Decarbonization and Renewables in the Gulf Cooperation Council (GCC): A Critical Review

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Abstract-The alarming increase of greenhouse gases production has boosted the proportion of renewable energy worldwide mainly in the Gulf Cooperation Council (GCC). The GCC states have recently supported several projects to replace gasoline and fossil fuels with energy produced from solar, wind and geothermal sources. Thus, the total installed renewable power capacity has increased significantly from 176 MW in 2013 to 5.6 GW in 2022 with a total CO2 saving of ~4 million tons per year. However, to meet the ever-increased demands for decarbonization and the tightening environmental requirements and regulations, various polices and regulatory codes are required to promote the transition from fossil fuel machinery operation to renewable energy resources and to effectively reduce the carbon footprint in the region. This review paper discusses in depth the recent progress and initiated projects, and measures undertaken by the GCC countries to transit from fossil fuel energy source to renewable energy resources. The state-of-the-art advances in decarbonization and renewable energy generation in the GCC region along with the effective codes, policies and regulatory limits for sustainable renewables are also discussed in this paper. The paper also discusses the potential of the renewable energy sources in the GCC region such as wind, solar, and geothermal as replacement for fossil fuel and suggested a holistic innovative approach to ensure smooth transition from gasoline powered cars to electric ones. The findings and discussions in this review are vital for readers, policymakers, and active researchers in the field of renewable and sustainable energy sources.

Keywords Energy transition, net-zero emissions, carbon capture, sustainable energy, climate positive, greenhouse emission, renewable energy barriers.

1. Introduction

The topic concerning the environmental sustainability, and the reduction of carbon dioxide footprint has received significant attraction from researchers, policymakers, various climate change committees and groups [1]. Among such concerns are the resource depletion, ecological crisis, and industrial pollution which induce sever problems to the degradation of the environment and thus require immediate solutions from the entire world [2], [3]. Several countries have implemented a variety of initiatives to compact these arduous environmental degradation challenges and global warming with policies and codes to promote and enhance the environmental sustainability [4]. Among such policies and measures are emission reduction, energy conservations, green development, and environmental protection among which have also received broad attention from academia. Several studies and reviews have investigated the importance of such measures for environmental sustainability, renewable energy sources, sustainable development, energy transformation and conservation [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. However, with the ever-increasing pollutants and the increased number of publications in this field, there is a huge room for new reviews to discuss the recent advances, policies, and projects in this field.

1.1 Decarbonization and Energy Transition

To meet the ever-increasing carbon dioxide (CO2) emissions, the process of decarbonization has become a more imperative way to curb climate change and restore clean and healthy air to our communities [17]. Decarbonization (net-zero or carbon neutral) specifically focuses on decreasing the emissions of greenhouse gaseous mainly CO2 from various

sectors such as energy, transportation, industry, and buildings [17], [18], [19], [20]. It involves implementing clean technologies and practices to achieve a significant reduction in carbon emissions, ultimately aiming for a carbon-neutral or net-zero emissions future. By reducing these emissions, decarbonization is a vital to mitigate the adverse effects of climate change which include the rise earth temperature, the rise of sea levels, adverse changes of the weather, and the disruptions of ecosystem. By shifting to cleaner and renewable energy sources, decarbonization leads to a reduction in these harmful emissions, resulting in improved air quality and reduced respiratory and cardiovascular health issues [21], [22], [23], [24], [25], [26]. On the other hand, energy transition refers to the process of transition from conventional fossil fuel-based energy to renewable and sustainable energy that include wind, solar, hydropower, and geothermal energy [27], [28], [29]. It involves reducing reliance on carbon-intensive fuels and adopting low-carbon alternatives to mitigate climate change and address environmental concerns. Both energy transition and decarbonization are interconnected and essential components of sustainable development and combating climate change [6], [9], [17]. They involve transitioning to zero carbon energy sources, enhancing the efficacy of this energy, adopting green technologies, and promoting sustainable practices to achieving environmentally friendly and climate-resilient energy systems [18], [30]. Decarbonization and energy transition are thus crucial for a sustainable environment for several reasons such as mitigation of the climate changes, air quality improvements, sustainable developments, protecting the ecosystems and biodiversity, and fostering innovation and technological advancements [17], [18], [19], [20], [21], [31], [32]. Figure 1 summarizes the regulatory solutions for decarbonization.

Fig.1. The regulatory solutions for decarbonization (Source: Research and Analysis Report 2020 by Sherri Billimoria, and Mike Henchen).

1.2 Decarbonization in the GCC

The recent energy challenges and the necessity to decreasing the emissions of greenhouse gases have also created a dynamic changing challenge worldwide and mor specifically in the GCC. As a results, GCC countries started the re-assessment of their renewable energy development plans and projects to face such challenges and to develop alternative energy sources and achieve sustainability goals [33]. While progress is being made, the GCC countries face unique challenges in their decarbonization journeys due to their heavy reliance on fossil fuel revenues and the regional climate characteristics. However, with their increasing investments in the sources of renewable energy, efficiency of energy, and efficiency practices, they are taking decisive steps towards decarbonization and transitioning to a more sustainable and low-carbon future. Additionally, such plans also aim to face the growing domestic energy consumptions, reduce the hydrocarbon pollutants, develop competitive economic changes, and promote cleaner energy. The GCC states have strategic geographic locations where various renewables are available including winds, geothermal, and solar. However, currently the hydrocarbons are still the dominate energy source in the region accounting for around 99% of total consumptions [34], [35], [36]. To tackle this issue, there has been growing rise on establishing several renewable energy projects [37]. The total installed energy capacities have raised from 17 MW in 2011 to 3271 MW in 2020 in the GCC region [38]. The total energy capacity in the GCC countries have grown significantly to 5.6 GW in 2022. However, this number is still very low compared to the hydrocarbon-based energy consumed in the region.

Recently, there are some key initiatives and trends related to decarbonization in the GCC countries [39], [40], [41], [42], [43], [44], [45], [46], [47]. These initiatives are summarized in the following points.

- The GCC nations have invested largely on solar and wind renewable energy sources. For example, the UAE aims at generating 50% of its energy from renewable sources by 2050 through initiatives like the Mohammed bin Rashid Al Maktoum Solar Park and the Abu Dhabi Future Energy Company (Masdar). Wind is an essential sustainable energy source which can play important roles in the developing and sustaining smart sustainable cities [48].

- The GCC countries are starting to implement energy efficiency standards and programs to minimize energy consumptions and improve overall energy efficiency by proposing building codes, conducting energy audits to identify areas for improvement and promoting efficient appliances and equipment.

- The GCC countries have explored implementing carbon capture technologies to capture and store carbon emissions from industrial processes and fossil fuel power plants. This can help reducing greenhouse gas emissions while utilizing captured carbon for enhanced oil recovery or other purposes.

- The GCC countries are adopting several measures for promoting sustainable transportation, including the development of Electric Vehicle (EV) charging infrastructure, deployment of electric vehicles (EVs), and the

implementation of public transportation systems. For example, Saudi Arabia has made vital efforts to encourage EV adoptions and plans to establish a network of EV charging stations across the country.

- The GCC countries aim at diversifying their economical sources beyond fossil fuels and hence they invest in various sectors such as clean technologies, renewable energy, and sustainable industries to reduce their dependence on hydrocarbon resources and enhance economic resilience. The transition from fossil fuel to using renewable energy sources is vital not only to ensure the usage of renewables in smart grids but also to aid in creating and maintain sustainable smart cities [49].

- The GCC countries are also focusing on green finance and sustainable investments. The GCC governments and financial institutions are actively supporting and encouraging investments in renewable projects, improving efficiency of energy, and sustainable infrastructure development.

- The GCC countries are participating in international collaborations and agreements related to decarbonization and climate action. For example, they are signatories to the Paris Agreement and actively contribute to global efforts to combat climate change.

2. Impact of Hydrocarbon-based Energy Sources

CO2 that traps heat in the earth atmosphere inducing global warming. According to the recent annual 2022 global climate report, 0.9 oC % earth temperature increment has been observed since 1906 [50]. The global warming's effects could be seen by the climate change in recent years and the constant glaciers and sea-ice melting worldwide especially in the Earth's poles which has contributed to sea level rise by 0.13 inches yearly and affected the wildlife and their habitats. This climate change will certainly induce sever adverse impacts on the environment and lead to devasting consequence unless proper attempts are taken towards decarbonization.

Global total emission from energy sectors accounts for 70 % of the total emission that cause global warming and thus require immediate attention [51], [52]. This means the transition from energy towards low-carbon developments and decarbonizing fuel and energy complexes to the energy mix is crucial for environmental sustainability and development [53], [54]. Thus, various initiatives to maximize the alternative energy sources have been carried out particularly in developed nations [55], [56]. Nevertheless, no change has occurred in reducing the greenhouse gases emission and global warm issue still arsing [57]. In fact, the British Petroleum Statistical Review of World Energy [37] indicated that the carbon equivalent emissions have increase by 5.8 % in 2021 and only minor reduction (less than 1%) occurred due to the lockdowns during COVID-19 pandemic.

To address such issue, energy policies must be implemented and reenforced in global and regional scales by implementing programs, projects, and technologies that achieve energy related goals such as the global access to affordable energy sources. However, the energy policies must be tailored to the regional context and requirements. Thus, the global energy policy scale is not suitable, for example the United States (US) polices aim at ensuring alternative available, reliable and cheap energy, while in Europe the policies aim to make a secure, affordable and environmental sustainability [58]. Indeed, the energy policy is influenced by the political agendas to implement projects for ensuring sustainable energy sources while ensuring cheap prices for citizens. Such regulations aim to focus on marketing supports for renewables and can relate to the quality, quantity, cost, access, etc for renewable energy [59]. Meanwhile, other regulatory polices focuses mainly on the determining prices as well as compensation schemes. Table 1 highlights the mechanisms, type, price determination and compensation schemes for renewable energy polices.

Table 1. Mechanism of renewable energy policy [59].

Policy mechanisms	**Types**	**Prices determinations**	**Compensations schemes**
Feed-in-premium (Fip) or feed-in-tariffs (FiT)	Priced based	Set by administration	Long-term fixed price contracts
Auctions or tendering	Quantities-based	Competitive prices amongst generators	Long-terms fixed prices contracts
Trading certificates	Quantities-based	Short-terms fluctuations in spot and credit market prices	Varying prices based on supplies and demands.
No meeting	Access-based	Pegged to the retail electricity rate	Offsets of system outputs and retails purchase.

3. Climate Change and Environmental Sustainability

Recently, the united nation (UN) has adopted energy as one of the sustainable development goals which abide all countries to achieve by 2030. It has been constantly argued that the major contributors to CO2 emission and global warming are the hydrocarbon conventional resources such as coals, oil, and gases. To protect against and save our planet, the Paris Agreement is considered an international treaty which abide the 196 countries to effectively reduce the emission of CO2 emission. As a result, countries, companies and industries have to abide by the above-mentioned agreement and hence made various initiatives and projects to mitigate climate change and minimize the impact of CO2 emission. Despite the great projects, the transition from hydrocarbon dependent to renewable energy is not an easy

task especially in the GCC where the main sources of energy are still hydrocarbons, and the renewables are still lower than 2%. However, the barriers that hinder such transition and development of energy from renewables are being investigated and studied in depth in recent studies such as [44], [45], [60], [61]. Among such barriers are the lack of dedicated planning capacity and mandate, regulations, polices, and enforcement environment to attract investors and users [62], [63], [64], [65], [66].

Currently, the world is heavily dependent on non-renewable energy as its main source of energy, a primary example being fossil fuel (oil, gas, coal). Explorations, production, and development, as well as the widespread use of fossil fuel have generated significant hazardous waste (US Environment Protection Agency, 2007). Climate changes have become serious issues in due to the alarming rising of global warming caused by the anthropogenic greenhouses gases emission resulted from the increased combustion of hydrocarbon sources such as the coal, oil and gas [67], [68], [69]. The increased usage and demands for energy are also among the triggers to seek alternative energy sources to reduce air pollution and achieve environmental sustainability. Figure 2 shows the global greenhouse gases emission by sector.

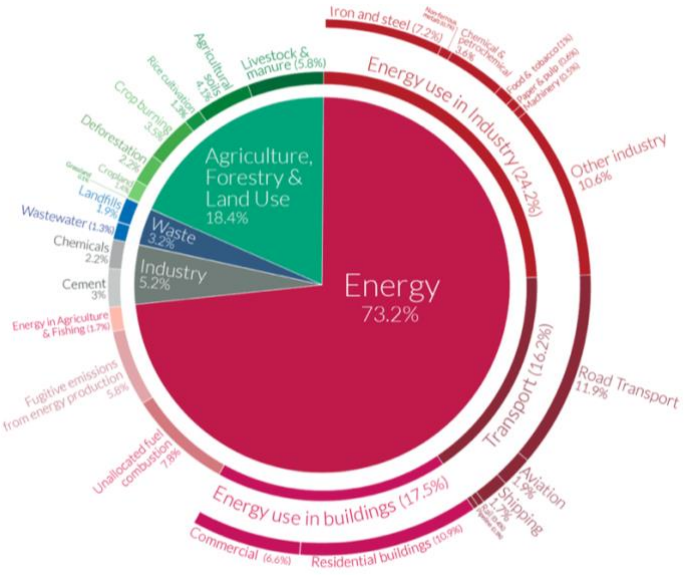

Fig.2. Global greenhouse gas emission by sector accounting for 49.4 billion tonnes of CO2. [Source: Climate Watch, the World Resources Institute (2020)]

Climate change is one of the critical adverse outcomes resulting from using and abusing such energy sources, which will inevitably negatively affect humanity and the environment. Many societies have started to put climate change at the top of their developing agenda; in a broader sense, most governments in developed and developing countries have embedded climate change in their national security strategies. However, this attempt at remedy is worsened by the continuous demand for fossil fuel and its by-products, especially in developing nations (for example, GCC States). In the GCC region, the greenhouse gases emission has increased due to the growth of consumption of energy that has impacted the quality of environment. Current yearly consumption of energy in the GCC per capita is 6260 MWh which is considered the highest in the globe because of the access to a large resources of fossil fuel, large population inclination and the increased industrial activities [62]. The two major sources of energy are the oil and liquid gases with Qatar is the largest natural gas exporters in the globe and Saudi Arabia being the largest producer of oil globally [37]. Around 4 – 12% of GCC regions' energy consumptions are the water distillation due to the lack of fresh water within the region [70]. Thus, GCC countries are considered among the top 25 most significant emitters of carbon dioxide per capita with Bahrain and UAE leading the others as shown in Figure 3. While only 0.6 % world populations live in the GCC states, their contribution to the greenhouse gas emission is around 2.4% per capita worldwide.

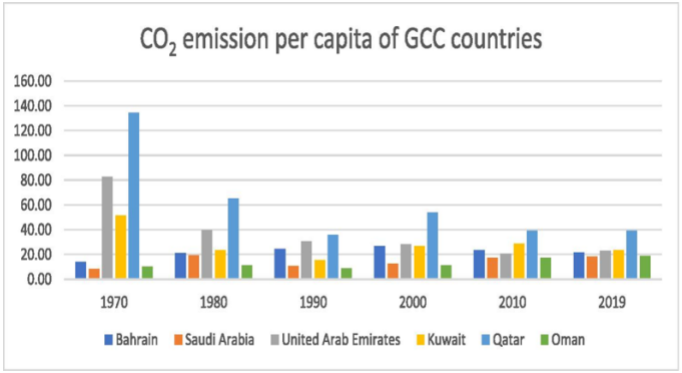

Fig. 3. Periodic comparison of the emission of CO2 per capita of GCC [71].

4. Renewable Energy in the GCC

Renewable sources of energy are among the crucial measures for attaining environmental sustainability and the reduction of carbon footprint as well as solving the issue of global warming and improve the policy of climate conscious for major oil and gas production countries such as the GCC. The reason for this is that the GCC are among the main oil producers in the world and they and depend heavily on oil and gas products. Hence, they are vigorously criticized by the international communities for their crucial impact to the emissions of greenhouse gaseous especially from the hydrocarbon fuel combustions. In the GCC the hydrocarbon sources accounts for a total of 20 % of the world's natural gas reserve and 30 % of its proven oil reserve which are major contributors for greenhouse emissions [52]. Due to the increased pressure from the international community, the GCC countries are facing several challenges to transit from hydrocarbon dependent countries to renewable energy sources which could trigger energy security profile across these countries. Therefore, to meet such demands the GCC countries have started promoting and implementing various initiatives and renewable energy technologies to reducing CO2 emission and switch from hydrocarbon to renewables and encourage their ambitions for diversified economic change.

The total renewable energy generation capacity of GCC region has grown in the past 10 years to more than 657 MW

with major score for UAE with 69% and with the solar energy as the main source with 93.9% of total RE generated as of 2021 [38], [72]. Table 2 summarizes the current RE productions in the GCC. As can be seen, the UAE is the leader in terms of the existing renewable energy generations in with 3 projects dedicated for covering 93% of the housing sectors to power nearly 180 000 homes [73]. The total installed capacity for RE production in the GCC exceeds 2800 MW which only contributes to 1% of needed energy in the region. It is expected that the number to increase in the coming years due to the demands for sustainable energy resources and the reduction of gaseous emission in the GCC and globally.

Table 2. Current implemented RE projects in the GCC countries.

Country	Project	Types	Year	Size (MW)	Sectors	Saved CO_2 (tons/year)	Refs.
UAE	The Solar Park	Photovoltaic Solar	2017	1288	Housing	1.4 M	[74]
UAE	Noor Abu Dhabi	Photovoltaic Solar	2019	1177	Residential	1 M	[73]
Saudi Arabia	Sakaka	Photovoltaic Solar	2019	300	Nation Grids	0.5 M	[75]
Bahrain	Askar Landfills	Photovoltaic Solar	2019	100	–	7.2 K	[76]
Oman	PDO Amin Photovoltaic Plants	Photovoltaic Solar	2020	100	–	225 K	[74]
UAE	Shams 1	Concentrated solar power	2013	100	Housing	175 K	[77]
Kuwait	Shagayas	Concentrated solar power	2019	50	National Grids	196 K	[76]
Oman	Dhofar, Phase I	Wind	2020	50	Housing	110K	[78]
Qatar	Mesaieed	Waste to Energy	2015	38	Industrial	–	[77]
Kuwait	Shagaya	Photovoltaic Solar	2019	10	National Grid	Included	[76]

To sum this up, for the past decade the GCC countries have gained more knowledge and experience in developing renewable energy projects and technologies which are expected to grow further. The GCC countries have since then invested tremendously in developing advanced and significant renewable energy technologies and projects such as the Solar Park in UAE with 1288 MW capacity, the Sakaka project in Saudi Arabia with 100 MW energy production from solar panels [62]. For example, between 2017 to 2020 the Solar Park in UAE has increased its energy generation capacity to nearly 1288 MW which has influenced the neighboring GCC states to implement lager scaled projects as well. Another project, Dhofar wind projects started in 2020 with a 50 MW capacity and expected to produce 150 MW energy capacity in 2023. Despite the crisis of COVID-19 that leads to shutting down of small projects, more initiatives are expected to be implemented within the forthcoming years. An example for that is the participation of Qatar and UAE in the renewable energy manufacturing and assembly with companies such as the Qatar solar energy and Echo solar energy manufacturing of UAE [35]. In the following subsections, the renewable sources and projects, and the barriers that hinder the transitions to renewables in the GCC are further discussed in detail.

4.1. Renewable Energy Sources and Projects in the GCC

The major renewable sources and projects in the GCC regions are the solar, wind and geothermal which are discussed in this section. The wind and solar sources are the highest with 90% contribution to the renewable's investments in the region and the new renewable projects made them simpler and cheaper [60]. The most promising source of renewables in the GCC region is the solar energy with 2726 MW capacity [35]. The renewable energy capacity is anticipated to grow to 65,490 MW by 2030 in the GCC region or more due to the recent implementation of various new solar systems to track and store energy from the sun like building integrated photovoltaic panels, solar skins and etc. Such solar skin technologies allow the integration of solar panel designs with conventional homes' rooftops in an efficient way to track and store tremendous energy for home appliances [14], [52], [63], [65], [79]. More importantly, these technologies reduce carbon footprint such as the solar farms which can be implemented in the GCC region to cover wide range of deserted areas to store massive energy from the sun and wind sources. These solar farms have also cooling effect to enable storing 10% more energy compared to the existing photovoltaics panels [79]. Another breakthrough in the newly power energy designs is a solar panel with six junction which provide 47.1 % efficiency six-junctions panels compared to the 17.4% efficiency produced using the conventional photovoltaic solar panels [80]. However, this technology still has not been implemented in

real-world applications and remains in laboratory scale and pilot studies. Some GCC countries are investing in the morphine photovoltaic solar panel rather than the stationary ones due to the possibility of customization, cooling, and convenience [73]. In short, solar is a very promising renewables in the GCC region primarily due to the strategic location and the existing and current massive projects implemented in the region.

For the past two decades, the wind power capacity has reached 564 GW in the past few years worldwide. It's worth noting that the wind power in the GCC region is approximately 56% suitable for energy generation due to the strategic location of these countries [81]. One of the promising aspects tis the availability of wind power innovations that can be utilized by the GCC countries which could be promising energy resource in the future years [81]. The overall anticipated wind energy generation capacity in the GCC region is 5230 MW by 2030 [35]. The Dhofar project Phase II in Oman is expected to produce more than 150 MW in the coming years [82], [83]. A recent study conducted by K.Okedu [84] to investigate the cost of using various renewable energy technologies in providing power solutions to Bukha, Musandam, Oman and found that the solar, wind and geothermal are the main contributors. However, the GCC region face some challenges with regard to the wind power like the lack of the regulations and measures, low oil and gas prices and the reduce public awareness [85]. As a results, some of the major wind energy systems have shut down such as the Jebel Ali facility and Sharjah sites [86].

Another essential natural energy source is the geothermal energy that generates power via the natural heating within the earth with temperatures that could reach up to 300 oC or more [82]. The GCC countries have underground heating temperatures that are suitable for the generation of geothermal energy for example Saudi Arabia has heating underground more than 250 oC, Oman has various geothermal areas [83]. Meanwhile, UAE and Bahrain have lower earth heating values of less than 150 oC which can only be utilized for water desalinations and heating or cooling purposes [84]. The Fujairah-2 Plant project in the UAE for example uses its power generated via geothermal approach for desalinations. Over the years, the technique to generate energy from the geothermal fluids have dramatically increased from the single flash technique to the double and binary cycles methods. The most sophisticated method is the binary cycle which uses the geothermal heat to heat a secondary fluid to produce vapor which can be further used for moving turbines [83]. In the GCC region, such methods implicit few concerns that must be considered including the toxicity of the fluids, cost before selection, and the combustibility [85]. Recently, the Conserve Energy Future recommends that the homes should install units to capture the geothermal energy to cooling or heating their homes which could be 400% effective than the standards air-conditioning units and contribute to reducing electricity bills by up to 50% [86]. However, in the GCC region the IRENA 2019 reports argues that it's very difficult to implement geothermal project in GCC because of the limited knowledge, lacks of local experts in this field, lack of technological advances, and limited public awareness of such power [35].

To sum up, in the GCC region, the major renewables are the solar, winds and geothermal given the strategic locations of these countries. As a result, the GCC states have developed various renewable initiatives and projects, and the total renewable energy capacity has grown in the last five years as shown in Figure 4. The solar photovoltaic cells represent 71% as the most dominant renewable sources followed by the solar (23%), wind (2%), and biomass and waste with 4%. The UAE is considered the leader in the region in renewable energy technologies with energy capacity of 68% followed by 16% and 9% energy capacities in Saudi Arabia and Kuwait respectively.

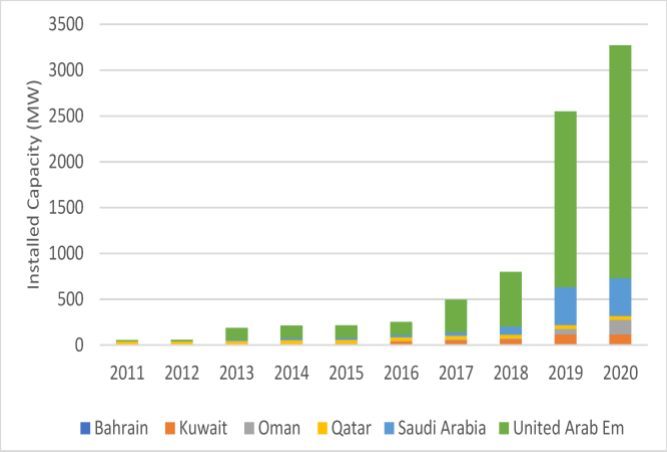

Fig. 4. The total energy capacities in the GCC installed from 2011 to 2021 [52]

4.2. Renewable Energy Challenges in the GCC

The GCC states have given prior attention to evaluate the potential barriers or challenges that have hindered the renewable energy growth in the region [62], [92], [93]. Among the found barriers are institutional, market, technical, cultural as well as the lack of policies and incentives to enforce the implementation and adoption of renewable energy [35], [94]. Additional key challenges that may hinder the transition of GCC countries from hydrocarbon products to renewable energy such as the cost competitiveness of fossil fuels compared to the renewables in the region, the limited renewable energy infrastructure and grid integration, lag regulations which could create uncertainty and slowing down of renewable energy projects' implementation as well as the limited local manufacturing and expertise [39], [40], [41]. Furthermore, the market distortions and limited promotions to the renewable energy developments, as well as the subsides for electricity and fuels have also been associated with the slow progress of the cleaner energy developments due to the low energy prices in the GCC region [95]. Recent studies in the region have also revealed similar findings and added additional challenge which is the challenge to design and implement financial policies to

support adopting cleaner energy development GCC [96], [97].

In short, the common barriers are categorized into institutional barriers, market related barriers, technical barriers and cultural barriers and are thus summarized in the following points:

i. Institutional barriers: Limited institutional power to aid the adoption and development of renewable energy's technologies and projects in the GCC. The institutional barriers including the approval process to obtain license, the limited experience with renewables, and the inconsistent national energy policy. Like any other technology, renewable technology requires approval process and permitting to be otherized and installed in the country. Such approval includes several processes such as consultations, reviews, multiple agencies approval which takes longer times to authorize the development of renewable projects. Figure 5 summaries the institutional barriers of the renewables in GCC.

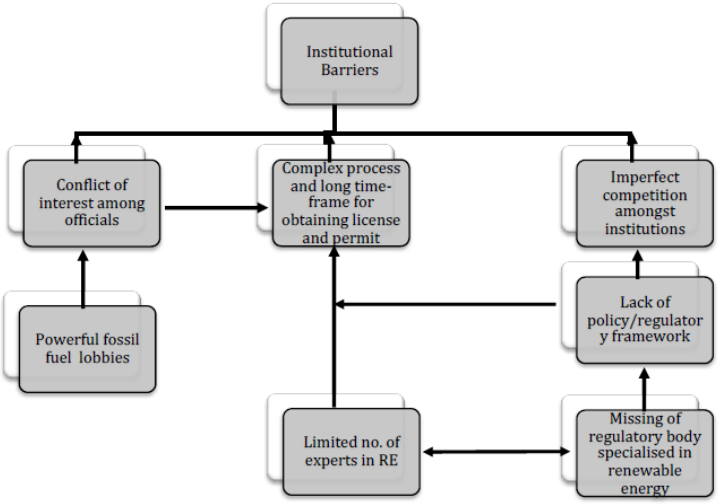

Fig.5. Flowchart summary of the institutional barriers in GCC [52]

ii. Market (Economic) barriers: The conventional energy market is still favoured over the renewables in the GCC region. This is due to due to the cheap availability of the fossil fuels-based sources and the high cost of renewable technologies in terms of approval and uncertain investment in the development, and adoption of such technology in the region. In addition, the limited data and information of the renewable energy technology makes both the approval and investments are difficult. Figure 6 summaries the market barriers of the cleaner energy in GCC.

iii. Technical Barriers: The technical barriers include the access to national grids, the confidence and familiarity with the new technology, the availability of skilled personnel, and the availability of areas needed for installing the new technologies in the region. Figure 7 summaries the technical barriers of the RE in the GCC region.

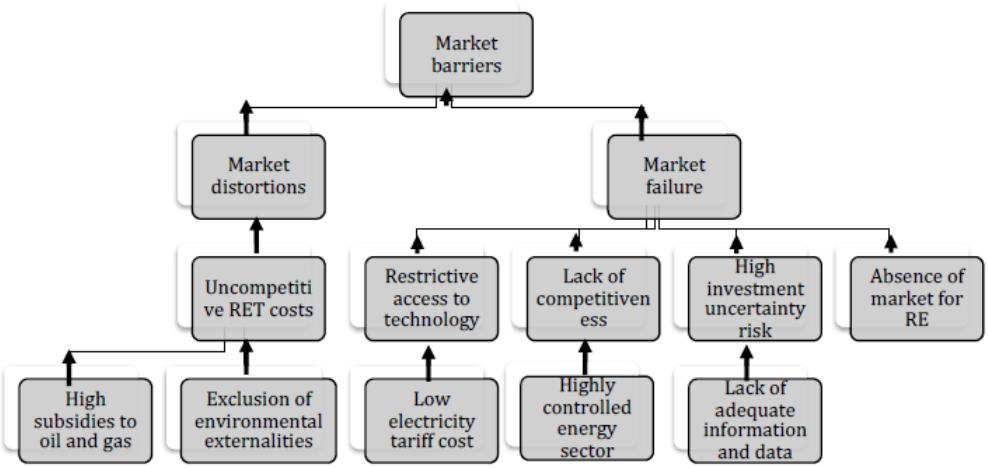

Fig. 6. The total energy capacities in the GCC installed from 2011 to 2021 [52]

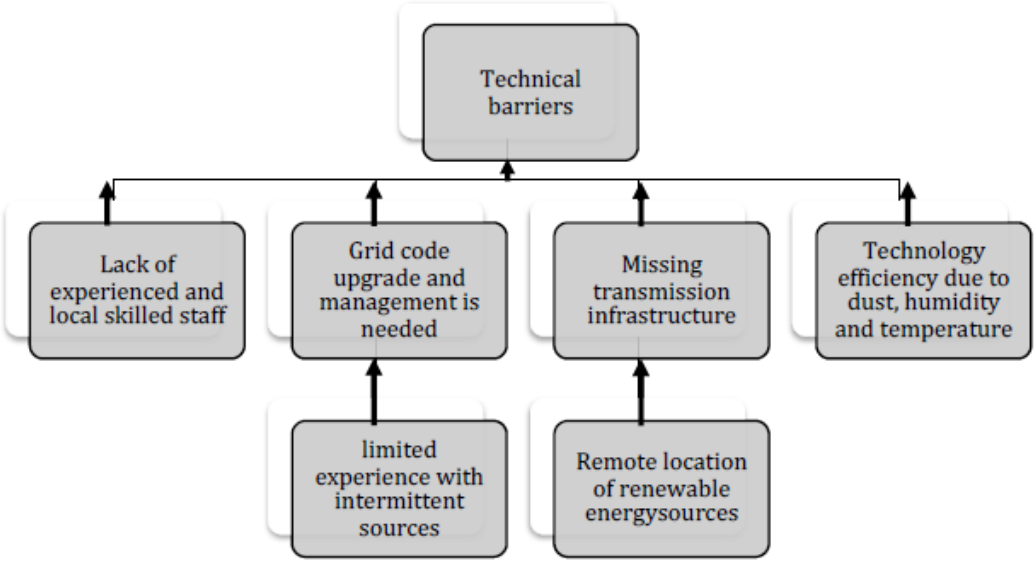

Fig. 7. Flowchart summary of the technical barriers of RE in the GCC countries [52].

iv. Cultural Barriers: The cultural barriers refer to the acceptance and the desire of the public to the new technology among the GCC nationals. Given the low cost and easy access of the conventional electricity as well as the limited awareness of the GCC nationals about the renewables, public acceptance of renewables remains at small scale. Figure 8 summaries the institutional barriers of the cleaner energy in GCC.

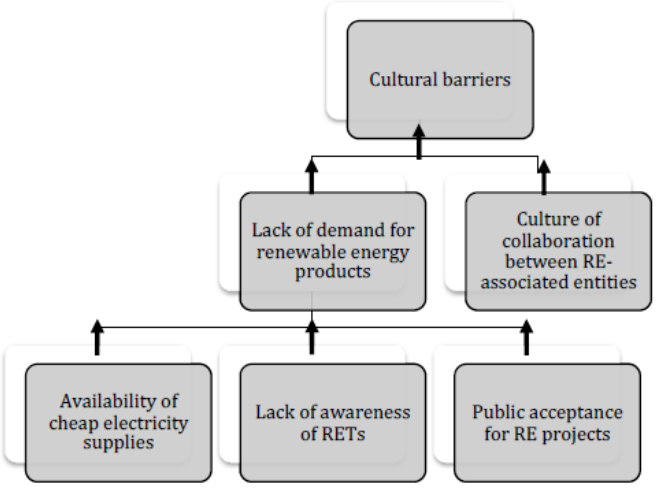

Fig. 8. Flowchart summary of the cultural barriers of in GCC [52].

5. Applications of Renewable Energy in the GCC

There are various uses and applications of the RE in the GCC. Overall, the industries consume nearly 47% of the produced electricity followed by the gas consumption and transportation sectors [62]. Electric vehicles have been well researched and designed and have received significant traction from the automotive industries with big companies such as Tesla that produce electric cars that are comparable in speed and mileages to gasoline powered cars [98]. The number of electric vehicles is increasing in the GCC region. The GCC states have taken some initiatives to reduce the emission of greenhouse gases by encouraging their citizens to use electric vehicles with many free charging stations implemented. There is a surge in the popularity of electric vehicles among population in GCC region that has sparked in recent years. Saudi Arabia aims for at least 30% of its cars to be electric by 2030 and expected to reach fully electric cars by 2060. Last couple of years, the Lucid international manufacturer announced that they will be the first electric manufacturer in Saudi Arabia targeting more than 150, 000 units per year. UAE aims for 42,000 electric vehicles in its streets within the next 10 years. To achieve their plans, UAE opened its electric vehicle manufacturing facilities in Dubai Industrial City last year with a total of $408 million. There is strong competition for a share in the GCC region market with various international brands including Tesla, BMW, Audi and Mercedes-Benz.

Despite all that, the recent crisis and the declining of the oil cost and high electric cars price and maintenance fees dejected consumers from owning electric vehicles as alternative mode of transport [99]. The major concern about the electric cars in the GCC are the lack of charging stations, high-cost maintenance, and the hassle of change [100]. The GCC administrations have indicated their worries also about the abrupt changes towards electric cars and the added necessities for new infrastructures such as chagrining stations. Besides, the increased popularity of electric cars may reduce the demand for gasoline powered cars which may results in a drop in the global prices of oil [101], [102]. Nevertheless, the governments in GCC have initiated some plans to supporting and promoting the transition from gasoline powered cars to electric ones. For example, the UAE has encouraged the transitions from private owned vehicles to electric ones by implementing free plugins and reducing the cost for electric batteries. Oman government

works closely with the electric cars Regulation Framework to implement and manage various charging stations in the country [103]. Bahrain is also working to implement electric cars by introducing the light rail projects for boosting the public transport capacities in the country [38]. Saudi government is also working to boost electric cars uses and expected to construct various charging stations in various places in the country [62]. Furthermore, the Riyadh Metro is expected to boost the electric power generation because it was constructed with at least 4300 photovoltaic solar panels on its roof [104]. Qatar also has started constructing multiple stations for charging electric vehicles to boost the adoption of these vehicles in the country [62]. Kuwait also has projected a massive transit metros and rail projects to link its main ports [78]. Table 3 summaries potential technologies of renewable energies in GCC countries and major future developments in the region.

Table 3. Currently implemented and potential energy developments in GCC [62]

Country	**Energy cons/capti (MWh/year]**	**Current implemented projects (MW)**				**Potential implementation**			
		Solars	Winds	Geothermals	WTEs	Solars	Winds	Geothermals	WTEs
Saudi	650	439	03	Minimal	0	20,751	3501	Maximum	750
UAE’	951	911	01	Minimal	1	29,001	301	Medium	601
Bahrain	901	05	01	Minimal	0	6061	21	Minimum	21
Oman	851	08	51	Minimal	0	4,181	1211	Maximum	111
Kuwait	1,411	68	11	Minimal	0	7,801	201	Medium	NA
Qatar	1,501	05	0	Minimal	39	3,001	N/A	Medium	101

In the GCC region, it’s anticipated that the demands for renewable energy to reach 15, 550 MW that accounts for total of 96.7% of general demands in the region. However, to attain such capacity, the GCC governments must optimize their renewable technologies further, for example to develop solar panels plants, geothermal sources and efficient wind energy capturing technologies. An example is the integration of solar tracking with bifacial panels and or robotics morphine to improve the efficacy of the RE system and combat the issues of the dusty weather in the GCC [62]. Countries such as KSA and Oman are forecasting to add more than 500 MW from wind harnessing energy with their two big energy industries namely Vestas and General Electric [62]. Note that, it is challenging for GCC countries and people to switch to renewables because low prices of hydrocarbon sources in the region. Thus, a comprehensive integrated approach associated with the requirements of each renewable and energy demands of the public is needed. The technological advances of such an approach would ensure rapid and wider integration of renewable sources into regional energy mixes. Such innovative systems also must be optimized with existing fossil fuel based one and offer cost-effective hybrid substitutes for decarbonizations of the energy mixes and provide clear guide and support for regional transition as well [105]. For example, the integrated of solar photovoltaic plants and oil-based powers in KSA and Kuwait are very promising initiatives where it was possible to decrease the cost of crude productions for generating electric power. Recent years have witnessed the initiation of sustainable plans and projects for renewable energy utilizing the natural sources (solar, wind, etc.), enhancing the efficiency of the energy generation, and applications of renewable sources. Figure 9 summaries GCC energy plans.

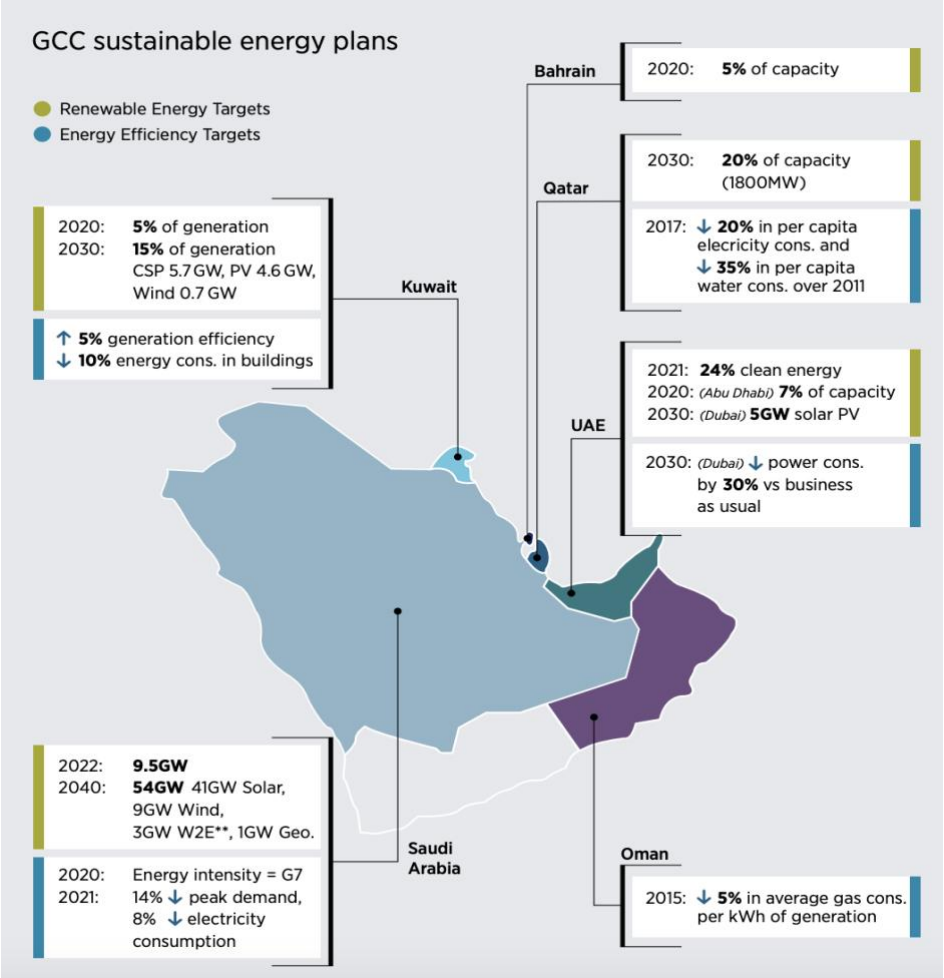

Fig. 9. GCC's Sustainable energy plans (source: IRENA).

6. Policies and Regulations for Renewable Energy in the GCC

Proactive policies are vital to ensure facilitating of renewable energy deployment in the GCC. This is to ensure that implementing of renewable systems benefits from the combination of renewable energy goals with wider polices to ensure greener and long-lasting efficient managements for energy conversion, markets, and cleaner energy' technologies development. More importantly, such proactive measures ensure the efficient usage of the greener energy, building efficient energy products/plants, fuel price reform and efficient supply side management. Among the goals is to ensure setting targets for decarbonization, codes for products/building, subsidies for energy, standards for appliance, and importing duties exemptions and etc. As demonstrated in Table 4, GCC region has individual targets for implementing renewable energy across various sectors including public transport, electricity production, green building developments, and energy-intensive industries. Despite all the efforts, concrete regulations and measures to spur the adoption and use of renewable energies are still lacking, which highlights a gap between the ambitions of the GCC countries and their actions. Various initiatives have occurred especially upon the Kyoto Protocol signing that obliged GCC countries to reduce greenhouse gases production. In GCC, the current energy-intensive sources are upstream oils and gases, aluminium's, refining of oils, cements and petrochemical manufacturing which are governed by the state governments. Despite all that, the GCC starts have implemented measures for reducing carbon footprint and they are striving to continue their purse for renewable energy sources, establish polices and regulations as well as encouraging regional transition towards adopting green energy sources [106]. These policies should be implemented carefully and strategically integrated with other associated systems and most importantly tailored to the unique conditions and regional aspects of the GCC.

In short, despite the abovementioned barriers, recent progress on renewable energy in the GCC have seen several key solutions and strategies to transit to renewable energy and reduce the dependency on fossil fuels. While each GCC country has its certain initiatives, the majority of GCC states have fixed renewable targets for cleaner energy generations, projects, auctions, policies and regulations, R&R and energy efficiency measures.

Table 4. Summary of the current policies in the GCC countries for effective implementation of RE [62].

Country	RE Targets	Steps taken after the sign of Kyoto Protocol	Green buildings codes	Transportations energy from RE	Measures in energy-intensive industries
UAE	-Dubai sets 7% target by 2020, 25 % by 20230, and 75% by 2050 for producing electricity. - Abu Dhabi sets 7% by 2020 [83]. -Energy mix project is set to 24% by 2021	-Established in 2009, the UAE Supreme Council or Energy (SDCE) is set to ensure the long-term growths be powered by green resources [84]. -SDCE coordinating institutional initiatives within the UAE for renewable energy transition	The Green Building Regulations and Specification was established in 2011.	25% of all transport in Dubai is expected to be smart and autonomous by 2030. This is monitored by the Dubai Autonomous transportation Strategy under the Future Foundation Project established in 2017.	-A 10% increase in energy efficiency by 2020 for the Abu Dhabi Nationals Oils Industry. -The UAE Nationals Oils Company in Dubai also adopted energy and resource management to improve energy saving in the forthcoming years. -In the UAE, the aluminum has achieved a great thermal efficiency, and it is anticipated to reach further in the next 10 years.
KSA	-King Abdullah City is set to produce 41,000 MW by 2032. -Final energy mix is set to 4% of renewable energy	-Established in 2010, the Saudi Energy Efficiency Center is aimed to achieve converse national sustainable energy and improve energy efficiency. -Established a master plan in 2011 to oversee the concerns regarding energy conservations and peak demand productions. -KSA also implemented the Feed-In-Tariffs systems and green certificates to accelerate the changes of RE to the market.	The Energy Building Code in the KSA was established in 2007.	-The capital city Riyadh has a project called Riyadh Metro that is powered by photovoltaic cells that are installed in the roof of the metro.	KSA plans to convert power plants with single-cycles to integrated-multiple cycle plants and its national phosphates and also mining companies.
Kuwait	Kuwait set 15% for electricity generation by 2030.	Established in 2014, the Energy Conservation Program and Code of Practice in Kuwait to ensure sustainable and conserve energy efficiency, power savings and cost-benefits as well as the effects of the code on energy demands.	Kuwait has updated its Energy Conservation Code to further specify the minimum energy for effective consumption for		

			new buildings.		
Qatar	Qatar set 2% by 2020 and 20% by 2030 of RE for electricity generation [83]	-Qatar has created several institutions such as Qatar Science & Technology Park for collaborating with national funds, foreign companies, local banks, etc. for the implementation of solar projects and RE infrastructures. -The First National Development Strategy of Qatar [84]	Mandatory green and sustainable building rate that facilities the energy saving on both phases; constructions and operations.	10% target was set by Qatar for producing transportations energies from renewables by 2021 and has started to build various points for charging electric vehicles.	Qatar is using solar photovoltaic plants for powering its Dukhan oilfields to reduce the dependency of consumers on diesels generators in remoted or less accessible places.
Oman	Oman set 20% electric generation from renewables by 2030.	Established in 2012, strategic plans and Authority for electricity regulation in Oman to continue pursuing ongoing targets to reduce the losses of electricity during transmissions and distributions	Oman first approved the green GCC code in 2017. -Oman installed solar panels around the country for several applications including rooftop water heaters, street lighting and televisions transmitters.	-Oman has devoted efforts to adopt technologies that ensure further development of green and sustainable buildings. - A committees have been formulated by The Supreme Councils for Plannings to develop inclusive cleaner and greener design codes to match the requirements of the proposed unified green code of GCC.	-Oman has created projects to realize efficient energy for its Amal oilfields as to diversifying from the gas injection and steams generation using fuels. -Oman was the first GCC to develop cost-reflective prices plan for its gas inputs to the power sector, and industry intensive operations.
Bahrain	Bahrain set 5% by 2030 for producing electricity	-Bahrain has recognized a green committee called designed national authorities (DNA) for green energy. -Various measures among the big companies such as Bahrain nationals for gas (Bangass), the BaPCO, and the Gulf Petrochemical Industry (GPICs) have promoted the reduction of greenhouse gases emission within their oil sector.		Bahrain works to implement electric cars to combat carbon dioxide emission by proposing light railway projects for improving the public transport efficacy.	Bahrain aims to switch to green gas turbines in its gas and aluminums industries. It also mandates manifold for electrification projects in its petrochemicals and oil industries.

7. Conclusion and Future Recommendations

The GCC countries hold up to 30% of oil reserves and 20% of natural gas worldwide which indicates a huge abundance of hydrocarbon resources. They are considerably defined by their abundant wealth of hydrocarbon and ranked among the top 25 world's major carbon dioxide emitting countries in the world. However, such abundance doesn't prevent GCC countries from pursuing alternatives renewable energy resources. The renewable energy sources present a chance for GCC for better addressing of the challenges of climate change, security of energies, quality of air and greenhouses emissions. Despite this, the current primary consumption of GCC countries to renewable energy still below 1%. Despite the growth of renewable energy capacity from 176 MW in 2013 to 5.6 GW and with reduction of CO2 of nearly 4 million tons per year, the majority of operational machinery and vehicles still depends on the hydrocarbon resources in the GCC region. Due to the recent demands after the Paris agreement, the GCC countries are facing significant pressure to minimize the greenhouse emissions, they have taken initiatives and are aware of the importance of green energy to the environmental sustainability and climate change. Among the abundant natural sources of energy in GCC are the solar, wind and geothermal. In recent years, several solar, wind, and geothermal projects to generate green energy have been implemented and promoted by the GCC governments. Indeed, these countries are going to lead the way to green energy and sustainable environment due to their strategic geography and the massive green resources support the transition; and alternative energy sources make economic competitive advantages. Of particular, the solar and wind sources are very promising in the GCC countries due to the huge open land space as will as long average hours of sunshine. Despite all the efforts, GCC's adoptions of the green energy technologies as a substitute for fossil resources faces many challenges such as the institutional approval barriers, the market barriers, the technical barriers and the cultural barriers. The GCC governments have implemented serious policies to enforce the transition from hydrocarbons to energy from renewables. Thus, a clear and well planned RE strategies with clear visions that allow easier institutional approvals for green energy projects, encourage public awareness of the RE, developing the required skills to handle such technologies as well as encouraging private investments and adoption of the RE are still required by the GCC governments.

Among the recommendations to be highlighted by the authors are:

- The GCC states governments should support the approval of renewable energy projects by hiring the skilled personnel to reduce the institutional and governor barriers. This is essential to ensure the full support and rapid approvals for renewable energy projects pertaining to hiring skilled personnel and facilitate the construction of renewable energy facilitates.
- Promoting the availability of renewable energy data, information and encourage private sector involvement in the investments of renewables. This is of a particular importance to encourage not only government sectors involvement but also the private sectors which will enable wider acceptance and adoption of renewable technologies in the region.
- Encourage public awareness and acceptance to renewables. When people are aware of the environment and economic benefits of renewable energy, they will be part of the transition from fossil fuels to renewables. Thus, various programs, ads, and educational programs are conducted in the GCC to improve people's awareness of renewables.
- Building good grid-tied renewable energy systems. Having good grid-tied renewable systems is essential due to the harsh conditions and weather changes in the GCC region.
- Encouraging the R&D of renewable energy in the universities to increase the availability of skilled personnel on the new technology. This is essential to not only have a proper R&D of renewables but also to encourage the involvement of educational sector in facilitating the awareness and skills in the GCC region.

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