, economic development, and social challenges, such as an aging population. According to the recommendation by the Committee on Climate Change (CCC), the power sectors must be entirely decarbonized by 2050. The decarbonization of the power sector implies a reduction in its carbon intensity, i.e., emissions per unit of power generated (CO2 per kWh). The CCC has reported that Great Britain must lead the global fight against climate change by reducing greenhouse gases to nearly zero by 2050. If all countries follow Great Britain, there will be a 50% chance of staying below the recommended temperature rise by 2100 [13]. In 2015, the Energy Applications Systems and Information (EnAppSys) reported that in Great Britain, the generation of renewable energy has grown to the same level of that of nuclear power plants (NPP) and coal use continues to decrease (claim made by Paul Verrill, Director of EnAppSys) [14]. On the other hand, an independent adviser to the government on climate change in Great Britain has reported that it may not be able to reach ''net zero ''emissions, and it still remains an extremely significant goal'' [13]. According to the CCC, the considerable drop in the cost of renewable energy promoted by government policies to nurture wind and solar power will be the main solution for addressing climate change and global warming issues [13].

Governments around the world are frequently called upon to contribute to the major share of the emission reduction, which entails the substitution of electricity generation based on fossil fuels with low-carbon technologies, such as renewable energy and NPPs. In addition, these endeavors will minimize the worldwide dependence on imported fossil fuels and eliminate the exposure to long-term high electricity market prices in the future. Nevertheless, it is difficult to achieve future low-carbon scenarios via renewable energy alone, and the support of NPPs is required. On the other hand, renewable energy is a variable source introducing changes that can affect the operational stability and reliability of the National Electricity Transmission System due to its specific physical characteristics. The challenges associated with the future mixed energy generation scenarios should be carefully considered and must be controlled as much as possible, as an imbalance in the electricity system is necessary to maintain the extremely high safety quality of the system.

However, there are global regions where the pressure to shift away from fossil-based energy sources is higher than ever. The Gulf Cooperation Council (GCC) countries are among the top 25 in terms of CO2 emissions per capita in the world, and they are considered actors that obstruct global climate change negotiations due to their large oil and natural gas reserves [15]. In addition to energy reliance, the GCC countries exhibit a significant economic reliance on oil and natural gas as well, with fossil fuels being the main income source, representing 31.6% to 55.7% of the GDP share and 60.8 to 93.8% of the government revenue (Table 1) [16]. Recently, the GCC region has raised concerns about global climate and environmental issues that require an integrated strategy to have a more proactive approach towards ecological modernization and energy policies. Regional authorities have identified the requirements for the development of a strategic partnership that focuses on the sustainability of the GCC region and its well-being [11]. The GCC countries are concerned with the consumption of a large amount of per capita energy [17], water, and other fossil-fuel resources in the region, generating waste, air pollution, and greenhouse gas emissions well above the global average levels. The region generates 99% of its electricity from fossil fuels, such as natural gas, crude oil, residual oil, and diesel – due to its large reserves of oil and natural gas – and the amount of the electricity generated from fossil fuels is being continuously developed annually. Power consumption as a result of activities from industries [18] such as the steel, iron, cement, and aluminum industries, as well as construction, accounts for 34% of the total energy-related pollution in the region [11]. The CO2 emissions of the GCC countries correspond to the burning of a considerable amount of fossil fuels for energy generation and the emissions resulting from oil and natural gas exploration activities.

Between 2000 and 2010, the CO2 emission levels increased up to 80% in the region, averaging 8% per year, and dominating 79% of the other emissions [11], [19], [20]. Climate change and global warming are game changers, which are enormously affecting all of the sectors in the GCC region [11]. The dilemma is to define climate change and global warming via the precise understanding of its effects and to determine how can one heal those impacts and treat them to eliminate the associated risks and increase benefits. On the other hand, limited studies have discussed climate change and global warming in the GCC region, and those that have typically ignore the crucial stages of the observed phenomena that require long-term effective solutions. The lack of GCC climate change studies and the clarification of the effects of this issue lead to uncertainties regarding future projections and future risks [21].

Climate studies have reported that temperatures have surged in the GCC region between 1960 and 2010, reaching an increase of up to 0.41 °C per decade [11], [22]. Furthermore, from 1960 to 2003, the cold days decreased in winter and the warm days increased during summer in the region [24]. In addition, the GCC region suffers from extreme climate conditions, and the climate is expected to become more severe with marginal quarterly rains, and the region attributes this to the desalination of seawater [11], [25]. Climate studies have revealed a strong correlation between the temperature increase and the energy consumption in the region.

TABLE 1. Details of GCC countries [16], [23].

GCC country	Area (km^2)	Population (millions)	Population density (per km^2)	GDP (billion dollars)	Per capita GDP (thousand dollars)	Oil reserves (billion barrels)	Natural gas reserves (billion cubic feet)	Oil & natural gas share in GDP (%)	Share of oil & natural gas government revenues (%)
KSA	2,149,690	33.5	16	646	20.8	266	8588	47.8	90.4
Oman	309,500	4.8	13	69.8	16.8	5.2	931	47.7	81.7
UAE	71,002	9.5	116	370.3	48.33	98.0	6,091	31.6%	75.9
Kuwait	17,818	4.2	223	114	28.7	102	1784	51.5%	93.8
Qatar	11,600	2.6	210	164.64	59.331	25.2	24299	55.7%	60.8
Bahrain	778.3	1.6	1696	31.13	22.71	0.12	92	44.2%	80.1

II. BACKGROUND

A. GULF COOPERATION COUNCIL OVERVIEW

In May 1981, the GCC was established as a union of six countries in the Arabian Peninsula [26]. The six members of the council include the Kingdom of Saudi Arabia (KSA), the Sultanate of Oman, the United Arab Emirates (UAE), the State of Kuwait, the State of Qatar and the Kingdom of Bahrain. Table 1 presents additional relevant details of the GCC countries, such as the area in square kilometers, the population in millions and the gross domestic product (GDP) with oil and natural gas reservations. The six GCC countries constitute the source of approximately 30% of the global oil and a quarter of the natural gas reserves (Table 1) [27]. The GCC region oil revenues are reported to have already been greater than 156 US$ billion in 1981 [28] and until very recently, the GCC region's crude oil was the main source of energy in the OECD [28].

The extremely rapid modern development of the GCC region and sustained economic growth were defined by the era of oil, which has a pivotal role in the region more than it does anywhere else in the world. Furthermore, massive development has been observed in the region, in all sectors, including the energy sector, infrastructure, heavy petrochemical industry, educational systems, and other economic sectors [28]. On the other hand, the exports and savings of the GCC region far exceed its domestic investment requirements [28]. Rapid improvements have been achieved at the cost of substantial capital consumption, implying that the oil and natural gas reserves of the region have started to deplete at rates considerably more rapidly than the physical capital created to replace oil and natural gas. On the other hand, the economic absorptive capacity of the GCC fell far shorter than the potential of the oil and natural gas revenues in the region due to the lack of long-term planning, scale-up limitation issues, scarce diversity of energy sources, and shortage of monitoring and control of the economy [28]. In addition, oil and natural gas constitute nonrenewable sources with limited lifetimes, leading to a lopsided, unprotected economy. In fact, the GCC countries have not yet reached the required sustained economic growth, which is independent of the oil and natural gas revenues, while the gestation period for the economic development of the GCC may be longer than the expected remaining life of the hydrocarbon resources [28]. The roles have proved to be expensive, and the GCC region needs to diversify its economy, including replacing the energy sources with a viable economic alternative, which is both pressing and difficult.

B. GCC COUNTRIES' ENERGY CONSUMPTION OVERVIEW

The populations of the GCC countries are relatively small, while the oil and natural gas consumption of these countries is considerably greater than that of Japan and Indonesia, and it is greater than the primary energy consumption in all of Africa [29]. Over the last 10 years, the energy demand in the region has increased by 6–8% per annum [29], [30]. The energy demand growth is associated with the population development, which has mirrored the GDP growth in the region. Currently, however, the main concern of the region is about delinking the GDP growth from the energy demand growth and development. The shared energy challenges in the region include energy diversification, energy efficiency, domestic energy security, and long-term environmental sustainability. To harness their climatic advantages, these energy challenges and visions were not appropriately considered in the GCC energy policies in the 1970s and 1980s. However, globally, several successful and ambitious plans for the reduction of energy consumption were implemented, for example, in China and India, via a mechanism of incentivizing efficiency and the scale-up of renewable energy sources [30]. Renewable energy is already a mature option as an alternative solution for the region to drive the reduction in energy consumption and the elimination of CO2 emissions [31], [32]; solar energy is abundant in onshore locations, while wind energy is abundant in offshore locations [31].

1) GCC COUNTRIES' ELECTRICITY OVERVIEW

In 2016, the GCC region recorded a generation capacity of 138 GW [33]. Fig. 1 provides an overview of the electricity generation capacity (dark blue) and peak demand (light blue) in the region in 2016 and the projected demand in 2030 (green). However, according to the Arab Petroleum Investments Corporation (APICORP), the generation capacity

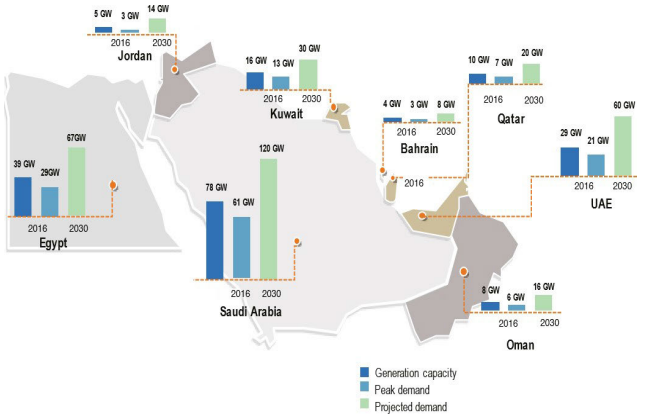

FIGURE 1. Electricity generation and peak demand in the GCC region, Egypt and Jordan in 2016 and the projected demand in 2030 [33].

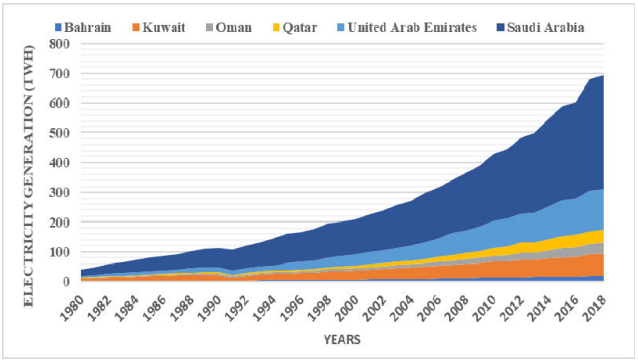

FIGURE 2. Electricity generation in the GCC region.

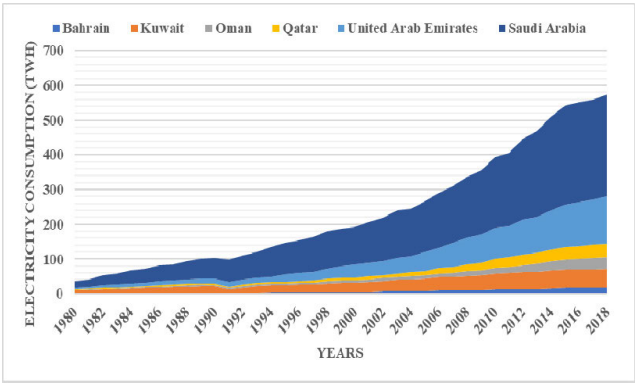

FIGURE 3. Electricity consumption in the GCC region.

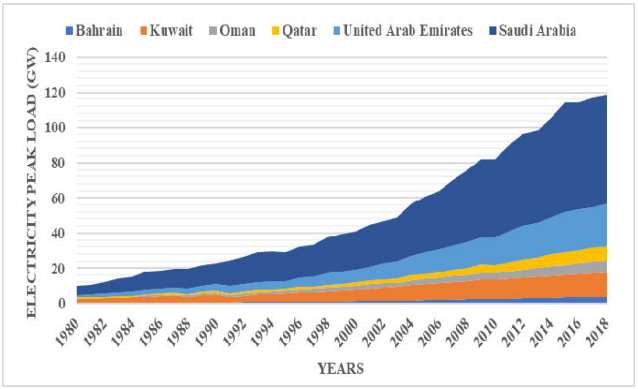

FIGURE 4. Electricity peak load in the GCC region.

increased to 151 GW in 2018, and KSA is the largest country with a generation capacity of 82 GW [34]. The KSA generates more than half of all of the electricity in the GCC region, while Bahrain generates the lowest amount of electric power. The rising demand in KSA leads to the addition of more than 4 GW of power annually [35]. APICORP has reported that GCC countries will be need to add a generation capacity of 43 GW within the next five years (by 2024) to meet the high demand in the region [34]. The generation side faces challenges in terms of the economic growth and demographic requirements. On the other hand, the main consumers in the region are broken down into residential, commercial, and industrial sectors.

In 2017, the total annual electricity generated in the region increased to 680 TWh, and in 2018, it increased to 691.5 TWh, corresponding to an increase of greater than 11 GWh within 1 year (Fig. 2) [36], [37]. In 2017, the total annual consumption was recorded as 559.3 TWh, which increased to 573.11 TWh in 2018, corresponding to an increase of 13.8 TWh within 1 year (Fig. 3). The consumption rate increased continuously, and the actions taken by the GCC governments failed to reduce consumption, which still requires improvement. Over the past decade, the peak load has surged in the region, contributing to the region's historical profile of facing the most challenges in the electricity sector; these challenges should be balanced by the generation side. The arid, harsh, and desert environment weather with an extremely high temperature during the summer, requires the use of more air conditioners, leading to the highest peak load value in the history of the region occurring in KSA in 2015, which was 62.25 GW (Fig. 4) [38]. The maximum peak load values are recorded during the months of July and August of each year due to the very high temperatures in this period.

On the other hand, the GCC countries can no longer continue to support the provision of electricity at heavily subsidized prices due to budget deficits and declining oil revenues. Improvements in income levels, as well as urbanization, which has relatively low energy costs compared to international costs, have led to an increase in the electricity demand. To control the power consumption, some of the GCC governments have increased the electricity prices twice between 2015 and 2018. Fig. 5 shows the reduction of the government subsidies [34]. The GCC governments implemented subsidy reform plans, and the domestic electricity tariffs significantly increased up to 250% in KSA. The GCC governments have other reform plans for the power sector, such as a kick-starting of the renewable energy initiative in the region. However, the slowdown of this initiative, coupled with delayed electricity reform plans, have adversely influenced

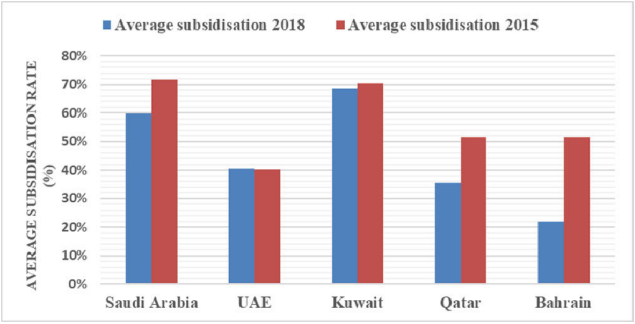

FIGURE 5. Reduction of government subsidization in the GCC region.

the growth of domestic consumption across most of the GCC region.

III. RENEWABLE ENERGY IMPLEMENTATION

The GCC countries are facing a fast growth rate of development in infrastructure and energy investment that has resulted in their electricity consumption increasing by 12.4% from 2005 to 2009, amounting to a growth of 3.15% annually [39]. The largest rate of electricity consumption was recorded in Oman (22.6%), while the lowest rate of increase in consumption was in KSA (6.3%). According to Alnaser and Alnaser [39] the increasing rate of electricity consumption in the GCC region is 3.15% annually, which is greater than the world average (2.2%) during the same period. The average per capita power consumption in the GCC region reached 1149 watts per capita in 2005, in contrast with 700 watts per capita in the European Union [39], [40]. Based on Alnaser and Alnaser [39], the electricity generation capacities of the region hovered approximately 75 GW in 2011; however, they needed to add 60 GW to increase their electrical capacities to meet the development in demand by 2015. The World Energy Council (WEC), on the other hand, estimated that the region will need 100 GW to meet its ever-growing demand over the next 10 years [39]. The governments of the GCC countries have recognized that their dependence on natural gas will not be a sustainable long-term solution due to their lack of alternative resources and the environmental externalities that exist. The total CO2 emissions share of the GCC is approximately 2.2%. In 2011, KSA recorded their lowest CO2 per capita values at 18 tons per capita, while the UAE recorded the highest at nearly 60 tons per capita [39]. Alnaser and Alnaser [39] estimated that, 13 GW of renewable energy may have been generated in the GCC region in 2015. The GCC countries plan to invest $200 billion in 14 to 20 renewable energy projects by 2020, which will save 1,000,000 tons of CO2 [39], [40].

Based on Weber [41] the oil and natural gas resources of the GCC region are ultimately finite wealth, and the region may face imminent oil-production declines. The increase in the domestic demand for natural gas and oil are contributing to the reduction in the national income of GCC exports [41], [42]. Since 2008, the domestic consumption of natural gas in the UAE and Kuwait has exceeded their production. Water desalination, residential demand, commerce, oil production and industries are the major sources of energy consumption in the GCC region. Another study reported that the low prices of oil and natural gas caused by government subsidies encourage overconsumption of water and energy in the region [41]. Taxes and tariffs can be implemented to reduce this consumption and to control the increasing power generation; however, they are risky policy decisions [41], [43]. The citizens of the GCC region are accustomed to the low water and energy prices, which they view as citizens' rights and view their governments as the distributors of oil revenue and the creators of employment opportunities [41] – therefore putting a greater pressure to substitute the existing energy generation options with more climate-compliant alternatives, as opposed to fostering a reduction in demand. The recent interest in renewable energy is entirely driven by the high growth of desalinated water demand, electricity generation, reuse schemes and the competitive low cost of solar and wind energy [41]. As the GCC countries seek opportunities to diversify their economies, renewable energy provides effective options to recycle the huge financial surpluses from oil production, which may be exported as energy to Europe's grid [41], [44].

According to a study conducted by Bhutto *et al.* [45] in 2014, the transfer to renewable energy technology would reduce fossil fuel consumption in GCC countries and address their environmental challenges [46]. The population growth and brisk economic expansion in the region, which is linked to the growth of energy-intensive industries such as petrochemical, aluminum and steel industries, led to increasing electricity consumption [45]. As a result, regional governments needed to take advantage of inexpensive energy and review their taxation policies [45], [47]. While Howarth *et al.* [47] reported that the GCC countries have a common strategic target to transition to economies less reliant on oil and natural gas sources, since economic growth and energy consumption have a strong relationship that is linked to all sectors in the GCC countries. This relationship has geopolitical implications and important policy development occur along with economic growth, future energy demand and climate change. Furthermore, the increasing consumption in the GCC countries far outpaces their GDP growth, in contrast to the OECD economies, which have been declining and have had relatively slower energy consumption growth in recent years. According to Howarth *et al.* [47], to shape future domestic energy demand, the GCC countries have the following broad, strategic diversification models available to them:

- Improving path dependence on access to low-cost energy to support industrialization in energy-intensive sectors, such as cement, petrochemicals, aluminum and steel. This model would lead to rising domestic energy consumption, but it would reduce the need for oil exports.
- Improving path dependence to include essential diversification into nonenergy sectors, such as renewable

energy, energy efficiency, financial services, medical services, tourism and education. This model would moderate domestic energy consumption and continue reliable energy exports, which can be channeled into investments in high value-added sectors.

According to Bhutto *et al*. [45] there is a strong correlation between a country's electricity consumption and its level of economic growth, which is also supported by the findings of Howarth *et al*. [47]. It also found that the region is likely to experience one of the fastest growth rates in economic and energy demand in the world over the next 20 years. The region requires wide energy investments to meet the requirements of its rising energy demand in the next 20 years [45]. The real opportunity of the GCC countries, thus, lies in the development and adoption of new technologies and in building a strong management system for an alternative energy mix, energy efficiency and carbon sequestration. Renewable energy investments would support their long-term energy security by facilitating the diversification of the energy mix and reducing a reliance on finite fossil fuel resources, in addition to creating opportunities for capital investment in the region. The investments in renewable energy could also potentially create high-value jobs within the GCC energy sectors and may contribute to a full energy value chain, including local and international deployment, manufacturing research and development.

Griffiths [48] wrote that each member country of the GCC had stated targets and ambitions for renewable energy, but their deployment to date has, in fact, been minimal. The majority of the GCC countries have only announced renewable energy targets rather than applying concrete policies to spur its adoption [48]. Therefore, the GCC countries need to address the gap between political ambition and the requirements of the power sector by reforming and enforcing appropriate policies and implementing clear strategies to guide the energy development in the region. GCC plans must be explicated into real actions via defined regulations and policies to achieve success to reflect the regional context [48]. Renewable energy auctions, which stimulate renewable energy deployment, are a suitable method, for example; however, consistent with international trends, GCC governments may no longer be focused on bridging the price gap between renewable energy and fossil-based energy generation [48]. Rather, the major trend in renewable energy is to support its sustainable integration in the energy mix. This trend is most pertinent to the GCC energy sector, where renewable energy sources, such as solar and wind, are attractive, economically viable options in many places due to the regions abundant reserves [48]. GCC policymakers have begun to consider these types of renewable energy, which have been widely deployed as a significant part of the global energy system and are increasingly cost-competitive. The International Renewable Energy Agency (IRENA) expects that, by 2025, utility-scale installations of solar and wind costs may fall even further, reducing solar costs by up to 57%, onshore wind costs by up to 12%, and offshore wind costs by up to 15% relative to the costs observed in 2015 [48]. However, progress is slow, possibly due to the region's lack of experience in implementing renewable energy projects. The region has unique circumstances that must be considered, such as its high temperature, occasionally low wind speeds and its dependence on the oil industry as the main source of income. The differences between energy policies and objectives are thus driven by differences in the economic, social and political contexts that shape policy formation. Additionally, the most important considerations in these types of new projects are the public financing, fiscal incentives and regulation that support their demonstration, research and deployment lifecycle to achieve technology push and market pull. Regulations can create fiscal incentives for improving market support regarding the quality, quantity, costs and access of renewable energy. Although these classifications are adequate, there are many variations and overlaps in the performance of each policy instrument, which have made the discussion regarding the optimal policies for various GCC contexts a topic of significant debate.

Ahmad and Babar [49] discussed the impact of the globalization energy markets over the power sector of GCC countries. The globalization of the energy market has changed the energy philosophy of the GCC region and has pushed it to pay more attention to controlling the supply and consumption of power [49]. Nevertheless, the globalization of the energy market in the GCC region not only reinforces free-flowing global trade but also invites foreign investment, industrialization and market-driven domestic economies. According to Ahmad and Babar [49] the rapid and uneven growth in the population and the consumption of energy have created some wrenching challenges for the world's policymakers and security planners. According to the Independent Evaluation Office (IEO), the world's net renewable energy generation will increase by 80% due to consumption requirements [50]. The globalization of the energy market is not a new phenomenon in the GCC region, which has been trading energy internationally for decades [49], [51]. The GCC countries plan to unbundle political barriers towards privatization and appreciating investments in the region by emboldening the private sector to invest in the power sectors [49], while before 1990, all the GCC's power utilities were government-owned. The deterioration of the GCC's economies as oil prices plunged in the 1980s and stayed low until the late 1990s had an impact on the worldwide use of petroleum [49], [52]. The recent surge in fossil-fuel prices, which power plants use to operate oil refineries, has raised concerns in the region.

These studies provide an expanded review of the fossil-fuel energy developments in the region, with adequate estimations of renewable energy as a new technology to meet the growth in the energy demand, which the GCC governments started to consider in the 1990s. In 2014, the GCC governments began executing their ambitious plans for renewable energy implementation after they realized that higher oil demand drove up global CO2 emissions [53]. Unfortunately, renew-

able energy technology has still not been featured widely in the GCC region, as renewable energy planning started late and its implementation has not been fast enough to meet the increasing energy demand, even though the GCC countries have been the main investors in renewable energy in the Middle East since 2014. However, the GCC governments have adopted a more proactive approach towards renewable energy technology that will likely lead the GCC region towards greater environmental sustainability. The extension in renewable energy projects is supported by the simultaneously falling cost of renewable energy technology and the rising prices of fossil fuels, such as natural gas, which will force the GCC governments to increase the volume of exported fossil fuels and decrease its domestic use. Aside from the financial benefits of reducing the subsidized domestic consumption of oil and increasing export capacities, the region could make transformational ecological gains that may prepare it for a post-oil age, or if oil and natural gas stay low for sustained periods of time, such as the during 1980s or very recently, starting with the end of 2018 – ongoing to some extent today.

Another – and perhaps more important – factor supporting the use of renewable energy technology is the increasing environmental pressure from international organizations on the GCC countries to review their energy strategies and improve their green credentials. These investments will not only fulfil the regional requirements for renewable energy but may also make the region a world leader in the renewable energy markets.

A. GCC REGIONAL ENERGY INTERCONNECTION

One important aspect that one has to consider when analyzing the future renewable energy development in the region is the existence of the high-capacity interconnection links between the countries of the region. The GCC regional energy interconnection was proposed at an early stage of the council's formation to connect the six member countries electrically through overhead lines and submarine cables [54]. According to Zhang *et al*. [54] the project was executed in three phases from 2009 to 2011 by the Gulf Cooperation Council Interconnection Authority (GCCIA) (see Fig. 6 and Table 2). The Power Exchange Trading Agreement (PETA) and the General Agreement were signed in 2009 by the governments of the GCC countries and the GCCIA to start the operation services [54]. The General Agreement set out the terms among the member states, while the PETA determined the laws and established a legal framework for the trading parties to exchange energy between countries through the GCC power grid [54], [55]. In 2011, a study was conducted by El-Katiri [55] from Oxford Institute for Energy Studies (OIES) and a research group that mentioned that the GCC interconnection was constructed as an emergency mechanism for energy security in the region rather than for trade. Later, it was improved for energy trading to create a common market for electricity. El-Katiri's [55] view is that, at present, the GCC energy interconnection may not be accruing economic benefits due to the high cost of its excessive capacity. Rather, it is merely an

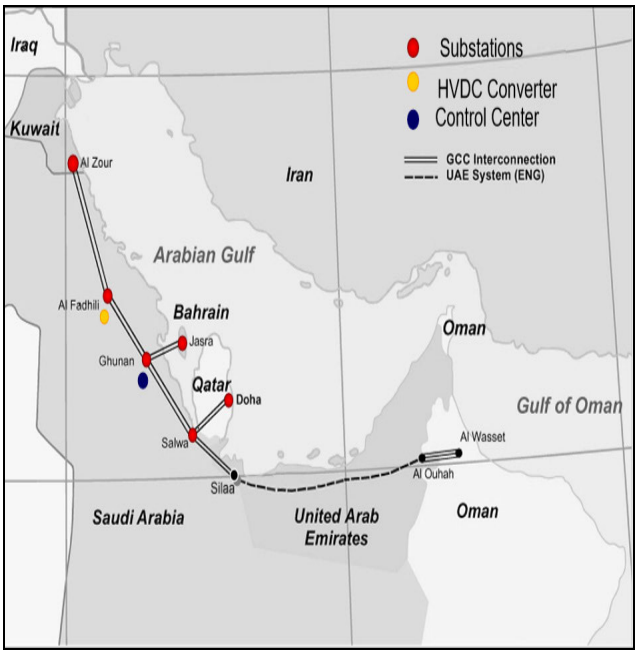

FIGURE 6. The GCC regional energy interconnection [59].

emergency supplier with enormous future economic potential. According to Wogan *et al*. [56], in 2018 the GCC interconnection trade market will increase the region's annual economic gains by $1.1 billion. The GCC interconnection has successful and reliable services in the region, even if it is not realizing its full operational potential. Based on the findings of Wogan *et al*. [56], this economic barrier was created by domestic energy subsidies, which reduce the benefits of electricity exchanges between the member countries. That means that with the supported subsidies across the region, the other GCC countries are purchasing the generated electricity at low prices. The legal framework defines the obligations and rights of all the concerned parties, whether it is the power generation level or the energy procurement of the GCC countries themselves [54]. Additional committees were founded to fully regulate the environment and to support a cooperative for energy exchange. Energy experts and specialists have demonstrated that the GCC interconnection not only is technically feasible and applicable to renewable energy but also is developing at an optimistic pace to secure and accommodate the GCC's future anticipated power consequences [54], [56].

The GCC ministries and regulators are working on unbundling the electricity utilities and initiating electricity sector reforms to integrate them more tightly within the GCC interconnector, as it represents more than energy security or economic benefits; it is the most strategic project for the region, reflecting the strong bonds between the GCC countries.

The GCCIA facilitates a bilateral energy trading system that makes the energy capacities of all member countries transparent, enabling them to place bids using yearly, monthly and daily options. Two main methods exist for trading

TABLE 2. Sharing of the Costs of the Interconnection [57] and Electricity Export, and Import of GCC Countries in 2016 [54], [58].

GCC countries	Phase I (%)	Phase II (%)	System size (MW)	Electricity export (GWh)	Electricity import (GWh)
KSA	40.0	31.6	1200	622	560
Oman	–	5.6	400	–	–
UAE	–	15.4	900	203	180
Kuwait	33.8	26.7	1200	238	236
Qatar	14.8	11.7	750	116	117
Bahrain	11.4	9.0	600	105	110

on the GCC energy interconnection, i.e., scheduled energy exchanges and unscheduled energy exchanges [54], [60]. The scheduled energy exchanges are prearranged bilateral trades between member countries and are freely negotiated between them [54]. The unscheduled energy exchanges are those that may be required when unexpected events occur [54]. The GCCIA is the first cross-border electrical interconnector in the GCC region and the Middle East, serving the region and beyond by developing the reliability and efficiency of the power market and integrating power systems. The main target of energy interconnection is to achieve a complete interlinking among the GCC countries, especially for emergencies, communication, transportation and information exchange [54]. In addition, it aims to share the energy reserve, to achieve a high level of stability and to improve the supply reliability to increase investments in power generation in the region – a property that is deemed highly valuable in the context of increasing intermittent renewable energy generation. The GCCIA is supporting GCC countries by providing numerous benefits, such as reducing the costs of installed capacity expansions and being an operations reserve with the most modern energy use of fuel resources [54], [61]. Additionally, GCCIA continuously conducts interactive forums, workshops and seminars to create common ground among the GCC power authorities, and it regularly launches various programs for promoting energy trading in the Middle East. GCCIA is a joint-stock commercial entity and is considered to be independent of any other organization [54], [62]. The GCC countries have nearly 50% of the estimated installation power generation capacity of the Middle East [54]. According to Zhang *et al*. [54], the GCC countries have the expected technical potentials for renewable energy of 65 GW of grid-connected wind energy and 34 GW of off-grid wind energy. In addition, the estimated technical potentials for solar energy are 505 GW of grid-connected energy and 283 GW of off-grid energy [54]. In 2016, the energy-trading volume between GCC countries had already reached 1.32 TWh, with member countries concluding more than 15 contracts (Table 2) [54].

Nevertheless, the amount of energy exchange in the GCC region is much lower than that of other regional energy interconnections. Although the transfer capacity of the GCC countries is comparatively high, the scheduled energy exchanges are limited due to the emphasis on reserve collaboration and the lack of experience in trading under the new agreements. The most significant problem is the lack of power-grid connections with other countries outside the region; thus, the GCC countries recently started to coordinate energy interconnections with other countries in the region, such as Iraq, Egypt and Jordan. Developing a wider regional energy interconnection system will lead to flexible renewable energy trading and will ultimately enable more countries beyond the GCC to balance the power demand and supply. The GCC regional energy interconnection also encourages energy exchange during the peak demand in the seasonal diversity in a hot summer season in specific locations within region, which will be supplied by other locations in GCC countries that have low demand at that particular time. Furthermore, in the longer term, the GCC countries might export their surplus electricity during the winter season, when domestic demand is low, to places where demand is high, such as the European region. In any case, the improvement of the GCC regional energy interconnection system will provide alternative solutions to importing and exporting energy to the world through the regional market, which will support the GCC economy and promote the private sector's participation in regional energy projects.

B. GCC RENEWABLE ENERGY PROJECTS

Recently, renewable energy as a clean energy alternative has become the main focus to eliminate carbon dioxide (CO2) emissions and slow climate change [63]. Energy security and renewable energy development are now the common future challenges facing the GCC countries' bottom-line value creation (both environmental and economic). According to Ramady [64], one of the sustainability projects' issues is that private investors, such as banks, are particularly reluctant to support projects in dry and desert areas. In 2018, the First Abu Dhabi Bank [65] agreed that renewable energy will be the primary means of change for the GCC markets in the long-term but that it still has limited actual impact on oil demand currently due to the vast infrastructural network that it requires. In addition, several environmental, economic and social considerations need to be carefully considered to identify the most desirable energy mix. Without a doubt, however, the environmental advantages afforded by wind and solar renewable energy make them the cleanest sources of electricity generation. According to Patlitzianas and Flamos [66], the investments of the unexploited renewable energy

potential in the GCC countries, which are synchronous with the growth of cash liquidity within the new climate regimes, will lead the way towards the application of renewable energy technologies. According to El-Katiri and Husain [67], the relatively strong economic position of the GCC countries allows them to move forward with investments in renewable energy projects. In the long-term, GCC countries can even gain from the deployment of alternative energy technologies [67]. Ferroukhi *et al*. [68] reported that the commercial side of renewable energy is actually the main concern of energy investors in the region, as they favor revenue over environmental sustainability. The key factor determining the deployment of renewable energy, in other words, is its cost [68].

Muench *et al*. [69] concluded that the use of renewable energy on a large scale would trigger the following two major developments: raising the amount of volatile energy supply and raising the total number of renewable energy suppliers on the national grids. This concern is shared by Alnaser and Alnaser [40], namely, extending large solar and wind energy projects and accelerating the execution of these projects in the GCC region might lead to several disturbances in the interconnections between the grids. The conventional electricity system has a baseline for its generation and depends on the rotation mass of its generators to maintain a steady frequency of (50–60 Hz) and provide system inertia [40]. However, renewable energy (wind and solar) has no generation baseline, does not provide synchronous frequency support to the system and provides no inertia to the system [40], [70]. This becomes a primary concern at high penetrations and with an unstable renewable energy generation system, which lead to grid instability, and system desynchronization [40], [70]. This leads to a careful discussion of the most important aspects of the renewable energy technologies, such as operation planning, the quality and security of the supply, and the safety requirements resulting from matching the demand and supply side. The nature of the generation, operation and transmission of renewable energy is different from that of conventional energy. Understanding this specific nature and its interaction with each element of the national grids and the distribution systems is the basis of the integration of renewable energy with the grids, especially with the increasing of the renewable energy capacity, which results in significant changes related to uncertainty and variability. Although, as we mentioned before, the renewable energy (wind and solar) market in the GCC countries is still in its nascent stages, it has become a subject of great interest to the government's development plans. Future energy systems will need different models to control the new demand and supply characteristics.

The KSA started to concentrate on renewable energy, such as solar energy, to minimize the risk of rising electricity prices when energy subsidies are cut [71]. In October 2018, the government of the KSA issued installation approval for small-scale solar systems to encourage the implementation of solar energy, expecting to invest $500 billion in renewable energy by 2030 [71], [72]. In 2018, the KSA began constructing a 300 MW solar energy project (Sakaka project) and announced a 400 MW wind energy project (Dumat Al Jandal project) – both currently ongoing – in the northwest, with the plan to construct ''Neom City,'' an urban area of 26,500 km2 that will be fully powered by renewable energy [71], [72]. In the early part of 2020, the Dumat Al Jandal project, which is the first wind farm project in Saudi Arabia and the largest development of its kind in the Middle East and Africa category, won the Renewable Deal of the Year at the annual Project Finance International (PFI) Awards (a regional award). PFI awards are one of the financial industry's most prestigious global events, attracting hundreds of the world's most senior project finance professionals. The KSA renewable energy generation target is 54 GW, where the first phase of the National Transformation Program (NTP) has an aim of 3.4 GW by 2020 and the second phase has an aim of 9.5 GW by 2023, while 2030 is the target date for achieving the rest of the renewable energy generation target [73].

Pursuant to these goals, the Saudi Vision 2030 involves increasing the renewables' share in the energy mix from 0 to 4% by 2030 [73]. Qatar has announced similar plans to generate 20% of its electricity from renewable energy by 2030 [68]. The UAE began focusing on renewable energy in 2006 when it built Abu Dhabi's Masdar City, a 6 km^2 sustainability project by the Mubadala Investment Company. The country plans to go even further, with an 800-MW solar-energy project in the works for 2020 and the concentrated solar power (CSP) Mohammed bin Rashid Al-Maktoum Solar Park in Dubai, which plans to have 1-GW photovoltaic (PV) and CSP in 2030 and will cover 48 km^2 [64]. In 2017, Nebras Power and the Qatar Electricity & Water Company (QEWC) signed a cooperation agreement with Masdar to develop renewable energy projects in Qatar and the UAE [71], [74]. The same year, Oman planned to integrate renewable energy in the energy mix with a 50 MW Harweel wind farm and 200 MW of solar energy [71]. In addition, 100 kW Hiji solar project, the 292 kW Al-Mazyonah solar project, the 4200 kW Saih Al-Khairat wind project and a wind project on Masirah Island that will produce approximately 500 kW are planned [75]. In 2016, Bahrain endorsed an energy-mix plan that seeks to improve electrical energy efficiency by 6% by 2025 and another 10% by 2035 [71]. Kuwait has its own plan to transform its power system into an alternative power–dependent country by producing 15% of total electricity consumption from renewable energy by 2035 with over 4.5 GW of capacity [71], [76].

The GCC countries have increasingly recognized the challenges of growing demand, which are forcing them to seek alternative energy options. Table 3 presents all the GCC countries' future targets for renewable energy projects, many of which are moving forward rapidly, depending on the ambition of each country, which, in turn, depends on its market size and readiness. Table 4 shows the updated GCC renewable energy project statuses at the end of 2020.

Fig. 7 summarizes the renewable energy targets of the GCC countries, including the development of generation efficiency, the reduction of electricity consumption and the

TABLE 3. The Primary GCC Renewable Energy Project Targets and Plans [18], [71], [77]–[79].

Project name	Capacity	Project type	Country	Start date	End date	Client	(US$ Mn)
King Abdullah City for Atomic & Renewable Energy.	1700 MW	Renewable Energy	KSA	-	-	king Abdullah city for atomic and renewable energy.	100250
Renewable Energy.	9.5 GW	Complex	KSA	-	2023	Renewable Energy Project Development Office.	-
Dumat Al Jandal.	400 MW	Wind	KSA	Q3 2018	Q3 2021	Renewable Energy Project Development Office.	1000
Wadi Ad Dawasir - Layla.	200 MW	Solar	KSA	2020	-	Renewable Energy Project Development Office.	-
Ar Rass -Saad.	1000 MW	Solar	KSA	2020	-	Renewable Energy Project Development Office.	-
Sakaka.	300 MW	Solar	KSA	Q2 2018	-	Renewable Energy Project Development Office.	500
Energy plants.	-	Waste	KSA	Q4 2018	Q4 2021	Constructions Industrielles de la Mediterranee, France.	300
Al Aflaj.	-	Solar	KSA	Q3 2017	-	Taqnia, King Abdul Aziz University & Saudi Electricity Company.	100
Power Plant in Misfah.	500 MW	Solar	Oman	Q4 2018	Q2 2021	Oman Power & Water Company.	800
Dhofar, Phase II,	150 MW	Wind	Oman	-	-	Oman Power & Water Co.	-
Manah.	1000 MW	Solar	Oman	-	2025	Oman Power & Water Co.	-
Ibri, Al Dhahirah.	500-600 MW	Solar	Oman	-	2022	Oman Power & Water Co	-
Duqm.	200 MW	Wind	Oman	-	2024	Oman Power & Water Co	-
Duqm.	1200 MW	CSP	Oman	-	-	Oman Power & Water Co.	-
Jaalan Bani Bu Al.	100 MW	Wind	Oman	-	2023	Oman Power & Water Co.	-
Mukhaizma Field.	2 GW	Solar	Oman	-	-	Occidental of Oman, Inc.	-
Adwea Sweihan plant.	1.2 GW	Solar	UAE	Q3 2017	-	Abu Dhabi Department of Energy.	868
Mohammed Bin Rashid Al Maktoum Park.	5 GW	PV & CSP	UAE	Q2 2013	Q4 2030	Dubai Electricity & Water Authority.	3200
Power Plant	-	Solar	UAE	Q1 2018	-	Expo 2020 Bureau.	25
Hatta in Dubai.	250 MW	Wind	UAE	-	-	Dubai Water & Electricity Authority.	-
Jebel Ali Free Zone and Mina Rashid Port.	55 MW	Solar	UAE	-	-	DP World PLC.	-
Ras Al Khaimah.	200 MW	Solar	UAE	-	2025	Federal Electricity & Water Authority.	-
Floating solar Jebel Ali.	60 MW	Solar	UAE	-	-	Dubai Electricity & Water Authority.	-
Solar Energy.	1 GW	Solar	Kuwait	Q2 2018	Q2 2020	Kuwait National Petroleum Company.	1200
Al Dibdibah/Shagaya.	1500 MW	Complex	Kuwait	Q2 2015	Q4 2033	Ministry of electricity & Water – Kuwait Institute for Scientific Research.	5610
Ratqa field.	100 MW	Solar	Kuwait	-	-	Kuwait Oil Company K.S.C.	-
Shakaaya.	10 MW	Wind	Kuwait	-	-	Institute for Scientific Research	-
Power Plant.	640 MW	Solar	Qatar	-	2020	Qatar government.	-
Al Kharsaah, Doha.	800 MW	Solar	Qatar	Q1 2020	Q1 2022	Ministry of Energy and Industry.	-
Al Kharsaah, Al Jumaliyah.	700 MW	Solar	Qatar	-	-	Siraj Energy Q.P.S.C.	-
Askar Industrial Area.	100 MW	Solar	Bahrain	-	2025	Electricity & Water Authority.	-
Awali, Central.	5 MW	Solar	Bahrain	-	-	Bahrain Petroleum Company.	-
Askar landfill site.	100 MW	hybrid	Bahrain	-	-	Electricity & Water Authority.	-

reduction of peak demand. By the end of 2018, the GCC countries had a total of 146 GW of installed energy generation capacity, of which renewable energy accounted for less than 1% at 867 MW [80]. The UAE accounted for 68% of the renewable energy as the installation planned share, followed by KSA at 16% and Kuwait at 9%, as shown in Fig. 8a and

TABLE 4. The Statuses of GCC Renewable Energy Projects in 2020 (Source: IRENA) [77]–[81].

Country	Project name	Capacity	Project type	Project status in Q4 2020
KSA	Waad Al-Shamal.	50 MW	Solar Thermal	Completed
	Sakaka	300 M	Solar PV	Completed
	Dumat Al Jandal.	400 MW	Wind	Under construction
	Wadi Ad Dawasir – Layla.	200 MW	Solar	Bid was invited
	Ar Rass – Saad.	1000 MW	Solar	Bid was invited
Oman	Dhofar, Phase I.	50 MW	Wind	Completed
	Dhofar, Phase II.	150 MW	Wind	Completed
	PEO Amin PV Plant.	100 MW	Solar PV	Completed
	Miraah Solar EOR.	1000 MW	Solar PV-thermal	Completed
	Duqm, Al Wusta.	200 MW	Wind	Under construction
	Ibri PV Plant.	500 MW	Solar PV	Under construction
	Duqm, Al Wusta.	1200 MW	Solar - CSP	Under construction
UAE	Shams 1.	100 MW	Solar Thermal	Completed
	Sweihan.	350 MW	Solar PV	Completed
	Mohammed bin Rashid Al Maktoum, Phase I.	13 MW	Solar PV	Completed
	Mohammed bin Rashid Al Maktoum, Phase II.	200 MW	Solar PV	Completed
	Mohammed bin Rashid Al Maktoum, Phase III.	800 MW	Solar PV	Completed
	Mohammed bin Rashid Al Maktoum, Phase IVa.	700 MW	CSP	Under construction
	Mohammed bin Rashid Al Maktoum, Phase IVb.	250 MW	Solar PV	Under construction
	Mohammed bin Rashid Al Maktoum, Phase V.	900 MW	Solar PV	Under construction
	Noor Abu Dhabi.	1177 MW	Solar PV	Under construction
	Hatta in Dubai.	250 MW	Wind	Under construction
	Jebel Ali Floating.	60 MW	Solar PV	Under construction
	Jebel Ali Free Zone and Mina Rashid Port.	15-20 MW	Solar PV	Under construction
	Ras Al Khaimah.	200 MW	Solar	On hold
Kuwait	Shagaya, Phase I.	50 MW	Solar Thermal	Completed
	Shagaya, Phase I.	10 MW	Solar PV	Completed
	Shagaya.	10 MW	Wind	Completed
	Al Dibdibah/Shagaya Phase II.	1200 MW	Solar PV	Cancelled
	Southwest of Kuwait City	300 MW	Solar PV	Under construction
	Ratqa field.	100 MW	Solar	Under construction
Qatar	Al Kharsaah, Al Jumaliyah.	700 MW	Solar PV	Under construction
	Al Kharsaah, Doha.	800 MW	Solar PV	Under construction
	Kahramaa.	220 MW	Solar PV	Under construction
	Mesaieed W2E.	38 MW	Waste to Energy	Completed
Bahrain	Tatweer Petroleum.	3 MW	Solar PV	Completed
	Al Dur Hybrid.	5 MW	Wind & Solar PV	Completed
	Awali Township, Manama.	5 MW	Wind & Solar PV	Completed
	Askar Industrial Area.	100 MW	Solar	Under construction
	Askar landfill site.	100 MW	Solar	Under construction

Table 5. The development of the renewable energy sector is not only the responsibility of governments, of course; the private sector must be involved, which can be facilitated by liberalizing government policies to expedite renewable energy projects. Most of the energy stakeholders in the GCC region expect, by 2030, both a substantial growth in renewable energy generation to 78 GW and a total global investment of $13.5 trillion in low-carbon technologies [82]. According to the King Abdullah Petroleum Studies and Research Center (KAPSARC) [82], in addition to being competitive, renewable energy is an economically suitable option to diversify the GCC's existing energy mix. The KAPSARC reported that, based on the renewable energy tenders in 2017, it can compete successfully under specific conditions and if the GCC energy reform includes three main factors [82]. First, it needs a credible economic plan with a reasonable schedule to improve the regulations required to achieve the stated objectives [82]. Second, it requires the reform of

TABLE 5. Installed Energy Generation Capacities for Renewable Sources (RES) Capacity in (MW) from 2014–2018 (Source: IRENA) [80].

GCC Country	2014 Total RES	2015 Total RES	2016 Total RES	2017 - 2018 PV	CSP	Wind	Biomass & waste	Total RES	Share of RES in the total electricity capacity (%)
KSA	24	74	74	89	50	3	0	142	0.2
Oman	1	2	2	8	0	0	0	8	0.1
UAE	137	137	144	487	100	1	1	589	2.0
Kuwait	0	1	20	19	50	10	0	79	0.4
Qatar	42	42	43	5	0	0	38	43	0.4
Bahrain	6	6	6	5	0	1	0	6	0.1
Total	210	262	289	613	200	14	39	867	0.6

large energy subsidies for long-term viability and to adapt to the changing global energy markets [82]. Third, renewable energy must be integrated in the generation portfolio, while natural gas can be used as an effective back-up in the energy system [82]. In 2020, AlKhars *et al.* [83] conducted a comprehensive systematic review based on 59 articles to analyze the relationship between energy consumption and economic growth in the GCC countries over 13 years (2006–2019). AlKhars *et al.* [83] reported that there is an urgent requirement for the expansion of renewable energy technologies in the energy supply mix of GCC countries to meet the sustainable development, economies growth, and environmental challenges in the region. Another study was debated by Haque [84] in 2020, which studied the relationship of energy consumption with specific key indicators, such as crude oil prices, GDP per capita, population growth, trade, and CO2 emissions in the GCC region over 29 years (1985–2014). Based on Haque's [84] analyzing, there is a need to upscale the adoption of renewable energy technologies in the GCC region. Recent research by Abul *et al.* [85] discussed the energy consumption performance and economic growth in GCC countries during the period (1980–2014). Abul *et al.* [85] highly recommended the implementation of energy technologies in the GCC region as a good alternative solution to deal with potential environmental issues. Many long-term studies have called for investment in clean energy technologies in the GCC region and exploitation of the natural resources that are available in abundance as effective long-term solutions. According to Abdmouleh *et al*. [18], short-term investments in renewable energy projects in the GCC region may not create adequate financial returns; in addition, the GCC countries face common challenges to renewable energy deployment, such as misunderstanding its cost, the ''dust effect,'' high temperatures and the paucity of research on regional weather patterns. However, the extreme growth rate of the energy demand will certainly lead the GCC's governments to seize the emerging opportunities to start renewable energy projects.

In the past, the GCC countries have faced sharp criticism for fully depending on conventional energy and ignoring the implementation of renewable energy. Even after the activation of renewable energy projects in the region, the region still faces criticism for its slow progress and limited performance. In 2014, OIES [86] reported that there is a lack of long-term energy strategies in the GCC that provide visible plans with a timeline to promote alternative supply and demand-side energy policies. The policies of alternative new energy options, such as renewable energy, are suffering from a lack of a sense of urgency in the region [86]. The lack of expertise with renewable energy technologies, such as CSP, wind technologies and solar-driven desalination, coupled with the immaturity of renewable energy technologies reduce investments from ready-made solutions to mere experiments [86], [87]. Private-sector investors have little visibility and incentive to invest in renewable energy, and the consumers do not have clear means to control their levels of consumption [86]. The OIES reported that, business-as-usual in the GCC region can no longer be sustained; the region must devise concrete, modern policies and strategies to meet both the medium- and long-term challenges of the energy demand and the energy mix [86]. In 2014, Munawwar and Ghedira [88] reported that the realistic accomplishments of low-carbon projects and renewable energy deployment in the GCC region are limited and only represent a future vision with no real demonstration of success or explicit progress updates. Many GCC countries have undertaken projects, sector-wide efforts and policies that still only exist on paper. In 2018, Malik *et al*. [89] pointed out that the lack of an adequate policy framework in the region is obvious, especially for wide-scale renewable energy utilization, which requires well-articulated policies to advance renewable energy deployment in each GCC country. Al-Maamary *et al*. [30] mentioned that the renewable energy projects in the GCC region are still below the ambition level; thousands of renewable energy projects in the region were suspended due to a drop in oil prices, which caused a temporary lack of funding.

To successfully deploy renewable energy in the region, the governments need to commit to a regulatory framework that involves financial incentives [88]. The OIES mentioned that the strong fiscal position of the GCC countries, however, may enable them to deploy alternative energy systems with savings from the domestic energy-price reform [86].

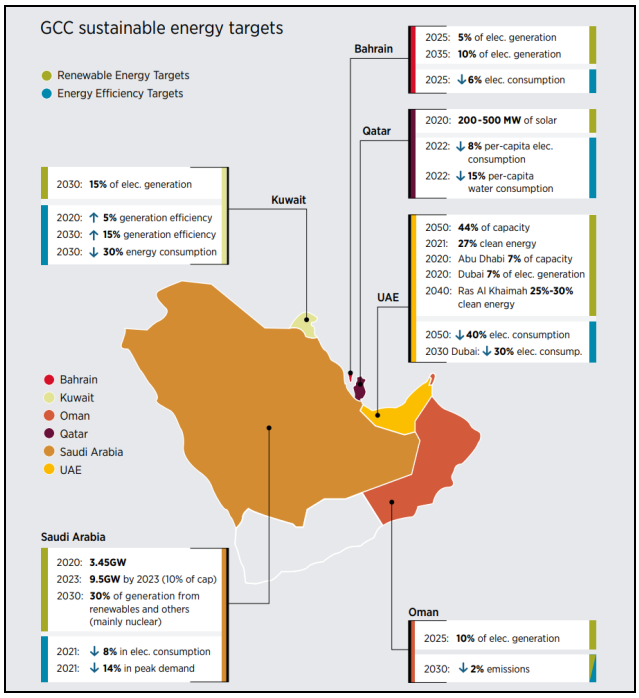

FIGURE 7. The estimated sustainable energy targets of the GCC countries (source: IRENA) [80].

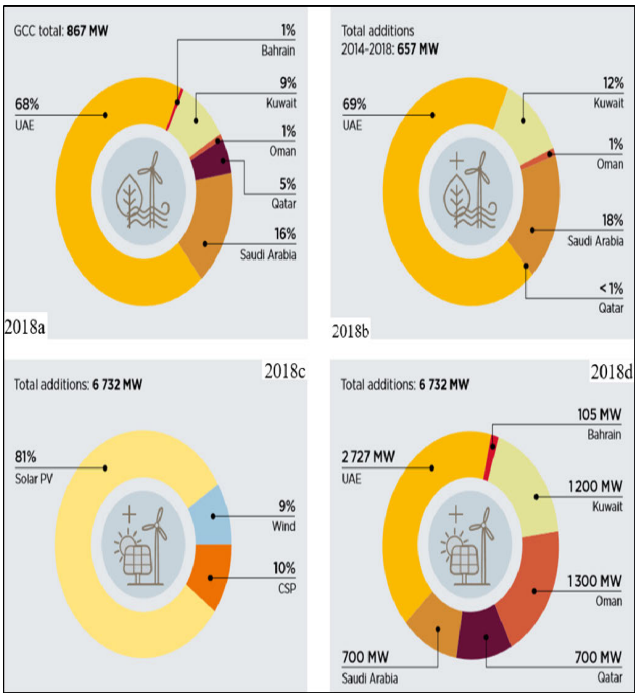

FIGURE 8. Installed renewable energy capacity share in 2018a, the growth of capacity from 2014–2018 in 2018b, the installation planned by technology in 2018c and the installation planned by country in 2018d (source: IRENA) [80].

In 2017, Al-Saidi and Elagib [90] indicated that, though barriers exist to renewable energy megaprojects in the GCC region, modernization policies are still emerging. Furthermore, Al Shidi *et al*. [21] state that the GCC countries indeed have a strategic plan, since the slow transition from fossil-fuel economies to low-carbon economies is necessary to improve their global image; without a doubt, they will deploy renewable energy, albeit at their own pace. Apostoleris *et al*. [91] reported that the unexpected leaders of large-scale and low-priced solar energy projects in the Middle East are the UAE and KSA due to the reduced cost of solar energy technologies. According to IRENA, since 2010, the average cost of electricity generated from solar PV technologies and wind energy has fallen by 73% and 22%, respectively [92]. In countries as dissimilar as India and Saudi Arabia, Chile and the United States, electricity is being generated in optimal locations for approximately 30 US$ per MWh [92]. Furthermore, both the low taxes and the low prices of hardware and labor should lead to large rapid renewable energy contributions in the region.

Governmental policies, of course, remain an important factor to remove obstacles, the most aggressive of which are claims in terms of costs, returns and risks. The cost of clean energy technologies is expected to continue to decline in the future, which creates a great opportunity to facilitate renewable energy deployment and increase the participation and diversification in these sectors. In addition, regarding this decline in the cost of renewable energy technologies, given the region's fiscal challenges, there is no room for delay, indecision or incoherence. Furthermore, this advantage must attract significant interest from developers and investors and support access to very low-cost project financing. It is worth noting that the focus should not be on the cost of energy only, but must include the energy efficiency, and these two elements are closely linked together.

IV. CONCLUSION AND REMARKS

Based on our analysis of the recent evolutions in energy generation and consumption patterns, the announced and commenced energy-related investments, and several efficiency and trade-oriented energy policies, it is apparent that the GCC countries have realized the importance of renewable energy and the urgent need to diversify their energy sources. Such diversification can increase the sources of their economic income, which has traditionally depended on oil and natural gas production and export. In addition, the energy sector has always been the cornerstone of economic development and social growth in the region; thus, the future of each member country has been closely linked with the future of its energy sector. Meanwhile, GCC countries have also recognized the great responsibility they must bear in regard to addressing climate change and global warming issues, which require that they reduce their carbon footprint.

Indeed, remarkable developments—even with slow and weak progress—in renewable energy projects have been achieved in the GCC region during the past five years (see Section *B. GCC RENEWABLE ENERGY PROJECTS* and Table 4). Given the energy policy context that we describe in detail, these steps can be considered a strong step in the

desired direction and they deserve commendation, as they put the GCC countries on a path to transition to sustainable energy. However, these advances are relatively small compared to those achieved by other countries, such as India, China, Russia, the USA and members of the European Union. Undoubtedly, in terms of the cautious and weak progress in renewable energy deployment achieved in the GCC region so far, a gap exists between what has been actually achieved to date and the huge financial possibilities, coupled with the great renewable energy resource potentials of the region, which could be better exploited. This gap may be explained by the different energy management techniques that renewable energy production requires, due to the intermittent nature of the sources and their efficiency and reliability as continuous sources of power. These factors continue to be the major concerns for GCC countries. However, the UAE and KSA are exerting major efforts in the field of renewable energy projects, as are Oman and Kuwait, which have also shown strong progress with their projects. Meanwhile, Bahrain and Qatar are languishing behind their peers and have shown unclear progress in their endeavors. A greater transparency in terms of announcing the developments of their sustainable and renewable energy projects would help clarify their progress towards targets. So far, both countries have only announced initial plans and set their primary targets for future renewable energy generation; they have yet to announce the real progress rates for any project (Tables IV and VI). Improved transparency is required for all countries in the region to achieve long-term sustainability in their policy support mechanism and accelerate the sustainable deployment of renewable energy in the entire region.

Moreover, several combined factors support the main goal of spreading the implementation of renewable energy in the GCC region, such as the following:

- The GCC region is one of the most attractive regions in the world in regard to the development of large-scale renewable energy projects, due to the abundant solar energy resources in the region, as well the wind energy found in Oman, Kuwait, Saudi Arabia and the coastal areas of the Arab Gulf and the Red Sea – coupled with a historical leading position in the global energy trade.
- The six GCC countries are already connected electrically by a modern and a large regional energy interconnection grid (currently with significant overcapacity) through overhead lines and submarine cables, which can support the implementation of significant amounts of renewable energy in the region, as well as help with balancing the regional disparities in the energy supply and demand.
- The availability of capital and the liquidity of competitive financing resources are supported by the strong socioeconomic conditions in the GCC countries, which qualify them to move forward and achieve success in their renewable energy projects.
- The sharp reduction in the prices of photovoltaic energy systems, hardware and modules, the very low taxes imposed, and the relatively low cost of labor can facilitate the faster completion of renewable energy projects.
- The surge of growth in energy demand and the increased social and political pressure to build a diversified energy mix in the region that would ensure the region's energy security in the long-term.

The GCC countries' decisive move towards renewable energy projects is a signal to global investors and to the energy community that the region is experiencing the start of an energy transition. These projects also provide further evidence of a change in global energy dynamics. The GCC countries have a great opportunity to double the gains they can benefit from expanding their sustainable projects and accelerating their completion to reach the stage of adequacy and abandonment of fossil fuels – while still maintaining a globally significant position in the energy trade.

A. THE SIGNIFICANCE OF THIS WORK

This article discussed the rapid development in renewable energy projects and their progress in the GCC region as the first phase of comprehensive research, which will be followed by a second phase that covers the potential of renewable energy resources in the GCC region. There is a lack of (solar and wind) renewable energy research and feasibility studies in the GCC region, which are required to support renewable energy implementation and diversification of the energy mix. This work aims to help fill that gap by assessing a long-term contribution to the sustainable energy strategy that protects the power supply from fluctuations and volatility, mitigates climate change implications and reduces carbon dioxide (CO2) issues in the region. The authors believe that this work is the first to do such a synthesis between the past and present evolution of electricity generation capacity and energy consumption, and the future evolution prospects as an updated review based on several resources, data and previous studies over the period (1980–2020). This work would provide more options for future directions and long-term research topics contribution in this area.

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FAHAD RADHI ALHARBI (Graduate Student Member, IEEE) received the B.Sc. degree in electrical engineering from the University of Hail, Hail, Saudi Arabia, and the M.Sc. degree in renewable energy engineering (solar and wind) from the University of Central Lancashire, Preston, U.K., in 2016. Since 2018, he has been a Ph.D. Researcher with the Department of Engineering, Lancaster University, Lancaster, U.K. He has working experience as an Electrical Engineer in the energy sector. His research interests include short-term and long-term energy predictions, energy planning, power analysis, and renewable energy.

DENES CSALA received the B.Sc. degree in electrical engineering from the Technical University of Cluj-Napoca, Romania, in 2011, and the M.Sc. degree in engineering systems and management and the Ph.D. degree in interdisciplinary engineering from the Masdar Institute of Science and Technology, Khalifa University, Abu Dhabi, United Arab Emirates, in 2013 and 2016, respectively. He currently holds a Lecturer position in energy storage systems dynamics with the Department of Engineering and the Energy Lancaster Research Center, Lancaster University, U.K. He is also a member of the International System Dynamics Society and the Faraday Institution.