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Review

Potential of Utilization of Renewable Energy Technologies in Gulf Countries

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Abstract: This critical review report highlights the enormous potentiality and availability of renewable energy sources in the Gulf region. The earth suffers from extreme air pollution, climate changes, and extreme problems due to the enormous usage of underground carbon resources applications materialized in industrial, transport, and domestic sectors. The countries under Gulf Cooperation Council, i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, mainly explore those underground carbon resources for crude oil extraction and natural gas production. As a nonrenewable resource, these are bound to be exhausted in the near future. Hence, this review discusses the importance and feasibility of renewable sources in the Gulf region to persuade the scientific community to launch and explore renewable sources to obtain the maximum benefit in electric power generation. In most parts of the Gulf region, solar and wind energy sources are abundantly available. However, attempts to harness those resources are very limited. Furthermore, in this review report, innovative areas of advanced research (such as bioenergy, biomass) were proposed for the Gulf region to extract those resources at a higher magnitude to generate surplus power generation. Overall, this report clearly depicts the current scenario, current power demand, currently installed capacities, and the future strategies of power production from renewable power sources (viz., solar, wind, tidal, biomass, and bioenergy) in each and every part of the Gulf region.

Keywords: renewable energy; bioenergy; biomass; solar energy; wind energy; Gulf Cooperation Council

1. Introduction

The scientific community and environmental professionals currently face the twin crises of declining fossil fuels and environmental degradation in the global renewable energy scenario. Indiscriminate mining and the lavish use of fossil fuels have contributed to a decline in underground carbon resources to produce energy for human needs around the world [1–4]. It is well known that fossil fuels are extracted by a simple natural process produced by the anaerobic decomposition of organisms that have been buried millions of years ago. Fossil fuel basically comprises majorly carbon (which involves coal, petroleum, and natural gas). In 2019, around 84% of global primary energy came from coal, oil, and gas [5]. Humans use these as an energy source, and some fossil by-products are also used for plastics production, rubber, pesticides, fertilizers, chemicals, solvents, etc. The existing energy landscape has stimulated the active research interest in nonpetroleum, renewable, and ecofriendly fuels in renewable research to support the human race and safeguard the global environment [6–8]. Oil reserves around the world are limited and are expected to decrease in the coming years due to the exorbitant use in all sectors. Over the past few decades, the tremendous growth of the human population, increased technological maturity, exorbitant industrialization, and living standards have contributed to this enigmatic situation in the field of energy supply and demand [9–11]. Due to the reasons mentioned above, the prices of petroleum products (such as crude oil, gasoline, diesel, kerosene, natural gas, etc.) keep rising day by day [12,13].

The Gulf Cooperation Council (GCC) controls almost one-third of proven worldwide crude oil reserves and one-fifth of global gas reserves [14]. The GCC produces about 30% of the world's proven crude oil reserves and 22% of its known gas reserves. Saudi Arabia has 266 billion barrels of oil reserves, second only to Venezuela, and may continue to produce at current rates for another 60 years [15]. Saudi Arabia also has the world's sixth-biggest natural gas reserves, the second-largest in the area after Qatar, which has estimated proven gas reserves of approximately 24.9 billion cubic meters, making it the world's third-largest holder of reserves after Russia and Iran.

The region's energy generation increased from 51 TWh (Terra Watt-hour) in 1990 to almost 536 TWh in 2015. The power usage per capita in the GCC nations is regarded as one of the highest energy consumption rates per capita, ranging from 5340 to 17,610 kWh in 2010, compared to the global average of 2728 and the Middle East average of 3378 kWh. Economic development and major industrial projects boosted immigration rates in this area, leading population growth to accelerate. Between 2005 and 2009, the rate of increase in electricity consumption was 8.87% among the GCC countries. The per capita usage of electricity was 11,362 kWh in 2009, 3.9 times the world per capita, 0.8 times the US per capita, 4.2 times per capita in China, and 1.7 times the per capita consumption in the EU [16]. The GCC countries are expected to increase per capita energy consumption by an annual rate of 2.5% throughout the 2007–2035 timeframe. The electrical energy consumption in the GCC is expected to reach about 2000 TWh by 2040 [14]. The physical infrastructure and size of the interconnections between GCC countries are presented in Figure 1.

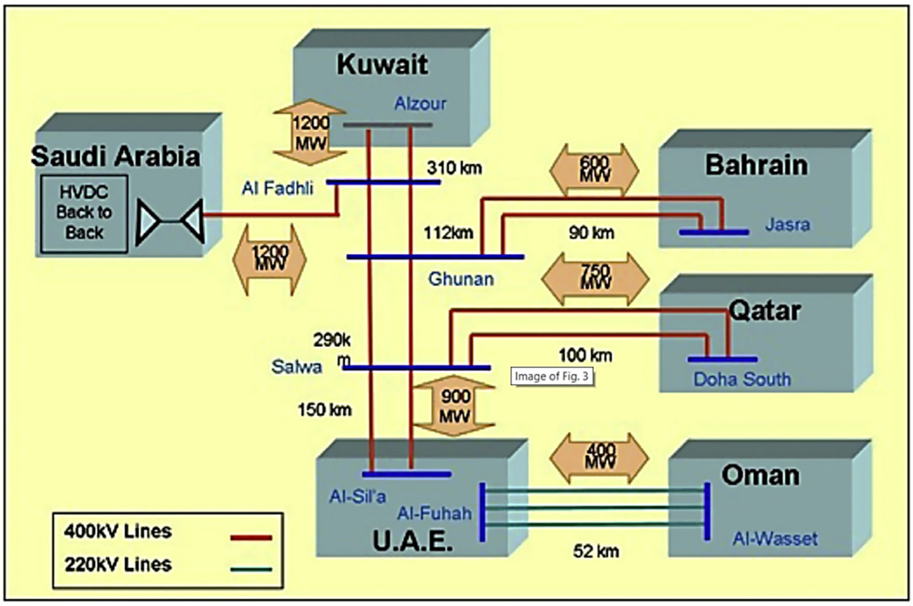

Figure 1. Power grid interconnection in GCC countries [17]. Adapted with permission from Abdul Waheed Bhutto, Aqeel Ahmed Bazmi, Gholamreza Zahedi, Jiří Jaromír Klemeš (2014). 2021 Elsevier.

The UAE is the leader among GCC countries with 134 MW, followed by Qatar with 41.2 MW in total renewable energy production through wind, photovoltaic, and concentrated solar power [18,19]. GCC countries are instilling renewable energy projects to meet the 2030 targets. Installed renewable capacity in 2018 within Gulf countries is illustrated in Table 1 [18].

Table 1. Installed renewable energy capacity in Gulf countries.

Country	Total Capacity (MW) (2018)	Wind (MW)	Solar (MW)		Bioenergy (MW)
			Photovoltaic (PV)	Concentrated Solar Power (CSP)	
UAE	596	2	494	100	–
Oman	8	–	8	–	–
Qatar	43	–	5	–	38
Bahrain	6	1	5	–	–
Kuwait	41	10	31	–	–
Saudi Arabia	142	3	89	50	–

GCC countries have set renewable energy targets to mitigate the energy crisis. However, there is also a significant variance in the use of renewable energy technology. While some nations have started to actively invest in renewable energy production, other—ostensibly comparable—countries lag and remain trapped in the old fossil-fuel economic paradigm. Very few studies have been conducted to explain this variance [18].

Saudi Arabia and Kuwait have focused on achieving 30% and 15% of electricity produced from renewable energy resources by 2030. The UAE plans to meet 44% of its energy demand from renewable energy resources by 2050. Oman and Bahrain aim to achieve 10% and 5% of electricity production through renewables by 2025 [18]. The proposed renewable energy projects in Gulf countries are illustrated in Table 2.

Table 2. Projected renewable capacity (MW) in Gulf countries by 2030 [18].

Country	Solar			Wind MW	Bioenergy MW	Total MW
	Concentrated Solar Power (CSP) MW	Utility PV MW	Building Integrated Photovoltaics (BIPV) MW			
UAE	6000	18,900	4200	300	600	30,000
Bahrain	70	520	70	20	20	700
Saudi Arabia	9500	10,500	750	3500	750	25,000
Kuwait	1000	5800	1000	200	–	8000
Qatar	600	2250	150	–	100	3100
Oman	770	2420	990	1210	110	5500

Over the years, environmental pollutant issues have been increasing ominously in the world [20,21]. Renewable energy scientists and practitioners have attempted to exploit the different forms of renewable energy sources to produce energy for human needs and satisfaction [22,23]. Various types of renewable energy sources (such as solar power, wind power, hydroelectric power, geothermal power, tidal power, biomass, biological waste power, bioenergy, etc.) are considered to be the possible solutions for catering to human needs in this region. Recently, bioenergy in bioelectrochemical systems (BESs) has gained extensive interest due to its crucial sustainable and renewable characteristics [24]. Preliminary research in the area of bioenergy has been initiated in the Gulf region [25]. Researchers have reported that bioenergy has huge potential to develop power in the Gulf region. In this regard, most of the GCC countries (viz., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) are putting their maximum efforts and dedication to harness the aforementioned renewable sources to generate electric power for all industrial sectors. In this context, in this study, most of the renewable energy sources which are tangibly available in the developing Gulf countries are critically noted and elaborated in the ensuing sections.

2. Bioenergy Generation through Bioelectrochemical Systems in GCC Regions

Bioelectrochemical systems (BESs) are becoming some of the most promising technologies to produce renewable energy from waste [26]. Over the past decades, BESs have gained substantial interest due to their inherent sustainability and renewable characteristic [24]. BESs are devices that use electrochemically active microorganisms to catalyze electrochemical reactions to produce bioenergy in various types by using organic matter inside wastes [27]. Various BESs have been discovered so far, which are different in applications and details of oxidation/reduction reactions [28]. However, they are all in common in terms of efficient generation of current from available feedstock to fuel their nominated applications [29]. Based on the application, BESs can be classified as microbial fuel cells (MFCs) to produce bioelectricity (Figure 2a), microbial electrolysis cells (MECs) to produce hydrogen (Figure 2b), microbial desalination cell (MDC) to desalinate sea/brackish water (Figure 2c), and microbial solar cells (MSCs) to produce electricity/chemicals (Figure 2d) [24,30,31]. Cong-Long Nguyen et al. [32] proposed a power management system adapted for operating bioelectrochemical systems with complex nonlinear dynamics to obtain power conversion efficiency up to 85%. Electrical efficiency ranged between 127.1% and 155.2%, with a blend of acetate and phenol (phe/ace) fed MECs producing the highest and bio-oil aqueous phase from red oak (ROBOAP) fed MECs producing the lowest electrical efficiency [33]. Most MDC studies have reported desalination efficiencies of at least 50% [34].

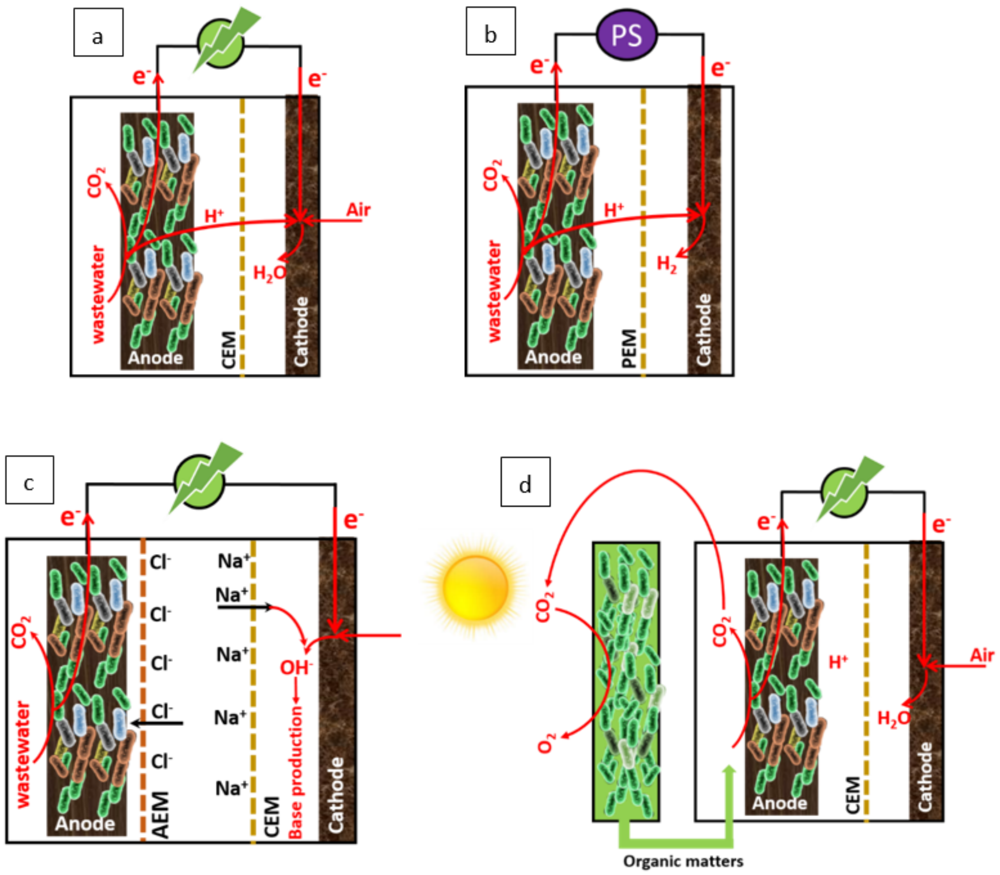

Figure 2. Overview of bioelectrochemical reactions in (**a**) microbial fuel cell (MFC), (**b**) microbial electrolysis cell (MEC), (**c**) microbial desalination cell (MDC), and (**d**) microbial solar cell (MSC).

Despite the high interest and attention toward BESs due to their green, environmentally friendly, and cost-effective nature globally, Oman is still in the early stage of the journey. Here in this section, we describe the principles of MFCs, MECs, MDCs, and MSCs as the technologies that can be applied in the GCC region, particularly in Oman, and discuss their tentative applications.

2.1. Microbial Fuel Cells

Among the BESs, MFC is the oldest-known type. The historical review of MFC discovery shows enormous efforts by different scientists in the 18th, 19th, and 20th centuries [35,36]. Nonetheless, the present MFCs which apply a direct electron transfer mechanism to produce electricity are innovated by Kim et al. [37,38]. A typical two-chamber MFC is composed of anode and cathode chambers which are separated by a proton-/cation-exchange membrane. An anode chamber contains a conductive electrode (anode), biofilm (biocatalyst), and an electrolyte which is wastewater. The cathode chamber contains a conductive electrode (cathode), catalyst (bio or abio type), electrolyte, and final electron acceptor (air normally) [39,40]. In an anode chamber, exoelectrogenic microorganisms catalyze the oxidation of organic matters present in wastewater to produce protons, electrons, and CO_2 (anodic oxidation reaction). Further, oxygen reduction reaction on the cathode results in bioelectricity generation, while water forms as the final product (cathodic reduction) [41,42]. There has been extensive research carried out on the factors affecting MFC performance in the recent decade owing to the green nature of the technology. This includes materials (electrode, catalysts, and membrane), operation conditions (temperature, pH, substrate type and concentration, flow rate, etc.), operation mode (batch, semi-batch, recirculation, continuous), and configuration (single chamber, dual chamber, stacked, etc.). Moreover, the applications of this sustainable and ecofriendly technology are expanding in line with its development: bioenergy generation, wastewater treatment, and biosensors [43,44]. Oman is an arid country with a dispersed population. Hence, MFC can be considered a decentralized wastewater treatment system, while producing bioelectricity for areas with difficulties connecting to the municipal sewage treatment system [45,46]. Hsu et al. [47] reported an average of 93% COD removal in an energy-neutral MFC configuration on a pilot scale. Moreover, Castro et al. [48] reported compost production as a product of wastewater degradation in MFCs as a decentralized sanitation system. It is worth noting that anodic and cathodic microorganisms, such as self-sustained biocatalysts, could successfully treat organic matters and ammonium present in the waste, respectively, while producing bioelectricity. The feasibility of treating raw waste produced from a house of five inhabitants by MFC-based wastewater pilot plant with no external energy use was investigated in another study. The results were promising in terms of the quality of the treated effluent, which could successfully comply with the maximum national standards [49]. Additionally, it was shown that the temperature could strongly affect various variables, such as wastewater conductivity, activation energy, charge transfer rates, electrochemical reactions, etc. [50]. Hence, considering MFC as a decentralized wastewater plant running at an ambient temperature, the change of temperature over a day and seasons plays an important role in MFC performance. The temperature profile of the GCC could improve the performance of the MFCs since the optimal temperature of 30–40 °C is reported to favor MFC performance [51]. Heidrich et al. [52] showed the sensitivity of power generation in MFCs to temperature change. A cold temperature was found to decrease power generation in MFCs [52]. Li et al. [53] reported a 199% increase in power generation when the temperature of MFC increased from 10 to 37 °C. However, the results of the existing studies for higher temperature range (40 °C) are not totally applicable to the GCC region, since the biofilm developed in those MFCs is established in the ambient temperature of 25 °C, which is not the case in Oman. Further studies on the effect of temperature on the performance of MFC as a decentralized wastewater treatment plant by considering the temperature profile in Oman using the local micrograms adapted to this temperature profile are extremely needed.

2.2. Microbial Electrolysis Cell

Microbial electrolysis cells (MECs) are the second known BESs that share similarities in the anodic oxidation with MFC. However, the cathodic reduction reaction of MEC results in hydrogen production. Although this process is not thermodynamically viable, low energy (<0.2 V) is needed to supply the energy required for H_2 generation in MECs [54]. The energy can be supplied by integrating the MEC with an MFC or by any renewable source. The hydrogen produced in MECs can be used in other technologies for further applications, e.g., fuel cells. Solar energy can be one of the promising renewable technology to supply the energy required in MECs, considering the generous amount of sunlight in the GCC.

2.3. Microbial Desalination Cell

With two-thirds of the world population under water scarcity threat, seawater desalination has become an inevitable approach to supplying humans with potable water for domestic purposes, i.e., drinking, irrigation, industrial development, etc. The Middle East, with 2.9% of the world population, possesses 50% of the global seawater desalination production capacity [55]. Currently, thermal and membrane-based methods are the two major commercial types of desalination technologies used in the world [56]. However, both technologies raise environmental concerns: high energy consumption of thermal-based technologies and discharge of concentrated brine back to the environment in the membrane-based desalination technique [57]. Microbial desalination cell is a solution to the issues raised by the conventional desalination systems. MDC is a modified version of an MFC with a central desalination cell that is separated from the anodes by an anion exchange membrane and the cathodes by a cation-exchange membrane. In fact, the electricity generated through oxidation of waste on anode and reduction of air on the cathode drives the desalination process. Jafary et al. [58] reported a promising desalination rate of seawater from Oman sea in an MDC with a self-controlled pH mechanism by using the energy stored in the municipal wastewater in the anodes. The group later increased the desalination rate and enhanced power recovery from the wastewater in a novel five-chamber MDC by significantly reducing the internal resistance of the system. They have suggested the internal resistance of the MDC as the limiting factor of desalination rate [25]. MDC still suffers from a low desalination rate due to the slow biological electrochemical reactions. Further improvement on the system could make the technology ready for real application as a standalone desalination technology or to be integrated with RO systems to optimize the efficiency of both technologies with a less negative impact on the environments. From a technology perspective, the decentralized MFC wastewater treatment plant proposed in Section 2.1 can be converted into a decentralized desalination and wastewater treatment plant in an MDC system running with household wastewater as shown in Figure 3. The small plant provides the opportunity for value-added products' recovery from wastewater and salt water, e.g., compost, alkaline.

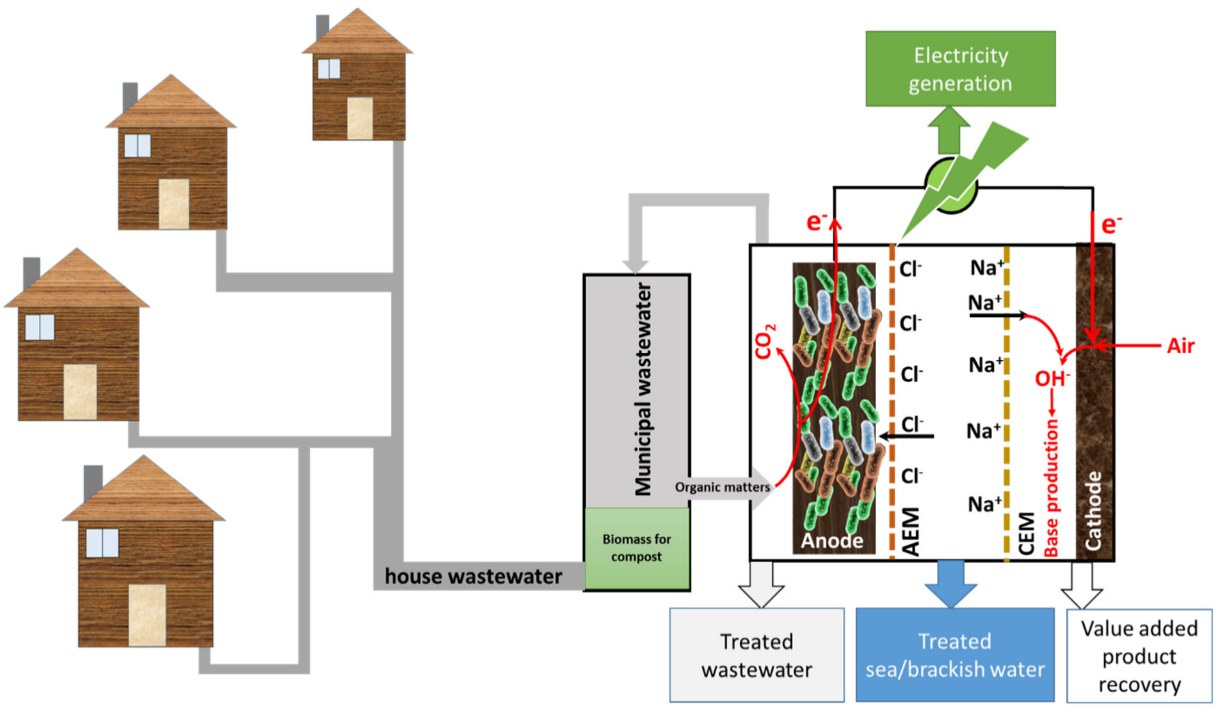

Figure 3. A schematic of the MDC-MFC integrated decentralized plant for wastewater treatment, sea/brackish water desalination, and value-added products recovery (e.g., alkaline and bioenergy).

2.4. Microbial Solar Cells

Microbial solar cells are the self-sustained version of MFCs in which photosynthetic microorganisms utilize CO_2 from the atmosphere and energy from the sun to produce bioelectricity and chemicals [59]. In other words, MSCs do not need additional organic matters as they generate their own fuel/oxidant [60]. Based on the ways solar energy is captured and the organic matter transfers, MSCs fall into four categories: MSCs with phototrophic biofilms, MSCs with photobioreactors, and MSCs integrated with marine ecosystem plant MFCs (PMFCs) [31]. Solar energy can be directly converted to bioelectricity through phototrophic biofilms enriched on the anode in MSCs with phototrophic biofilms [61]. Photobioreactor-type MSCs harvest solar energy using photosynthetic microorganisms [62]. PMFCs utilize plant roots to fuel anodic exeo-electrochemically active bacteria by excreting rhizo deposits. Current improvement in design, electrodes, and membrane increased the electrical performance of PMFCs to 679 mW/m^2. Rather than bioelectricity generation, wastewater treatment, biosensing, remediation of polluted sediment, and greenhouse gas mitigation are among the main applications of PMFCs, which are discussed in detail by Kabutey et al. [63]. No specific research in this field has been reported in the Gulf region so far. Nevertheless, this technology has the potential to be implemented in the GCC due to the available solar energy and costal marine ecosystem resources. The complete details of bioenergy research are listed in Table 3.

Table 3. The performance of bioelectrochemical systems in terms of power output, advantages, disadvantages, and the technology development status.

Raw Resources	Harvesting Technology	Output	Technology Development Status (Lab/Small/Pilot/ Industrial Scale)	Energy Output	Advantages	Disadvantages	References
Wastewater, organic matters, plants, etc.	MFC	Bioelectricity	Pilot scale	50 W/m$^{3\,a}$	Low activated sludge generation, wide operating range for pH, temperature, and biomass, no harmful environmental impact	Low power output, high capital cost for membrane and electrode, membrane and electrode fouling	[44,64,65]
	MEC	Hydrogen, methane	Pilot scale	17.8 LH$_2$/d/m$^{2\,b}$	Low activated sludge generation, High theoretical energy and thermal yield, self-sustainable, low equilibrium cell voltage, a wide range of feedstock	Impurity of product, low production rate, High capital cost for membrane and electrode, membrane and electrode fouling	[66]
	MDC	Bioelectricity and desalination	Small scale	82.6 W/m$^{3\,a}$	Low activated sludge generation, an ecofriendly desalination approach, no need for energy or pressure input	Membrane and electrode fouling, high material cost, no real-scale database, low desalination rate	[67,68]
	MSC	Bioelectricity and chemicals	Small scale	277 W/m$^{3\,a}$	CO_2 neutral, self-sustainable, high-value products, aquaculture and animal feed production	High material cost, long-term operation stability challenge, not applicable in areas with low sun exposure, low power output	[69–71]

[a] wind speed; [b] wind density.

3. Biomass Energy Potential in the GCC Region

Biomass comprises biological materials which are obtained from living or recently living organisms. It is not only taking plant-based products into consideration but also animal and vegetable products. The different types of materials which can be a vital source of biomass include, viz., agricultural residues, animal wastes, industrial waste, and coproducts. The chemical composition of biomass is carbon, which plants absorb from the atmosphere as CO_2 and mixtures of organic molecules (such as hydrogen, oxygen, nitrogen, and small quantities of alkali, alkaline, and heavy earth metals) [72–76]. The biomass sector has the potential to expand without harmful effects on food supplies and the environment if conducted in a sustainable manner [77]. However, the power generation from the biomass sectors in the GCC is limited in magnitude. Municipal waste is identified to be a leading bioenergy prospect, with a cumulative 19.35 Mtpa of the resource being transferred to landfill sites otherwise for energy usage across the GCC. According to research findings, up to 22.5% of GCC's electricity from bioenergy technologies could be supplied by indigenous biomass sources. In total, 25.52 Mtpa of animal wastes and 1.68 Mtpa of residue crops could also be used for bioenergy in GCC countries [78]. Bioenergy is considered to be a lower potential renewable energy technology option within GCC countries. Solar energy is a well-recognized renewable energy resource utilized due to weather conditions within

GCC countries [79]. The majority of wastes are landfilled due to waste management that can be utilized as a potential bioenergy resource. There are a few initiatives started in Saudi Arabia and the UAE to convert waste into useful energy [80,81]. In Sharjah (UAE), sewage sludge waste is used for the production of bioenergy [82], and in Ras Al Khaimah (UAE), camel manure, along with wood waste, is utilized for the generation of bioenergy [83]. Available waste characteristics in GCC countries are shown in Table 4.

Table 4. Potential of waste material in GCC countries [78].

	Waste per Capita per Day (kg)	Total Waste Generated (Mtpa)	Waste Processed through Landfill Management Strategies	Organic Wastes as a Proportion of Total Wastes
UAE	1.6	12.3	71.0%	64.0%
Saudi Arabia	1.4	17.4	85.0%	77.5%
Bahrain	1.8	2.6	92.0%	71.9%
Oman	1.2	4.0	100%	49.0%
Kuwait	1.5	3.2	100%	67.0%
Qatar	1.3	11.4	93.0%	68.0%

Bioenergy and biomass potential in GCC countries are presented in Figure 4 and data reported in Table 5. Biomass resource has different physical and chemical characteristics. Bioenergy potential basically indicated the total production of bioelectricity that can be generated from indigenous resources.

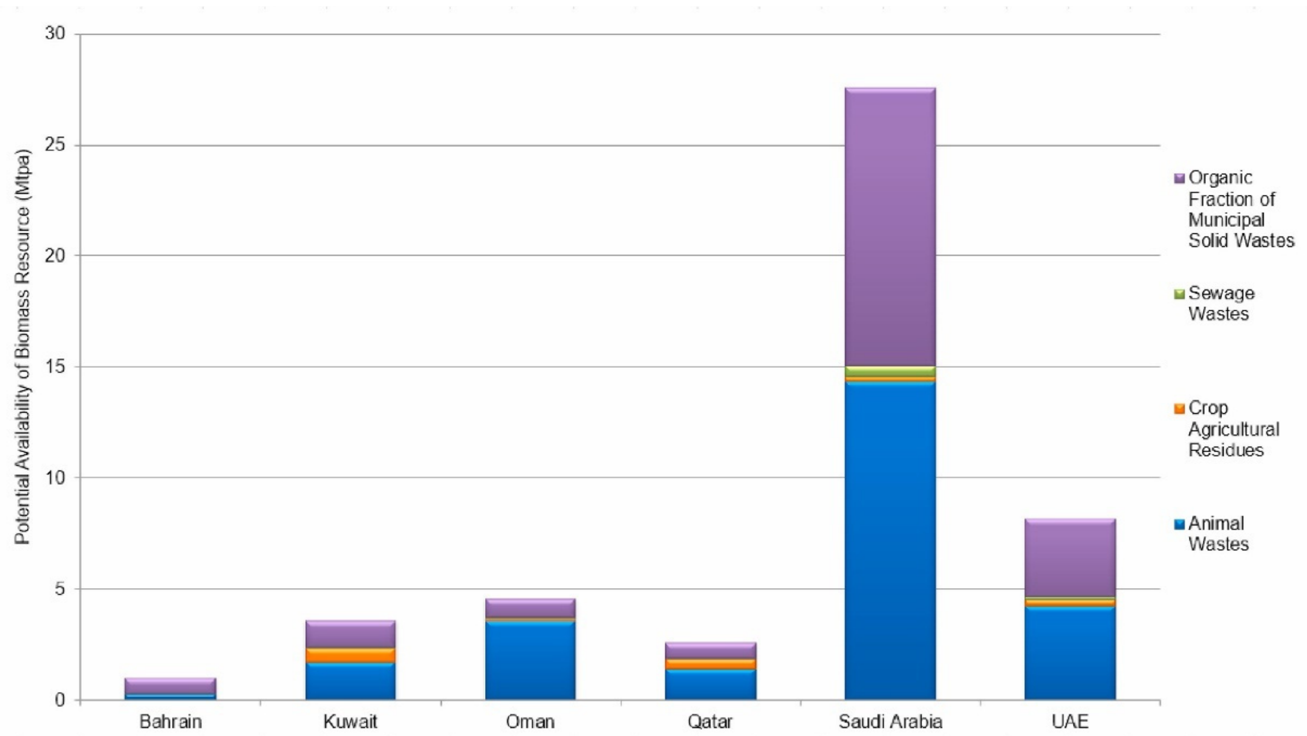

Figure 4. Potential of biomass resources for bioenergy generation [78].

Table 5. Bioenergy potential and biomass resource potential in GCC countries [78].

	Biomass Resource Potential (Mtpa)				Bioenergy Potential (PJ_{elec})	Proportion of Overall Electricity Consumption (%)
	Animal Wastes	Crop Residues	Sewage	MSW		
UAE	4.24	0.30	0.15	3.46	50.71	11.0%
Qatar	1.39	0.47	0.04	0.68	16.40	9.9%
Oman	3.57	0.07	0.07	0.85	27.59	22.5%
Saudi Arabia	14.35	0.20	0.51	12.50	179.45	14.4%
Bahrain	0.27	0.01	0.02	0.68	6.59	6.3%
Kuwait	1.71	0.64	0.06	1.17	23.10	10.1%
Total	**25.52**	**1.68**	**0.87**	**19.35**	**303.84**	**13.07%**

Very limited research has been carried out in biomass power generation. Researchers [77,84,85] have devised many efforts to transform bioresources to fuel oil which can be used as a potential candidate for the sake of power generation. Basically, the biomass resources should be converted into oil which should possess the adequate properties before being put into use for electric power generation. Some research works have been reported in the Sultanate of Oman in the biomass sector (particularly considering date seeds as a major bioresource).

The majority of crop production in Oman in the last ten years shows an increase in Perennial fodder crops such as Alfalfa, Rhodes grass, etc. In Oman, Data Palm constitutes 50% of the total agricultural area and 80% of all the fruit crops. It is considered the eighth largest producer of dates in the world, with an average annual production of 260,000 MT per annum [86]. The literature study reported by Yahyai and Khan [86] mentioned that only half of the dates produced are used for human consumption, with the other half being utilized primarily for animal feed or considered surplus and wasted. Thus, this opens an opportunity to use the date palm seeds and leaves as a source of biomass for producing various bioenergy products. Sait et al. [84] studied the kinetics of pyrolysis and combustion process for date palm wastes using the thermogravimetric analysis (TGA). Their studies showed that date palm seed and leaf are high-volatile-content biomass materials and possess very high calorific value [84]. They reached the conclusion that a high degree of reaction and conversion of date palm seed and leaves occurs at a temperature range of 250–400 °C in the thermos chemical process, and hence, it has a very good potential either to be converted into biofuels or to be used as fuel. Joardder et al. [85] produced bio-oil and activated carbon from date palm seeds in a fixed bed reactor using the pyrolysis technique. Moreover, studies have shown that date seed can be used for extracting oil and can be converted into biodiesel using the transesterification process and found to have properties such as high cetane number (60.3), low iodine value (46), viscosity (3.84 mm^2/s), and flash point (140 °C) with a slight disadvantage of its high pouring point (−1 °C) which obstruct its usage in the cold countries [87]. The biodiesel derived from this process has a high yield of about 98%. The analysis of the fatty acid esters reveals that the date seed biodiesel possesses similar properties to other vegetable-derived biodiesels and hence becomes a potential source of raw material for biodiesel production. Further studies in this area have shown that the conversion of date seed into pyrolysis oil by fixed bed pyrolysis reactor system yields liquid fuel, char, and gas with a heating value of 28.64 MJ/kg when compared with other pyrolysis oils as well as the direct burning of solid date seed wastes. Char generated from wheat straw is a relevant energy usage alternative in current pulverized coal-fired facilities such as cofiring fuel at low temperatures [88]. This method produces a maximum yield of 50 *wt*% of the dry biomass feedstock at the temperature range of 500 °C [85]. The analysis of the oil leads to the result that the density, which is 1042.4 kg/m^3 at 26 °C, the viscosity of 6.63 cSt at 26 °C, and the flash point is 126 °C, etc., are the favorable features for handling, storage at normal temperature, and transportation. Since Oman has topographical, climatic conditions (18–45 °C throughout the year, ("Directorate General of Meteorology," n.d.)), which suits the properties of fuel oil properties derived from date seeds and hence becomes a very good feedstock biomass waster for the biodiesel production. Another important resource can be considered as the perennial forage crop such as Alfalfa which has seen a drastic increase over the decade in sultanate mainly for cattle feed purposes. Alfalfa (*Medicago sativa* L.) is an important forage crop with potential biofuel production, has advantages of high yield and high lignocellulose concentration in stems, and has low input costs. It is found that the biomass-type Alfalfa breed has good potential for ethanol conversion and biofuels conversion studies shows that the efficiency of energy production by alfalfa is 2–3 times better than corn grain or soybeans [89]. Animal waste, especially the waste from meat and poultry, forms a huge potential biomass feedstock for converting it into useful form of bioenergy. It is found that the annual meat consumption in Oman [90] has undergone an increase of 30% over the last decade as shown in Figure 5.

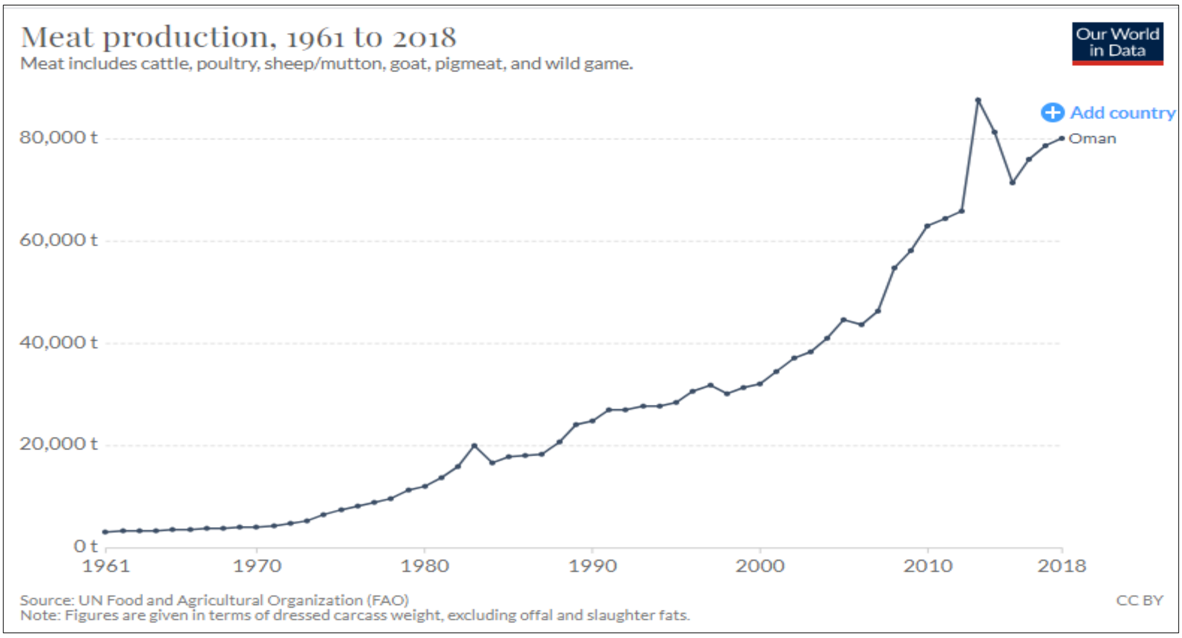

Figure 5. Details of meat production [90].

Generally, biomass conversion technologies currently use various forms of physical, thermal, biological, chemical, and a combination of these processes, which produces three main pathways—physicochemical, biochemical, and thermochemical, which can lead to high-value products [91,92]. Currently, the thermal recycling process (thermochemical technologies) constitutes the main method of waste management from the meat and poultry industries by incineration, torrefaction, hydrothermal conversion, pyrolysis, and gasification process using fluidized or fixed bed reactors, etc. [26,93–96]. A study of the conversion of poultry litters through hydrothermal carbonization and pyrolysis over a temperature range between 250 and 500 °C was performed to produce biochar. The biochar produced by the pyrolysis at lower temperatures as compared to hydrothermal carbonization yielded greater energy due to the higher mass yield. Biochars obtained by both processes were comparable to coal [97]. All these methods, depending upon the biomass feedstock and its nature, produce heat, char, tar, and oil. The aqueous phase and gas are their primary products, upgrading these leads to secondary products such as electricity, chemicals, and biofuels. The wastewater treatment from these industries uses physiochemical methods with recent technology emerging as the membrane technology, which uses the principle of reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF), thus facilitating the treatment of wastewater [98,99]. Biologically induced chemical transformation is taking place in three pathways: anaerobic digestion, aerobic digestion, and ethanol fermentation [100,101]. Based on the nature of biomass, these methods can be chosen for the primary products heat energy, compost, bioethanol, and methane which can be possibly transformed into secondary products such as electricity, biofuels, and bioproducts. In addition to the above two methods, Thran explored the physicochemical conversion technologies for the production of biodiesel by the transesterification process of the initially extracted lipids within a suitable biomass sample [102]. Using the various emerging technologies within the fields mentioned above a conversion of biomass feedstock in the form of date seed, Alfalfa perennial forage grass and the meat and poultry waste conversion along with the industrial waste conversion using other potential technologies can contribute to a sustainable and economic development of Oman in its strategic Vision 2040. Since enormous numbers of date palm trees are abundant in the GCC region, an attempt for the conversion of bioresources is more evitable in the future. The complete details of biomass energy scenario at the GCC are listed in Table 6.

Table 6. Biomass research scenario in the GCC.

Raw Resources	Harvesting Technology	Output Product	Technology Development (Lab/Small/Pilot Scale)	Energy Output	Advantages	Limitations	References
Date Palm- Seed, Leaf, and Leaf Stem	Pyrolysis and thermal degradation	Biofuel, biochar	Small scale	Calorific Value of Date Seed 18.97 MJ/kg, Date Leaf 17.9 MJ/kg, Date Leaf stem 10.9 MJ/kg	High calorific value as compared to another biomass. High energy density and high bulk density, low pyrolysis temperature in a range of 200–300 °C, lower residue after thermal degradation	The high moisture content in the leaf steam yields a lower calorific value as compared to a seed. Date leaf and leaf stem other than date seed need some preprocessing cost to remove the moisture content.	[84,85]
Date Palm- Seed	Fixed Bed Pyrolysis and Transesterification	Bio-oil, solid char and gas.	Small scale	Liquid oil—28.636 MJ/kg	The liquid yield of 50 *wt*% is obtained at a reactor bed temperature of 500 °C.	Operating temperature specific. If the temperature is varied, the yield and the product are not yielded in an optimum manner.	[87]
Date Seed	Transesterification	Bio diesel	Small scale	HHV: 39.55 MJ/kg	Biodiesel from the date seed oil is high cetane number (60.3), low iodine value (46), viscosity (3.84 mm^2/s) and flash point (140 °C)	One main disadvantage of its high pouring point (−1 °C), which limits the use of date seed biodiesel in cold weather.	[87]
Meat and Poultry Waste	Direct combustion, Thermal Waste Recycling System	Steam Generation, Mineral fertilizer	Pilot-scale	1.1 kW/kg and 0.22 kg/kg of bone	The heat efficiency of the entire system was 58.1%, and heat flux for the steam generation was 759.1 kW. Better heat recovery for steam generation, Reduction in pollution, and production of mineral fertilizers from the ashes after the incarnation.	—	[93]

4. Solar Energy Potential in the GCC Region

One of the largest sources of renewable energy on the earth is solar energy which can be converted easily into electrical energy, cooling, or thermal energy with the aid of solar energy harvesting technologies [103,104]. The most common solar technologies are photovoltaic (PV) and concentrated solar power (CSP). In addition, the use of solar energy provides a positive impact on the environmental, economic, and political issues of the world [105,106], because electricity or thermal energy generated via nonrenewable sources (such as coal, gas, and burning of oil) will lead to global warming and environmental pollutions. Whereas renewable energy via solar is available in a free and environmentally friendly manner [107,108]. The Gulf region is located where the light and heat energy from the sun is available for the whole year and for a long duration of about 9–11 h per day. In the Gulf region, the average solar radiation with 80–90% clear skies is 6 kW/m^2 daily. Solar energy is the most suitable and recommended in the Gulf region and the GCC countries. Each country has set its targets for the next two decades to increase its share of renewable energy in its overall energy supply [109].

According to the current scenario, the GCC nations aim to use renewable energy with their maximum efficiency. There are targets for the utilization of renewable energy from 2020 to 2030 that some researchers in Oman reported. It has been planned to utilize 10% of its renewable energy by 2020 and in the near future. The main factors are their contribution to cost competitiveness, economic diversification, and the region's high potential for renewable energy sources.

The study of the International Renewable Energy Agency [15] explains that solar PV is now the cheapest way of electricity generation in new GCC projects, thus beating natural gas, liquefied natural gas (LNG), oil, coal, or nuclear. Other reasons behind the decreasing costs are the increasing familiarity with the technology and investments. Additionally, the two largest renewable projects Miraah Solar (1021 MW), for enhanced oil recovery Ibri PV Plant (500 MW), are under construction [110,111]. Saudi Arabia started to concentrate on renewable energy especially solar energy, to minimize the risk of rising electricity prices. Saudi Arabia started its plan in 2010 to achieve a target of 41 GW by 2032, and this target is divided as 25 GW by concentrated solar power and 16 GW by photovoltaic technology. Near the end of 2018, the government of Saudi Arabia gave the approval of small-scale solar systems to motivate the implementation of solar energy and investment of about $500–600 billion in renewable energy by 2030. Additionally, one renewable energy project Sakaka Solar PV (300 MW) is also under construction [111]. The target of renewable energy generation of Saudi Arabia in their first phase was 3.4 GW by 2020 and in the second phase, 9.5 GW by 2023 [112]. The UAE aims to include about 7% of their renewable energy with 7% reduction in CO_2 emission up to 2020. Additionally, the two largest renewable projects, Noor Abu Dhabi Solar PV (1200 MW) and Mohammed Bin Rashid Al Maktoum Solar Park, in different phases, are under construction. In this project, Phase-I (13 MW), Phase-II (200 MW), and Phase-III (800 MW) are completed, Phase-IV (1000 MW) is under construction, and Phase-V (900 MW) is planned in the near future [112]. Qatar has set a goal of meeting 2% of its solar electricity needs by 2020. The aim is to produce one-third of its electricity from renewable energy by 2030, resulting in approximately 54,000 MW of renewable energy installations. In the near future, the construction of Al-Kharsaah PV (700 MW) will start. Kuwait aims to utilized 5% of its solar energy potential by 2020 [109], and one announced project of Al Dibdibah/Shagaya Phase-II (1200 MW) photovoltaic was suspended due to COVID-19 [111,113].

Among the Gulf countries, Oman receives the maximum solar insolation per year. As reported by the Directorate General of Meteorology and Air Navigation, Oman, the solar radiation (kWh/m^2) per day for different cities of Oman were given as Khasab 6.09, Salalah 6.06, Suwaiq 5.9, Fahud 5.69, Muscat 5.6, Seeb 5.6, Ibri 5.6, Sohar 5.43, Buraimi 5.38, and Sur 4.52 per day [105]. Due to the maximum duration of the sun all around the year, there is a huge potential of harnessing solar energy to convert into electrical energy by using photovoltaic (PV) and concentrated solar power (CSP) technologies [19]. Oman has also set a target of producing between 9–12% of its electricity demand from renewable energy sources. Different solar projects are in progress, such as (500 MW) Solar Power Plant in Misfah will be ready at the end of 2021; (1000 MW) Solar Power Plant Manah will be ready by 2025; (600 MW) Solar Power Plant Ibri, Al Dhahirah will be ready by 2022; and (1200 MW) CSP Plant Duqm will be ready by 2023 (Alharbi and Csala, 2020). Qatar has set a goal of meeting 2% of its solar electricity needs. (800 MW) Solar Power Plant Al Kharsaah, Doha and (700 MW) Al Kharsaah, Al Jumaliyah will be ready by 2022 [112]. The ultimate aim is to produce one-third of its electricity from renewable energy by 2030, resulting in approximately 54,000 MW of renewable energy installations [114]. In the UAE, Abu Dhabi intends to produce at least 7% of its energy power from renewables (along with a 7% reduction in CO_2 emissions) by 2020. Additionally, (1.2 GW) Adwea Sweihan Plant, (5 GW) PV and CSP Power Plant Mohammed Bin Rashid Al Maktoum Park, (55 MW) Jabel Ali Free Zone and Mina Rashid Port will be ready by 2030 and (200 MW) Ras Al Khaimah project will be ready by 2025 [112]. In Bahrain, there is also a huge potential of solar energy but as compared to other GCC countries. In their Energy Vision of 2030, Bahrain set a target to generate 7% of their required energy by renewable energy. In this regard, the National Oil and Gas Authority, Bahrain Petroleum Companies, and two US-based firms made a joint venture in 2012 for the development of 5 MW solar PV project and 5 MW Petra solar park completed in 2017. Additionally, they boosted PV panels for streetlights which consist of 1.51 MW carports, 250 kW solar trees, and 48 kW street light poles. Additionally, (100 MW) Askar Industrial Area Solar Plant, Bahrain, (5 MW) Solar Plant Awali, Central Bahrain will be ready by 2025 [112]. Kuwait aims to increase solar energy conversion into electrical energy from 1% to 15% between 2020 and 2030. Different projects such as solar cooling projects, street lighting, traffic signals, and water distillation plants are included in this project. Kuwaiti government signed a USD 385 million contract with a Spanish company (TSK Group) to build a 50 MW solar energy project in the Kuwait region [114]. The most common solar technologies which are widely accepted in all the countries are photovoltaic (PV) and concentrated solar power (CSP).

In photovoltaic (PV) technology, solar energy is directly converted into electrical energy with the help of solar panels. In this technology, the conversion of solar energy into electrical energy is due to the photovoltaic effect or photoelectric effect. The sunlight (photon) hits the surface of semiconductor material and emits the electrons which derive the current in the circuit. Basically, this photoelectric current is DC (direct current), which can be used to operate DC-based electronic items and can be stored in batteries. This DC current can also be converted into AC (alternating current) with the help of investors to insert in power plants. Some PV technology-based projects are already available in Gulf countries. In the UAE, solar system cells and Aviation Warning LED are installed at Dubai International Airport (between Dubai and Oman traffic monitoring system) by photovoltaic technology. In Saudi Arabia, two remote tunnels are equipped with a speed radar camera, traffic monitoring system, and highway lighting system based on PV technology. Additionally, Oman is also utilizing their potential for solar energy, and in this regard, PV-based technologies projects are available in different places inside the Sultanate of Oman. In these projects, LD repeaters are available in 27 different places inside Oman, seismic equipment at 10 different places inside the country, water pumping system in Haima, Maabar, and Wilayat, and remote electrification in Damanyat island and in Iizki [109]. Photovoltaic technology is cheap and easy to install as well as environmentally friendly. Thus, all Gulf countries, especially Oman, focused to utilize this clean and green energy for their domestic and commercial use, but there are some limitations in these technologies (such as fog during the winter season, dust accommodation, lack of rainfall, and fog combining with dust particles). Mas'ud et al. [114] reported that it is very necessary to clean the solar panels/plates to achieve maximum efficiency.

On the other hand, concentrated solar power (CSP) technology is utilized with the help of mirrors and reflectors. The light energy is then converted into heat energy and steam to run the turbines of AC or DC to produce electrical power at a small scale or large scale. The advantage of CSP technology over PV is that with the help of a thermal energy storage system, steam can be produced during cloudy weather or after sunset. According to the "review of renewable energy and solar industry growth in the GCC region", about 80–90% of potable water comes from desalination. For each m^3 of water production, the required energy is about 5 kWh, and about 3 kg of carbon dioxide emits into the atmosphere [109].

Most of the Gulf countries produce fresh water with the aid of solar techniques in this prospects. Manawwar and Ghedira [109] reported that solar energy can be adopted or utilized to produce fresh water through desalination techniques. In Gulf countries, some existing and proposed desalination units, Bahrain produces 250 gallons of fresh water by mobile solar desalination unit and requires 1.5 kW energy for this plant to run. In Oman, besides desalination water plants, they developed a seawater greenhouse which provides the sufficient temperature and environment for the growth of crops. Additionally, Kuwait produces fresh water with the help of a multi-stage-flash desalination unit. The Environment and Energy Research Institute (member of Qatar Foundation) and the Spanish Research Centre for Energy, Environment, and Technology installed a 300 kW concentrated solar power desalination project. In Qatar, additionally, another project under the name of Qatar National Food Security Programme proposed to produce about 50 m^3 fresh water by the desalination plant for irrigation and agriculture. In solar desalination technologies, Saudi Arabia leads among the Gulf countries. Their mega solar desalination projects are located in Solar villages and Sadous, since 1990. In addition, by 2012 with the coordination of researchers from King Abdul, Aziz City and IBM constructed a mega project which produces 30,000 m^3 of fresh water on a daily basis with the aid of ultrahigh concentrator PV technology. In addition, Saudi Arabia plans to develop the desalination industry inside the whole country. After Saudi Arabia, the UAE is the second-biggest desalination industry in Gulf countries. With the help of each small-scale solar plant, they produce about 30 m^3 fresh water per day. Till 2014, total 22 plants were installed, and 8 more were considered additionally. Thus, by every single plant, they can produce 11,000 m^3 fresh water per year.

Due to the maximum solar insolation in the GCC region, concentrated solar power has been most focused on in Gulf countries. In this regard, Oman planned a project of 600 million US dollars by using CSP technology in collaboration with Germany and Switzerland to generate 200 MW electric power. In addition, in 2013, the UAE completed a 100 MW solar electricity project by installing 768 parabolic mirrors accommodated 2.5 square kilometer area. The cost of this project was 600 million US dollars. This project provides electric power to 62,000 houses. In addition, Kuwait planned a project of 720 million US dollars in collaboration with Kuwait and Japan to produce 220 MW by combined cycle and 60 MW by solar collectors. In addition, Petroleum Development Oman also constructed a 7 MW solar steam generator of enhanced oil recovery to reduce the consumption of gas. This project was completed in 2013, and an average of 50 tons of steam is produced daily [109]. This Solar Thermal Enhanced Oil Recovery Project was the first CSP plant in Oman that was used to extract 33,000 barrels of oil and can reduce 80% of gas [105]. Interestingly, Burj Khalifa (Dubai iconic tower) is equipped with 378 solar collectors to supply 140,000-L hot water per day. This technology saves about 3200 kW of energy per day and cooling the potable water by using air conditioning condensate, which is used for irrigation purposes for the tower's landscape [109]. As discussed in CSP technology, the advantage over PV is more due to the thermal energy storage system, which can be utilized during the night or cloudy weather. In addition, this technology is the most recommended for industrial and commercial level, but there are some disadvantages in this technology as it needs a huge amount of water for cleaning the reflectors and solar panels to increase the efficiency [105]. Since solar energy is more enhanced for producing electricity, more efforts are needed to produce and increase the efficiency. The discussion of existing and proposed projects in this review report is an indication toward the research projects and utilization of solar energy potential in the Gulf region in their economic benefits and clean and green environment. The complete details of solar research are listed in Table 7.

Table 7. Solar energy research scenario in the GCC.

Raw Resources	Harvesting Technology	Output Product	Technology Development Status (Lab/Small/Pilot/Industrial Scale)	Energy Output	Advantages	Disadvantages	References
Solar Energy Potential in GCC Countries	Concentrated Solar Power (CSP)	Solar Electricity	Concentrated reflectors and mirrors, Heat engines, and electric generators	7–25%	More efficient compared to photovoltaics. Less maintenance is required because solar energy is converted into heat energy first and running heat engines and electric generators.	Long time required to convert water into steam. Construction and installation cost is very large. Large space is required for installation.	[105,109,114,115]
	Photovoltaic (PV) solar project	Solar Electricity	Solar panels or semiconductors materials	15–22%	In photovoltaics, solar energy is directly converted into electrical energy. This type of solar energy use consists of a photon is the emitting electron that drives a DC current. This DC current can be used directly in some device or can be converted into AC with the help of investors to insert in power plants.	Important to clean the solar plates to obtain maximum efficiency of solar panels. Due to dust particles, the efficiency of solar panels is decreasing. Efficiency is depending upon the intensity of light. Not suitable for cloudy weather and nighttime.	[105,109,114,115]

5. Wind Energy Potential in the GCC Region

Wind energy is a very promising renewable energy source and is gaining widespread global acceptance (due to its low production and operation) besides the convenient accessibility to environment-friendly windmills, particularly in the Gulf region. It is estimated that as of 2016, the international total cumulative installed wind energy electricity technology amounted to 486,790 MW [116]. The GCC nations are the primary investors in renewable energy in the Middle East. It is expected that new solar- and wind-generated electricity in the GCC is expected to reach 10 GW by 2022 [16]. It is observed that the central region of the Arabian Gulf has a higher annual average wind speed. It is approximately, ranging from 6–8 m/s at 10 m elevation, 7–8 m/s at 30 m elevation, and 8–9 m/s at 50 m elevation. It is clear the GCC international locations have reasonably exact offshore wind energy possible, and there are inclinations to invest in commercial offshore wind farms [117]. In the ensuing section, the detailed scenario of wind energy potentiality and current strategies of each GCC are discussed exhaustively.

5.1. Recent Developments in Saudi Arabia

The Kingdom of Saudi Arabia (KSA) is one of the largest countries in the Gulf region. It has many coastal areas where the possibility of generating wind power is at a maximum. The target of Saudi Arabia is energy generation from nonhydrocarbon resources, which will contribute to 50% of total energy capacity by 2040 [118]. In the KSA, another target was stated by Saudi Arabia's vision 2030 of producing 9.5 GW/year of renewable energy by 2023 [119]. The Saudi government is predicted to grant full help in the shape of financial incentives for solar and wind electricity projects to raise renewable power development [118].

Considering the important variable of wind speed, the Saudi Arabian Government has found some places with the potentiality of wind power generation. The standard values of wind velocity at 40 m in height at different five regions for half-hour intervals. They noticed that the optimum wind speeds take place at Dhulum and Arar with 5.7 and 5.4 m/s, respectively. The wind speeds slightly decrease in Qassim and Yanbu to 4.3 and 4.9 m/s. The average wind speed at Dhahran after 6 months was 5.2 m/s. The mean power density for Dhahran was observed to be 151 W/m^2, Arar (182), Yanbu (142), Dhulum (176), and Qassim (91), which are directly proportional to the wind speeds discussed [118]. The most suitable locations for the construction of wind farms in Saudi Arabia are in the eastern province, northern region, and northwestern borders region [119]. The wind speed used to be observed to be higher in the western mountains and the northern region with an accurate probability in overall performance in the southern area of Saudi Arabia [120]. Recently, some researchers devoted their efforts to questing the wind power capacity in KSA by using simulation software. The recent simulated software used in Saudi Arabia to measure the potential wind energy is Monte Carlo simulation (MCS) and Brownian motion (BM) [121]. Both were used to predict the future conduct of solar and wind energy and long-term temperature performance, primarily based on 69 years of daily historical data. Furthermore, a multicriteria decision making (MCDM) tool was used for predicting the suitable location for constructing wind farms based on the geographic information system (GIS) and then applied to the entire Kingdom of Saudi Arabia [119]. They reported that the center and southeast regions are unsuitable due to a lack of wind resources, population, transportation, and electrical grid connection.

5.2. Recent Developments in Kuwait

Kuwait has a desert nature with major climate differences temperature that represented the following variation between 13 and 39 °C in January and July, respectively, throughout the year [117]. Kuwait's offshore wind power potential is found more commercial because Kuwait is offshore environmental conditions are suitable. The optimum wind power density at Beacon N6 580 Watt/m^2 was observed in the summer, followed by South Dolphin and Ahmadi oil pier 360 and 320 Watt/m^{2,} respectively. The wind energy density at beacon M28 is the lowest at 140 Watt/m^2 [117]. Furthermore, the intensity of wind speeds reaches the peak during the summer in the Sea Island Buoy (Beacon SPM22). Recently, the recorded high wind power density (WPD) during January, February, March, October, and November, with values alternating from 278.6 and 402 W/m^2 [117]. Currently, researchers devised their ideas on finding the wind power capacity in Kuwait by utilizing some simulation software. In order to forecast the potential wind energy at higher altitudes, the Weibull distribution was generated and compared with the annual wind speed frequencies [16].

5.3. Recent Developments in Qatar

The abundance of sunshine in Qatar has driven the use of solar energy. Thus, this is the most popular renewable energy source in this region. A study into public awareness of renewable energy in Qatar showed that 69.9% of the respondents preferred solar energy, and only 3.3 percent picked wind, 0.8 percent chose wave, and 1.8 percent chose biomass, while over 20 percent were undecided [122]. Between onshore and offshore wind energy systems, offshore systems are more favorable in Qatar, as pointed out by some studies based on the suitability of different wind turbine generators because the offshore average wind speed exceeded 6.0 m/s [117,123]. A case study performed in Arabian Peninsula countries showed that the entire cumulative capacity of offshore wind power contribution (from high suitability regions alone) to these nations is projected to be about 35 GW for an 8 MW turbine capacity. The findings also showed that offshore wind could provide approximately 25.7 percent of the Arabian Peninsula nations' total power capacity in the same scenario. Saudi Arabia has 17 GW of specific offshore wind capacity potential, Oman has 8 GW, Kuwait has 4.9 GW, and Yemen has 4.8 GW, according to this research. Bahrain and Qatar have 2.37 GW and 0.9 GW of offshore wind generating capacity, respectively [124]. Another study analyzes the feasibility of a home-scale solar–wind system linked to the grid to cogenerate 14 kWh of electricity and 85 kg/day of hydrogen every year using fuzzy MCDM in Qatar [125]. A study was performed in Qatar by selecting five stations (AbuSamrah, Ar-Ruways, Doha Intl Airport, Duhan, and Musayid) in Qatar, and 20 year average data extracted from the NASA website [126] were analyzed, showing that the highest annual average wind speed (4.10 m/s) is associated with Doha Intl Airport followed by (4.06, 3.82, 3.77, and 3.76 m/s) Ar-Ruways, Duhan, AbuSamrah, and Musayid, respectively [125].

5.4. Recent Developments in the UAE

In 2015, Dubai planned its Clean Energy Strategy for 2050, aiming to produce 7%, 25%, and 75% of renewable sources in 2020, 2030, and 2050, respectively. Solar projects are the major source of renewable energy in the UAE, with the limitation being the used wind power potential in the UAE because of unsuitable areas. Bachellerie et al. [127] reported that the wind rate could not surpass 5 and 7.5 m/s onshore and offshore, respectively, in the UAE. These values are among the lowest wind speed reported in the Gulf region. On the other hand, the coastal areas of Oman and Saudi Arabia could record the highest wind speed in that region. Therefore, the UAE invested in solar energy as one of the most potential renewable sources, while Oman, Kuwait, and Saudi Arabia could harvest a good portion of renewable energy share from wind sources [128]. Because of the limited application of wind energy, a small wind turbine in Abu Dhabi with 850 kW was installed in Sir Bani Yas Island [129].

5.5. Recent Developments in Bahrain

Bahrain has an abundance of wind and solar as major renewable sources. According to IRENA, 2019, from the total energy production, 6 MW is extracted from renewable sources, which targets 5% by 2025 and 10% by 2035. Furthermore, it shows that only a small amount of Bahrain's maritime area is suitable for offshore wind because it has a limited land mass of 765 km^2. That said, this quantity totals 407 km^2, which provides the sufficient space for the installation of 100 of turbines and 1.52 GW of wind capacity.

This research fills a knowledge gap. No detailed studies of potential energy production from offshore renewables were previously conducted for Bahrain. This work displays the capability of offshore wind to contribute to Bahrain's future renewable energy mix [130]. The major offshore wind capacity potential determined in this study in Saudi Arabia has 17 GW, followed by Oman with 8 GW and Kuwait with 4.9 GW. Bahrain and Qatar have moderate offshore wind energy capacities of 2.37 and 0.9 GW, respectively. The lowest potential is in the UAE [124]. The wind speed variation from one area to another is seasonal or based on location. From the recent study, the monthly average wind speed exhibited two maxima (within the months of July and March at a speed of 2 m/s). On the other hand, the lowest was recorded within the month of November at a speed of less than 1 m/s. The wind season extended from August to December, within which the characteristic speed was from 1.18 to 1.4 m/s [131]. The average annual wind speed in Bahrain at 10 m height is 4.8 m/s. The full load hours of wind annually are very low, which is not reproduced to be an economically feasible wind energy potential [127].

Some companies in Bahrain invest in some public places for implemented renewable energy sources projects just as the Bahrain Petroleum Company stated in the 100 MW Bahrain PV Park in Askar Landfill. Moreover, the Bahrain Electricity and Water Authority (EWA) planned to construct the Al Dur PV Plant and the Al Dur Wind Farm, with the installed capacities of 3 and 2 MW, respectively. The prediction of wind energy potential in Bahrain used a hybrid renewable energy system that utilizes both renewable sources, solar, and wind. The analysis was performed by using the Boxe–Jenkins-based modeling approach in analyzing and forecasting the daily averages of wind speed, solar irradiance, ambient air temperature, and the PV module temperature [132].

5.6. Recent Developments in Oman

Different studies have been conducted within the coastal and southern parts of Oman for assessing wind energy resources in Oman. The most promising sites are those located in the southern and eastern regions of Oman near the sea, which are Thumrait, Qairoon Hairiti, Masirah, and Ras Alhad [133]. Oman currently lacks production from renewable energy sources. However, Oman has a future in renewable market energy in projects such as the 200 MW solar plant in the Dakhiliya region and 50 MW wind plant in the Dhofar region, which are under consideration [134]. Several studies were carried out on Masirah Island to examine the efficiency of hybrid systems by combining wind power with diesel generation. This determined that the best location to construct this wind power system is in the rural areas. Oman is exposed to the strong summer and winter monsoon winds. The average wind speed reaches more than 5 m/s [127]. Moreover, wind speeds reach their peak during the months of April–September. The weather indicator shows the high-range wind speeds are found along the coast from Masirah to Salalah, but the optimum wind speeds are in the Dhofar Mountains Chain north of Salalah [135]. In the previous study, the estimation of the annual energy content was performed at 80 m above ground level for five stations (viz., Thumrait, Qairoon, Hairiti, Masirah, and Joba), and the energy is specified as kWh per year through a vertical area of one m^2, kWh/year/m^2. The optimum rate of expected energy is at Thumrait, and the lowest at Joba for 4.5 kWh/m^2/year and 3.5 kWh/m^2/year, respectively [135]. Studies commenced in Oman show that the highest wind speeds were recorded (during the summer seasonal months, June, July, and August). On the other hand, they are lower during October and November. The historical and future variation of the wind power was evaluated by a high-resolution regional climate model (EC-EARTH) obtained from the CORDEX program for the MENA domain. The obtained results of the simulation of wind power in terms of mean annual, mean seasonal, and directional distributions were analyzed for historical and future periods.

Generally, because of the abundance of wind resources, the best GCC countries for the installation of wind farms are Kuwait, Oman, and Saudi Arabia. The average annual wind speed reaches above 7.5 m/s in different areas of those countries. The current projects were installed in those countries with different wind energies: in Kuwait, the Shagaya project with wind potential 10 MW; in the western region, Oman 50 MW; in the southwestern region of Dhofar and Saudi Arabia Dumat-al-Jandal project (400 MW) in the northern province of Al Jouf [136]. The recent IRENA study in GCC countries showed that the highest wind energy potential was recorded for Saudi Arabia at 3500 MW, followed by Oman with a potential of 1210 MW. The lowest potential is predicted for the UAE, Kuwait, and Bahrain (300, 200, and 20) MW, respectively. Oman's renewable energy authorities have identified seven renewable-based wind power electricity generation pertinent to the Oman Vision 2040. The locations identified are Sur and Jaalan Bani Bu Ali (North Al Sharqiyah), Duqm-1 and Duqm-2 (Al Wusta), and Al Jazir, Shaleem, and Sadah (Dhofar Governorate) [137]. The complete details of wind energy in the GCC are listed in Table 8.

Table 8. Wind energy prospect for GCC countries.

Name of the Renewable Resource	Country	Energy Output	Best Installation Location	Wind Energy Simulation Software	Future Strategic Plan	References
WIND	KSA	17 GW, 8 MW turbine	Dhahran (151 W/m^2, 5.2 m/s) Arar (182 W/m^2, 5.4 m/s) Yanbu (142 W/m^2, 4.9 m/s), Dhulum (176 W/m^2, 5.7 m/s), Qassim (91 W/m^2, 4.3 m/s)	Monte Carlo simulation (MCS) and	50 GW of wind and solar capacity by the year 2040 producing 9.5 GW/year of renewable energy by 2023	[118,119, 124]
	Kuwait	4.9 GW, 8 MW turbine	Beacon N6 580 Watt/m^2, South Dolphin 360 Watt/m^2 Ahmadi oil pier 320 Watt/m^2, beacon M28 140 Watt/m^2	Weibull distribution	Generate 10% of its energy needs by the year 2020	[117,124]
	Qatar	0.9 GW, 8 MW turbine	AbuSamrah 3.77 m/s Ar-Ruways 4.06 m/s Doha Intl Airport 4.10 m/s, Duhan 3.82 m/s Musayid 3.76 m/s	HOMER software and fuzzy MCDM	Membrane and electrode fouling, high material cost, no real-scale database, low desalination rate	[124,125]
	UAE	Negligible compare with other GCC countries	Abu Dhabi with 850 KW, wind turbine prototype, installed in Sir Bani Yas Island	—	7% clean energy sources by 2020, 25% 2030 and 75% by 2050. Solar energy collectively makes up 90% of all RE use in the RE map 2030 Case, with the remaining 10% provided by geothermal heat, wind power and waste-to-energy systems	[18,124]
	Bahrain	2.37 GW, 8 MW turbine	—	Boxe Jenkins	renewable energy target of 5 percent by 2025 and 10 percent by 2035	[124,132]
	Oman	8 GW, 8 MW turbine	Thumrait 4500 KWh/m^2/year [c], 8.2 m/s, Qairoon Hairiti 4250 KWh/m^2/year, 9 m/s, Masirah 4300 KWh/m^2/year, 8.2 m/s Joba 3600 KWh/m^2/year, 7.8 m/s 80 m above ground level	A high-resolution regional climate model (EC-EARTH) obtained from CORDEX program for the MENA	200 MW solar plant in Dakhiliya region and 50 MW wind plant in Dofar region, 2020	[133,138]

[c] energy content is specified as kWh per year through a vertical area of one m^2.

6. Tidal Wave Energy Potential in the GCC Region

Tides are energy created by forces due to our planet earth's rotation and the gravity pull of the sun and the moon. Tidal waves are exorbitantly available in the Arabian Sea. However, they have a low relative energy density. It is potentially marginal compared with wind and solar energy resources. Tidal stream, tidal range, wave energy, offshore wind energy, and thermal energy currents could be used by the pivoting motion of mooring lines, tidal barrages, and the underwater turbines, which are produced by the Simec Atlantis company. The wind pushes the ocean surface with the sun and heat factors, which in turn create ocean currents. Marine energy is one of the newest potential technologies to generate electricity without harmful emissions. According to the IEA, the estimated growth for marine technology is not on the right track, seeing a 3% increase only, and it needs to increase up to a 24% growth rate to achieve the target of 2030. Tides are predictable and have constant validity, which can change four times within the 24 h rustling of the earth's rotation and to the sun and the moon gravity, especially in the spring tides, which can happen when the earth, sun, and moon are aligned. There are massive low tidal borages stations such as the one in South Korea and France that have been protected by cathodic protection, but it has high cost and a large barrier that can affect the marine environment. This is why the Simec Atlantis company produces underwater turbines that can be fully submerged with safe sonar. Kaveh Soleimani et al. [139] studied how tidal wave energy production can generate 15.8 MW, which relies upon important parameters such as the tidal velocity, wave heights, wave period, water depth, and shore condition. In other countries, the installation cost is a huge challenge, but finding the right place for such projects that does not affect the coastline ecosystems is a big challenge for such projects, and an almost impossible task even for a fully submerged turbine with an area of 1 km for marine life. There are some areas to develop according to European Commission such as the following:

- Dielectric elastomers: fewer moving parts and to reduce power take-off complexity
- Third-generation tidal energy devices: to exploit untapped resources efficiently
- A novel approach to first-generation wave energy: to increase energy capture and quality power output
- Innovation tidal and wave energy power take-off: to increase the reliability of ocean energy devices
- Improve morning compliance: to improve power production and survivability of ocean energy devices.
- Blades innovation: to reduce fatigue and extend the lifetime
- Rotor innovation: to increase power capture and overall efficiency
- Flouting tidal concepts: to ease installation and maintenance and optimal power extraction in the upper part of the water column
- Breakthrough materials for first-generation tidal devices: to reduce structural weight and to improve the thrust loading capacity

Some technologies could fit the Middle East and Oman, such as the ocean thermal energy conversion (OTEC), which does not utilize fuel and has a fixed cost. The Arabian Sea is one of the best areas to use the ocean thermal energy conversion technology because of the temperature difference between the cold deep ocean water and warm surface ocean water, which is greater than 20 °C. Research is in progress for the utilization of the tidal waves across the GCC coastal areas to generate electric power in the near future. The complete details of tidal energy research are listed in Table 9.

Table 9. Tidal wave energy potential in the GCC region.

Raw Resources	Harvesting Technology	Output Product	Technology Development Status (Lab/Small/Pilot/Industrial Scale)	Advantages	Disadvantages	Ref
Tidal Stream	Underwater turbines	Electricity	Industrial scale	Zero harmful emissions, predictable and constant validity.	High costs affect the coastline ecosystems and high corrosion.	[140]
Tidal Rang	Tidal barrages	Electricity	Industrial scale	Zero harmful emissions, predictable and constant validity	High cost and large barrier which can affect the marine environment, affect the coastline ecosystems, and high corrosion.	
Waves	Mooring lines	Electricity	Industrial scale	Zero harmful emissions, predictable and constant validity.	High cost can affect the marine environment and high corrosion.	
Offshore Wind	Wind turbine	Electricity	Industrial scale	Zero harmful emissions, predictable and constant validity	High cost and large long columns can affect the marine environment, affect the coastline ecosystems, and high corrosion.	
Ocean Thermal	OTEC	Electricity	Industrial scale	Zero harmful emissions, predictable and constant validity	High cost, it can affect the marine and high corrosion	[141]

7. Conclusions

According to the literature review, all Gulf countries have natural nonrenewable energy resources (such as oil, gas, and coal) and huge potential and future prospects for renewable energy. Renewable energy sources have an abundance of promise and sustainability in Gulf countries. Renewable energy use has steadily increased in Gulf nations such as Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates during the last few decades. The GCC regions are located on the coast, where they may make use of a variety of renewable energy sources such as wind, tidal, solar desalination, and so on. The majority of Gulf nations have set a long-term strategic aim of achieving the planned power capacity using renewable energy sources with their own country's vision in the area of solar energy, wind energy, biomass, tidal, bioenergy, etc. The Gulf-bordered nations obtain the most solar energy in the globe, making it one of the most important energy-producing driving forces for generating power. Likewise, wind energy is another viable alternative for generating electricity. It is self-evident, and the research confirms that the GCC nations have several notable locations for wind energy power generation, which is a totally nonpolluting source of electric power generation. The majority of GCC nations have identified a number of viable locations for generating higher-density electric power. Apart from the solar and wind energy potentials in the GCC, entrepreneurs and researchers are actively researching biomass conversion to generate electricity. The potential of biomass industries has been thoroughly discussed in GCC's study of the literature. The intensity of investigation in the biomass sector, on the other hand, must be investigated in the majority of GCC nations. In GCC countries, effective biomass usage serves two purposes (waste minimization and electricity generation). Further, several researchers are also researching a new study topic known as bioenergy power generation in the GCC. Despite the fact that bioenergy is a relatively saturated field of study, the Gulf-bound countries have enormous potential to explore electrical energy in larger magnitudes. Furthermore, the GCC should also concentrate on tidal wave energy generation (because all the GCC nations are located near the coast, and hence, the production of the same is very high). GCC countries can become a potential benchmark for the strong utilization of renewable energy resources for the global community, not only for the exploration of renewable sources but also for safeguarding the global pollution hazards.

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