Renewable energy technologies adopted by the UAE: Prospects and challenges- A comprehensive overview

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Abstract

The United Arab Emirates (UAE) is an oil-rich country which is located in the eastern part of the Arabian Gulf. The country is considered among the highest energy consumer in the world. Likewise of the other GCC countries, UAE's economy mainly depends on the oil, gas and other fossil fuels. In the recent timings, with a continuous increase in UAE's population require further demand in its energy production which is essential for its economic growth. However as the fossil fuels are limited sources, consequently additional sustainable and renewable energy (RE) resources are necessary to be explored. In this context, the UAE is considering alternative RE resources to overcome such issues as well as to reduce environmental pollution and its carbon emission. The present work addresses the issues and challenges related with the RE resources technologies, in the scenario of UAE. The possible current, RE resources choices for UAE and potential future prospects of such technologies are mentioned. Further at the present timings, renewable energy resources such as photovoltaic energy, concentrated solar power, wave energy and fuel cell energy etc., which UAE's is mainly focusing are reviewed. Similarly the past and ongoing research work conducted on such technologies has been also discussed. It is expected that by exploring RE technologies, with proper utilization and with better planning these renewable energy sources will provide a suitable solution for the UAE's energy, economy and environmental issues.

Keywords: Renewable energy, Solar, Wind, CSP, Geothermal, Hydro-power, Biomass, Fuel cell etc,

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1. Introduction

In a modern world, as we look into today, would have not been possible without energy. Energy plays a major key role in the development and progress of a nation. It is a fact that the progress of a nation could be estimated in terms of how much energy it consumes per person. In a today's era energy is so important that affects our lives, and livelihoods down to the grass root levels. Energy might best be described in terms of what it can perform for us. We cannot see energy, only its effects; we cannot make it, only utilize it; and we cannot destroy it, only waste it through inefficient manner [1].

Two major categories of energies are: (1) Renewable energy and (2) Non-renewable energy. The formal case of energy, is the type of energy obtained from regenerative or virtually inexhaustible sources of energy that occurred in the natural environment. Some examples of this type of energy include solar energy, wind energy, geo thermal, wave power etc. They are present whether we harness them for practical uses or not. This is also commonly referred as non-conventional sources of energy [1].

While the latter case is related to the energy obtained from static stores of energy. Such sources remain bound unless released by human interaction. Some of the examples of the non-renewable energies are fossil fuels of coal, oil, and natural gas. This type of energy is initially in an isolated energy potential which requires an external action to initiate its supply for practical utilization. Sometimes, it is also called finite energy or conventional sources of energy [1].

The United Arab Emirates (referred as UAE) is located in the Middle East and in the eastern part of the Arabian Peninsula. The land of UAE is largely hot and dry desert [2]. It consists of the seven emirates. Among the seven states, Abu Dhabi is by far the largest and controls 90% of all oil and natural gas reserves in the UAE. The federal government of the UAE recognizes that diversification of its economy plays a vital role in maintaining its growth. The other additional main industrial activities in the country are construction, aluminum, chemicals and plastics, metals, and heavy equipment [2].

In the present world, the emergent worldwide commitment to sustainable development places a special responsibility on technology policy. Such situation creates specific challenges for any oil-rich economy like the UAE in which reliance on conventional sources is generally seen as the backbone of its survival. Therefore, in the past few years the United Arab Emirates (UAE) has taken some important key steps to establish a renewable energy (RE) sector to address its CO₂ emission problem and to diversify its economy [2]. Generally the reduction of CO₂ emissions from energy use can be done in three ways: energy efficiency, RE, and carbon capturing and sequestration. According to report of CDIAC [2, 9] the UAE and other Gulf states have the highest CO₂ emissions per capita. It is worth to mention that according to the World Energy Council (WEC) report the total current CO₂ emission to the planet by GCC countries is about 2.25 %, in which UAE's contribution is 0.4 % [36]. The CDIAC report further clarifies that the UAE has the second highest water consumption per capita after the

United States. The historical CO₂ emissions in the UAE can be seen in Fig. 1 [2, 9].

Generally, the renewable energy is considered an attractive option because it substitutes for fossil fuel and the economic feasibility of RE technologies is improving with time [2, 3-4]. Although carbon capturing and trading are effective and provide practical solutions for reducing CO₂ emissions, they do have some uncertainties concerning GHG inventories in the context of compliance evaluation related to an emission trading program [2, 5, 6]. Furthermore, CO₂ is still emitted and remain a problem. On the other hand, fossil fuel will remain as the main source of energy for decades to come, nevertheless eventually alternative sources of energy will surpass fossil fuels [2, 7].

Fig. 1: The historical CO₂ emission in the UAE. [Taken from courtesy of Ref. [9] CDIAC (2014)].

The aim of this work is to present an overview of the activities UAE is employing to attain the country's development via sustainable and renewable energy resources. The paper will highlight the possible potential and challenges the UAE's is confronting in order to utilize and adopt such RE resources and their respective technologies, which can substantially contribute to the country's energy requirement. Here, the possible RE resources and the choices which are being utilized and employed by the UAE's are reviewed extensively. Moreover the article focuses on the research and development in dealing and adopting such RE resources. A conclusive summary of work has been mentioned in the last section of the paper.

2. Possible choices for UAE

The two factors namely the climate change and fossil fuel depletion are the main reasons, which have attracted recent attention on finding alternative energy resources. Renewable energy (RE) is considered as an obvious choice in order to reduce carbon dioxide and other pollutants contributing to global warming [10]. In such scenarios, the deployment of RE in any country will have an impact on its sustainability. Such deployment of RE will provide that country a wide variety of socioeconomic benefits such as contributing to the diversification of energy supply, enhancing its the regional and rural development, and creating an opportunity for a domestic industry and job creation potential [2, 8].

Upon looking into the UAE's case, we found that with the rapid economic and demographic increase in its growth over the past decade is pushing the country's electricity grid to its limits [11]. For an instance, the electricity consumption in 2010 was estimated at 85.2 billion kilowatt hours (kWh), which remained 8.5 percent higher than in 2009. While the installed capacity in the UAE continues to rise, reaching 23.25 gigawatts in 2009 [11]. It is important to note that, most of the UAE's electricity is produced via gas-fed thermal generation. Thus the country plans to integrate the seven Emirates' gas distribution networks, which should help alleviate some of the peak-demand deficits that were experienced in the past [11]. For this purpose, the UAE, in spite of having some of the largest deposits of hydrocarbons in the world, the country is planning to diversify its energy mix beyond hydrocarbon-based electricity generation, which includes nuclear and renewable-energy technologies [11]. In the next step, the UAE is also investing in renewable energy technologies, most notably through the Masdar initiative, which

was built in 2006. Masdar institute is a subsidiary of Abu Dhabi's state-owned Mubadala Development Company. Masdar mainly focuses on being a leader in the development of renewable and sustainable energy technologies [11]. The additional RE resources on which the UAE is mainly focusing for its power generation are mentioned in the next sections.

3. Renewable Energy sources of UAE: current situation

The UAE is a federation of seven different emirates, in which each emirate has its own ruler. As mention by the country's constitution, oil and gas reserves belong to the local government of each of the UAE's emirate. For this issue, the federal intrusion in decision-making about natural resources is impossible. Accordingly the electricity and water services therefore kept under the purview of the each emirate individually [12].

Owing to the fragmentation of the power and water sectors in the UAE as well as the local imports/exports of such commodities between the emirates, it is challenging to quantify the linkage between hydrocarbon usage and electricity consumption for each of its emirates. However, on a national level, a vibrant linkage between oil, gas and electricity consumption can be viewed [12]. As mentioned by ref. [13], the net consumption of electricity reach at the peak of 70.58 billion KWh in 2008. While the, petroleum and natural gas consumption extended to 3,257 trillion British Thermal Units (BTUs) in 2008 [12, 13].

Although the economic slowdown caused by the financial crisis in 2008, a great demand for electricity growth has been seen the recent years. This level of demand caused the national reserves of natural gas to be no longer sufficient to meet the country's demand. In order to resolve this issue, the UAE has had to import natural gas from neighboring countries. Such natural gas import causes an unbalance of trade of the country [12]. This trend can be seen in Fig. 2[11]. As reported by the UAE government's white paper regarding the nuclear energy, the peak demand for electricity by 2020 will remain upto 40.85GW. Nevertheless after 2008, the UAE Ministry of Energy reviewed its power peak demand predicted its ranges from 40GW to 33GW by 2020 [12, 14].

In order to achieve such growth prospects, coupled with current and future shortages in the UAE's natural gas supply. This situation has prompted the UAE leadership to foresee a diversified energy mix, which permit electricity production via the conventional sources - oil and natural gas, renewable energy sources (RES), and via nuclear energy [12].

In 2009, the government of the UAE announced its first RE policy. According to this policy, by the year 2020, 7% of the energy for the power sector will come from renewable energy (RE). It means RE resources will be utilized along with fossil fuel to power electricity generation and water desalination plants [2]. Similarly according to a work by R. Ferroukhi et al., [19], in case of Abu Dhabi, 5% of the energy will be produced by renewable sources by the year 2030. Additionally the UAE can also be considered home to some of the region's most high-profile initiatives in utilizing and producing energy from renewable sources [37].

According to UAE's RE policy at the Emirate-level governments are creating policy/incentive framework to deliver their targets such as 100 MW CSP (concentrated solar power) plant, 100 MW PV plant approved, 28.8 MW wind plant and 100 MW waste-to-energy plant [38]. The

UAE's leadership also support the RE production projects. Despite the fact that renewable energy production cost is higher at the present timings, Abu Dhabi and Dubai governments have backed them [38]. According to ref. [38], renewable energy technologies demonstrate great potential of the UAE strategy since they enable us to:

- (i) Construct new industries and reduce dependence on fossil fuel revenues
- (ii) Ensure long-term role in the global energy market
- (iii) Achieve "green growth"
- (iv) Decarbonize, especially the power sector
- (v) Engage with leading international partners, e.g., via IRENA
- (vi) Backing for additional renewable energy related to competitiveness with other fuel types

Fig. 2: A view of the net deficit for all the UAE in natural gas. In 2009 alone, such deficit was recorded as 361 billion cubic feet. [Re-produced from Source Ref. [11] EIA's UAE Analysis Brief].

4. Renewable Energy Policy for the UAE:

The United Arab Emirates is one of the main petroleum- exporting countries in the Arabian Gulf. Located in the Middle East Gulf region, the UAE shares some basic features with Kuwait and Saudi Arabia that includes a small population relative to the country's resource base, an economy which is rapidly developing on the basis of oil wealth, in addition to a common language, culture and history [15]. However unlike the Kuwait and Saudi Arabia, the leadership of the largest emirate, Abu Dhabi, has initiated to coordinate and define its energy policy for the twenty first century. The launching of this strategy can be considered as a systematic approach to establish a renewable energy sector [15].

The new policy was introduced for the first time at the World Future Energy Summit meeting in 2009, which was held in Abu Dhabi. The policy was announced by Dr. Sultan Al Jaber, (the CEO of Abu Dhabi Future Energy Company (ADFECC)). The policy set the goal that at least 7 % of the emirate's power production capability will come from renewable energy sources by 2020 [15-16, 10]. According to this strategy, the initial seeds of a renewable energy policy to be coordinated under the new Masdar Initiative. This policy sets explicit targets for power generation capacity over time and efforts to fabricate domestic expertise in renewable energies. Eventually by following such steps, the goal of positioning the UAE as a leader in the sustainable energy sector can be achieved [15-16]. A comparison of the renewable energy targets planned by GCC countries can be seen in table 1.

This announcement is entirely uniform with two important features. The first trend is the growing awareness about the global of environmental concerns, with more attention being paid to cleaner production, environmental remediation as well as waste reduction. It is worth to mention that the UAE has one of the highest CO₂ emissions rates per capita in the world, and its total emissions growing over 150 percent between 1990 and 2007 [15, 17]. The second trend is about the emerging consensus which goes beyond purely environmental matters to address a wide range of apprehensions that are jointly referred to as the search for sustainable development [15,18]

At present timings, the concept of sustainability is recognized both in the academic and policy

circles. The key policy challenge is to minimize the gap between the policy formulation and its actual implementation. The UAE shares with other rich countries the traditional close relationship of energy use, economic activity and environmental degradation - with an additional fact that energy influences the entire production process. Nevertheless unlike in other oil producing countries, energy in the UAE is largely produced to meet outdoor demand. According to a study conducted in 2006, by the Energy Information Administration evaluated that the UAE produced 2.9 million barrels of total oil liquids per day (bbl/d), however for its own domestic oil consumption averaged only 423,000 bbl/d [15, 11]. Such data proposes that the outlining, planning and execution of sustainability targeted policies is fixed in a context of increasing energy demands driven by the imperatives of rapid growth – though from relatively modest fundamental levels - over and above the critically key export factor [15]. More details about the UAE’s renewable strategy can be seen in Ref. [15, 10].

Table 1: Renewable Energy Targets set by the different Gulf Cooperation Countries (GCC).

5. Potential of Renewable Energy Sources (RES) for UAE – future Prospects

The climate of UAE is arid, and hot. Its climate is humid in the summer with very high summer temperatures reaching 46°C and relative humidity reaching 100 percent. However, due to its geographical position – between latitudes 40° North and 40° South, or what is called ‘the solar belt’ –luckily UAE is blessed with an abundance of solar energy [12].

The research investigations endorse that the UAE has a potential in solar energy. As evident from the Fig. 3, the UAE is the most active country which is working on the renewable energy resources, it has 14 projects already launched for the generation of renewable energy power production [12, 20]. In case of harnessing of energy from photovoltaic (PV) cells, the Annual Global Horizontal Irradiance (GHI) of the UAE reaches at 2.12 MWh/m²/y. The UAE with such a large amount in PV energy is considered to be the highest potential in any member country of the gulf cooperation council (GCC). Furthermore the UAE similarly attained a relatively high potential for the Direct Normal Irradiance (DNI) with a value of 2.2 MWh/m²/y. Such a DNI figures is considered to be suitable for Concentrated Solar Power (CSP) technology [12, 21a].

Fig. 3: The number of RE projects (including planned) per each GCC country upto 2015. [Re-produced from Ref. [20].

5-1: Photovoltaic Energy

Similar to the global trends, solar PV has been growing most rapidly in the region, although its share of the total demand is still modest. The United Arab Emirates is the leader in the gulf region in PV electricity generation with a total of 22.5 MW of installed capacity [22]. According to the various research performed, the employment of PV cells in the UAE demonstrates one of the most promising and reliable renewable energy technologies [12].

In order to evaluate the suitability of the UAE climate for the implementation of PV energy technology, the Petroleum Institute in Abu Dhabi conducted an investigation to analyze the Global Horizontal Irradiance (GHI) in multiple locations of the emirate from 2007 to 2009. In this study, hourly, daily, monthly GHI values were computed and statistically evaluated.

According to this investigation, the highest values of monthly GHI were found in the ranges of 657 W/m^2 in January to 929 W/m^2 in June. While the month of May, June and July contributed the most to the annual GHI, while November, December and January had the lowest values [12]. However, it is worth to mention that between July and September, Abu Dhabi – like the rest of the UAE – sees a dip in GHI due to its characteristic high temperature and humidity. Further the results of the study indicated a high percentage- 82 % - of clear days during the year and that the annual average number of hours per day of suitable GHI –above 500 W/ m^2 . It indicated six hours a day, which further indorses that PV application in Abu Dhabi is technically feasible [12, 23].

At the same time, results of the study, reveal a high percentage – 82 percent – of clear days during the year and that the annual average number of hours per day of suitable GHI – that is above 500 W/ m^2 – that means six hours a day, which confirms that PV application in Abu Dhabi is technically viable [12, 23].

However, an evaluation report of the technical and economic viability of some PV systems and their linkage to the grid in the Abu Dhabi region brought mitigated results. Working onto this context, a study by the Petroleum Institute has been performed focusing on the environmental effects impacting a specific PV technology based on thin-film, amorphous silicon (a-Si) photovoltaic system, via its intrinsic power output or its connectivity to the grid. It is worth to mention that such types of cells have lower electricity production costs. However their efficiency ranges from 6- 8 percent only. According to this study, the group observed that the average efficiency of the system did not surpass 4.82 percent. In such situation the 30 percent drop in efficiency inherent to the a-Si technology also known as Staebler Wronski effect. It is notable that the further decrease occurred mainly due to dust accumulation instead of humidity and/or increasing temperatures. The overall performance of their employed PV system has been mentioned shown in Fig. 4, which shows the efficiency of the system. Moreover, a substantial loss in power was recorded since the latter was fed into the grid via the inverter, as a result it degraded the efficiency of the system by 11.82% from 4.82% to 4.24 %t [12, 24].

Fig. 4. Efficiency of system over duration of project. [Re-produced from Ref. [24]].

On the other hand, keeping in view the environmental and health features involve with the PV technologies, such useful features have validated governmental funding for such clean energy projects. In the same trend, a study was conducted by the University of North Carolina, Chapel Hill to find out the feasibility, costs and benefits associated with such projects. The analysis was performed to estimate the forecast energy production, financial feasibility, and anticipated reductions in Greenhouse Gases (GHG) emissions in a PV-powered 10 MW grid-connected PV plant [12, 25].

According to the reported work [26], the effect of the Abu Dhabi climate – that include mainly the dust – on PV cells will decrease annual production by 5 percent. Consequently this factor limits the production of the proposed plant to 24.4 GWh. However its peak production will still coincide with peak monthly demand [12, 26].

Table 2: The cost comparison for a ten years period. [Re-produced from ref. [27]].

Meanwhile an investigation has been carried out by Lisa A. Lamont et al., [27], to overcome the critical issues like the dust accumulation and bird droppings, which cause the serious problems for the operation of off-grid solar devices. These two factors not only reduce the available power of the modules but also make the cost of solar devices ineffective since cleaning, especially on well-head towers, is very expensive due to the location [27].

The study suggested the technical solutions in term of the PLC based cleaning system [28] and Microcontroller (PIC) based cleaning system [29]. Both of these designs are comparable and approximately 1.5 times more cost effective than the manual cleaning for a 10-year-period as mentioned in Table 2 [27]. According to the study, both of these systems only clean offshore photovoltaic panels but also deter birds, hence removing one of the major factors that affect PV performance. Both of these designs deploy the same movement for their cleaning strategies but the mechanical and electrical components incorporated in each system differ as illustrated in Table 3 [27].

Table 3 : A comparison of the cleaning systems. [Reproduced from Ref. [27]].

Nevertheless, upon considering into account the initial costs and the exported electricity rate (in case of exporting electricity from the nearest plant to the local power grid, that is assessed at \$0.082/kWh), and assuming that the PV project does not receive greenhouse gases (GHG) emissions credits. This report finds that investment in solar energy is financially not profitable since the total initial costs would be around \$92 million (NPV negative) with a 30-year time delay to positive cash flow [12].

Keeping in view of the present scenario of UAE in terms of photovoltaic energy, explain us that the Net Present Value (NPV) that roughly depends on the initial costs, and the income of the project was found to be negative (-\$51million) demonstrating that solar power costs are still too high. However, if the PV electricity export rate was raised to \$0.16/kwh or higher (instead of \$0.082/kWh), or the total initial costs were to go below \$41million, the NPV for the project would be positive [12].

However according to the conclusions of the studies reported in ref. [12, 30], confirms that if environmental damage costs and social benefits of reduced air pollution – estimated to have a current value of approximately \$47.4 million - were taken into consideration. Then such findings would justify support to PV projects and endorse that government incentives are required to make these projects profitable.

5-2: Concentrated Solar Power (CSP):

Generally it is argued that Concentrating Solar Power technologies (CSP) have relative advantages over PV panels, especially upon considering the major inconvenience of solar energy intermittency. Indeed, the storage of solar power becomes as important factor as its generation since the sun is not available at all times. However, in case of solar thermal technologies, solar heat collected during daylight hours can be stored in concrete, molten salts or ceramics forms. Such stored solar heat then can be harnessed for steam turbines to produce electricity at night timings when solar energy is not available. In other words, the molten salt is considered an effective storage system employed for solar thermal technology similar like

CSP which can be achieved at a low cost [12, 21b].

According to ref. [2, 21b, 31-32], the CSP technology, parabolic troughs, has proven its economic, energy, and environmental benefits in California and other part of the world. Various studies suggest that CSP technology has proven to be very competitive to any new power plant, including coal power plants. Variable power requirements are a problem for the grid according to consumers' demand varies during the day time. As compared to other RE technologies, such as wind and solar cells, have limitations because of their lack of storage capacity and their strong variability. The CSP plants have the ability to compensate for the variations in both demand and power inputs into the grid through thermal storage. Additionally, CSP technology is also suitable for both electricity and water desalination in a cogeneration setup. The potential for cogeneration of desalinated water on a large scale is a major advantage of CSP technology [2, 33]. All this suggests a closer look at the planned and the potential implications [2].

Considering such advantageous features of CSP technology, through the Masdar institute's Initiative, a series of CSP plants have been built in the middle of the desert in Zayed City in Abu Dhabi, where the land and the sun are abundant. These CSP plants should supply part of the energy needed for electricity generation and water desalination production [2]. Shams 1 is the first CSP, parabolic trough, power plant went under construction in the United Arab Emirates, in 2010. Construction of Shams 1 completed by 2012 [2]. In 2013, the UAE started the operation of Shams 1, which is considered as the world's largest CSP plant [22]. On 17th Jan, 2013, the first electricity generated by the Shams plant was fed into the national grid power [34]. Table 3 of ref. [2] shows all the key data related to the Shams 1 CSP plant [2]. A view of the Shams 1 solar power plant can be seen in Fig. 5 [40].

Fig. 5 An aerial view solar thermal project (100 MW) at Abu Dhabi (Shams 1). [Adopted from Ref. 40].

In addition to shams 1, the Masdar institute will built additional CSP plants on a yearly basis until a total capacity of 1,500 MW_{el} is obtained in the year 2020 (as shown in Table 4 [2] as the current plan, Scenario 1). Also shown is the maximum potential of CSP plants that can be constructed technically if the UAE retains the political will to remain on the trajectory path that it has framed. Such potential is shown as Scenario 2 in the same table [2]. At present, the current power generation in Abu Dhabi is approximately 40,000 GWh/year, and it could be totally satisfied by CSP plants and the cost could reach \$30 billion. The land area needed to build such capacity is 400 km², which is available in the desert [2,35].

According to such various scenarios, it is useful to consider some of the critical issues. Though CSP plants are excellent source of energy, there are some challenges associated with operating and maintaining them in Abu Dhabi. First issue explains that the weather in the summer is hazy and will affect the solar radiation. Secondly sand dunes exist in the desert and flat area is required to construct CSP plants, so this will increase the cost to clear the site when needed. As mentioned in the Table 3 [2] that predicts that only 220;000;000 kW·h/per year of electricity will be generated from the Shams 1 plant operating for 2,200 h/year. All the following CSP plants will have thermal storage capacity, which will allow the plant to operate for 4,400 h/year and will double the annual solar generation like many existing CSP plants around the world [2,

33, 36-37].

As mentioned by Akella et al. 2009 [38] the present gas-powered electricity production has a carbon footprint of 430 g/kW·h and solar thermal electric generation has an average carbon footprint of 32 (26–38) g/kW·h. As a result, when CSP plants are deployed, the CO₂ emission reduction will be 398 g/kW·h (430-32) [2]. According to ADWEC report [39], all the existing power plants in Abu Dhabi are powered by natural gas. As addressed by the different scenarios in Table 4[2], there is great potential for CO₂ reduction in Abu Dhabi (as indicated in Fig. 5 [2]). Thus the current scenarios will have an effect on the reduction of CO₂ emissions [2]. The three scenarios demonstrate reduction in CO₂ emissions, however none of them show a peak. Even though, it is considered an important step forward in the sustainable energy deployment in the UAE [2].

5-3: Wind Energy

At the good locations, the energy generated from the wind on the land competes production of energy from the fossil fuel in terms of the economic cost. Still, the main problem in the wind is that it is intermittent, as the wind does not storm at all times when there is a need to generate electricity. This problem can be resolved partially by distribution of wind turbines on a wide geographic area [46].

According to 2002 data related to UAE wind energy, rough estimates assessed by the German DLR showed that onshore average wind speed does not go beyond 5.0 m/s. However it can reach 7.5 m/s on the shore line. In addition, the UAE has just 1,176 of full load hours per year at 80 meters height. This trend refers to a capacity factor (efficiency indicator) that is quite low to ensure an economically feasible wind energy plant [47]. Based on such efficiency indicator, the construction of wind farms in the UAE would not be a prudent investment. Nevertheless, the obtained data confirmed that in some parts of the UAE, an average wind speed is more than 6 m/s, that is considered very suitable for small-scale power production or pumping water for irrigation purposes [12, 47].

In a study A. H. Siddique *et al* reported [48] and according to [49], that for the UAE wind is an excellent option as the UAE has large costal area which gives the country a suitable platform for deploying wind turbines. UAE consists of the third largest area in the gulf region and this extra land which is not inhabited making it suitable for the deployment of wind farms. A view of the monthly wind speed can be seen in Fig. 5 [48]. Although due to the weather it is commonly considered only about of the solar power for the UAE – wind is definitely an additional option not to be dismissed. With 13.4% of the year suitable for full load wind operation in UAE, it might not be the main renewable energy source, however wind energy could be used as a support for the others energy resources [48, 49]. In an additional work done in 2007, wind speed data were similarly collected for Abu Dhabi by the Petroleum Institute. The study indicated that higher winds blow in the April to October period, particularly when average wind speed fluctuates between a maximum of 13 km/h and minimum of 7 km/h [50].

Working on the same RE option, wind energy conversion systems were also explored in term of theoretical or demonstration studies. From the data collection and analysis performed for an 18-month period, by Spanish-based wind energy company (EHN) engineers collaborating with

the Fujairah Department of Industry and Economics and the UAE University, the wind farms with power generation capacity in the ranges between 130 and 200 MW per year were likely to be installed near Dhadnah, Masafi, and Fujairah city in Fujairah [12, 51].

The deployment of wind energy conversion systems occurred in the UAE, with Sir Bani Yas Island, which is located 250 km southwest of Abu Dhabi, displayed a large 850 KW Vestas wind turbine [12, 52]. Connected to the island's grid, the Sir Bani Yas wind system can be seen as a possible trend maker for sustainable development in the UAE's electric power generation. Following this first experience, Masdar Institute is considering to build an onshore wind farm on the same island. This wind system is considered as the Middle East's largest onshore wind turbine farm with a capacity to produce 30 MGWs on one of the most beautiful natural reserves situated on Sir Bani Yas Island on the west coast of Abu Dhabi, which aims to preserve the eco-friendly environment of the Island. Upon this wind system's completion the generated wind energy would be connected to the Abu Dhabi grid [12, 52-54].

5-4: Hydrogen Energy/Fuel Cells Technology Energy

According to the working principle, the fuel cells transform chemical energy directly into electrical energy. Generally all fuel cell technologies consume hydrogen and oxygen. In this technology, hydrogen is obtained from a fossil fuel and the oxygen from air. In the next step, inside the hydrogen the fuel cell is oxidized at monitored and controlled conditions, where in the presence of a catalyst that combines the hydrogen and oxygen to produce water [56, 48]. In comparison, the fuel cells provide a number of advantages over rotating fossil fuel generations in distributed generations such as high efficiency, low pollution, very low noise, easily re-usable heat out-put as well as quick installation [55, 48, 56]. According to ref. [56] a total of five (05) types of fuel cell exist that include proton exchange membrane fuel cells (PEMFC), alkaline fuel cells (AFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC). Figure 6, explains the fuel cell electrolyte membrane [58]. Ever since the UAE has an abundance of fossil fuel which makes this technology an easily accessible for its utilization [57].

Fig. 6: A schematic view of the Fuel cell electrolyte membrane. [Reproduced from Ref. [57]].

In the past, some studies have also been performed in the UAE to obtain the potential of hydrogen energy as an energy carrier source that can be used in fuel cells to generate electric power. Although hydrogen is storable and transportable. Especially when hydrogen is produced through renewable energy sources, it is further considered environmentally clean and inexhaustible [12]. The first mentionable work in this category was carried out in 2001 by A. Kazim et al., [58], investigating for the feasibility of implementing a solar to hydrogen energy system for the UAE. In their studies, the authors considered the factors such as population growth, energy demand and production, income from sales of fossil fuels, and PV cell area. These factors are essential for installing such a system for estimating the potential production and income from sales of solar hydrogen till 2100 [12, 58]. Their study predicts that for an area of 1,000 km² employing PV cells of 18 percent of efficiency will be needed to generate 10⁹ Giga joules per year of hydrogen. Around the year 2020, the value of hydrogen rated upto 20 % of the total energy income of \$ 80 x 10⁹ of the UAE [12, 58].

On the similar trend, the potential of conventional and non-conventional energy resources that could add considerably to the production of hydrogen in the UAE have been perused for the last 10 years [51]. The report proposed utilization of hydrogen fueled PEM fuel cell in three major sectors namely commercial, power generation and transportation sectors to fulfill the country's energy demand and achieve the desired sustainability as well as environmental and economical benefits associated with such schemes compared with business as usual [51]. This review concluded that, although with the low operating efficiency and high CO₂ emissions of the natural gas steam reformation process, the cost of hydrogen produced by such process – at 10 percent of utilization rate of the UAE's current production of natural gas. Such a trend proves to be more promising than hydrogen produced from renewable resources. While the cost of the former is \$ 8.2/Giga joule, which is considered on comparison to be 10 %, 45 %, and 57 % lower than the biomass hydrogen, the solar-hydrogen, and the wind-hydrogen systems, respectively. Nevertheless, as the cost of natural gas will increase accordingly of its huge consumption and its imminent scarcity in the coming future. As a result the cost of hydrogen produced by gas will rise by 70 % in the long term period [12, 51].

However, according to ref. [12], the sustainability of the biomass-hydrogen resource in the UAE will depend on the sustainability of the country's agricultural sector as well as its growing consumption of limited water resources. On the other hand, since the wind potential is low, that left the solar to hydrogen option as the most technically feasible among all the RE options for the UAE [12].

5-5 : Bio Fuels

Keeping the sustainability constraints in view, an integrated seawater agriculture system for the generation of aviation biofuels has been the subject of interest. Such an area of study led by the Sustainable Bio-energy Research Center (SBRC) to evaluate its technical, economic and environmental feasibility in the UAE [12, 59].

By adopting a five-year Industry-University relating program. This program involved organization such as Masdar Institute of Science and Technology, Etihad Airlines, Boeing and Honeywell's UOP, and SBRC. The researchers of this program have performed agronomic studies on *Salicornia-bigelovii* cultivation in the arid land of the UAE by employing seawater irrigation. These studies addressed the sustainability of the yields and the consumptions of *Salicornia* (e.g., for the biomass electricity production, fish feed in aquaculture, etc.), the agronomic risks as well as the land availability. The study was conducted to improve a low-impact biomass system that did not compete both with arable land and fresh water supply [12,59].

By working on such RE source, the R&D program (initialized in 2010) merged aquaculture, *salicornia* cultivation, mangrove silvi culture, biomass processing, and the technology required to improve feedstock production efficiency via constructing sufficient quantities available, mostly for a sustainable biofuel production system [12,59]. Upon considering the UAE's growth and export potential in the biofuels-from-algae sector to a delegation of industry and academic experts, Masdar Institute of science and technology developed a novel research projects which is undertaken at the laboratories in the sustainable campus [51]. At present, the Algae Research Laboratory along-with the Microbial Environmental and Chemical Engineering Laboratory (MECEL) are conducting research which investigates for creating new

types of fuels that could be used for specialized high-end needs – like aviation fuel and jet fuel [60].

According to the industry experts [51], the UAE is uniquely positioned to make a strong impact, in the biofuels-from-algae market. Firstly, the native algae have evolved to cultivate under a wide range of temperatures and salinities. It is worth to mention that the production of biofuels employing these strains of algae were not expected to compete with the fresh water supply or with the food fabrication in the UAE. Secondly, the development of the algae-for-biofuels industry can be used to supplement the growth of the aquaculture industry in the UAE. Such special traits along with others, make the UAE an ideal place to develop a world class and internationally competitive algae for biofuels industry [60].

One useful feature of algae is that algae do not depend on being grown in the ocean. In the UAE, there is the ability to use non-habitable land, such as the desert in the western region, for algae growth. Furthermore, a properly designed and constructed algae growth facility will not have an impact in the marine ecosystem of the Arabian Gulf [60]. According to Masdar report [51], the UAE also has the potential ability to become a world leader in the biofuels from algae industry. Not only the country has the potential for biofuels export, but the establishment of this industry in the UAE will create a unique knowledge base for algae growth. This opportunity will allow the UAE to also export the necessary know-how to help implement this industry in other parts the world [60].

The report further explains that the cost of producing energy is currently projected between US \$8.00 to US \$20.00 per gallon of biodiesel produced from algae [60]. However the recent technologies and co-production schemes, producing nutritionals, pharmaceuticals, and high-value chemical projects, along with novel growth production schemes are making the overall cost of producing biofuels from algae a profitable venture [60]. Additionally the profitable production schemes are expected to come online in the next 3 to 4 years [60]. Ever since, there has been a large push to establish a biofuels-from-algae industry in many places. As a results considering such potentials of biofuels-from-algae the UAE has started to focus on biofuels RE technology more seriously [60].

5-6: Biomass Energy

Over the last 30 years, the population of the United Arab Emirates has increased 10 folds and the country's agricultural and animal production have been also increased with this growth. According to Ministry of Agriculture and Fisheries, in the year 2000 UAE's the average crop season yields were above 600,000 tons of crops including tomatoes, lettuce, dates, cabbage and animal feed. Similarly, the seafood production increased from 68,000 ton/year in 1975 to 115,000 ton/year in 1998. On the same trend, the numbers of cattle and sheep have increased from 108,000 heads in 1975 to 550,000 heads in 2000 [61, 51].

Hydrogen energy can be also produced via biomass energy by means of biomass gasification. This trend has been under intensive study over the last two decades. Though such technology has been facing obstacles economically rather than technically due to high capital and operational costs. However, with the passage of time, the increasing demand for a clean energy such as hydrogen energy will create biomass gasification economically feasible in the near future. Keeping in view such situation, as an application of biomass gasification, many large

and small-scale demonstration plants have been installed worldwide [51].

In 2002, a preliminary study was performed on the utilization of the UAE's major biomass resources and residues to produce hydrogen energy through biomass gasification, which addressed the country's present and future biomass resources and investment cost associated with erecting biomass gasification plants [51, 53]. In this study, both animal and agricultural residues produced on a daily basis as the UAE's biomass resources were considered. Some of the examples of biomass include trees, grasses, vegetables, agricultural and food processing wastes, manure and sea plants. Based on the growth rates of the country's biomass resources, a future trend for the next 10 years was also investigated with a complete economical assessment of installing biomass gasification plants that will accommodate country's future biomass resources. The study concluded that, with an average annual biomass production of 15 dry tones per hectare, a significant potential of hydrogen production of 75×10^6 GJ per year can be obtained in the United Arab Emirates via its agricultural residues making up to 10% of the total agricultural land [51, 62].

The annual energy production through UAE's (from 1980 to 2000) can be seen in Fig.7, which consists of animal (cattle, poultry) and agricultural (fruits, vegetables and cereals) wastes. The data shows that biomass resources energy production have significantly increased at an annual growth rate of 9% with agricultural waste contributing about 85% of the total country's biomass resources. Alternatively, the animal waste contributed the remaining 15% of the country's total wastes. According to the data, of the total wastes produced annually, vegetable residues made up approximately 65% of the entire wastes. Whereas, cereals made up less than 1% of the country's entire biomass resources [51, 63].

Fig. 7: Annual energy production of UAE in terms of Biomass. [Re-produced from Ref. [51]].

Table 4 [51] demonstrates the present and the predicted cost breakdowns of the biomass gasification plant in the next 20 years. According to the analysis, hydrogen production was carried out at plant thermal conversion efficiency, plant lifetime and a plant capacity factor of 70%, 25 years and 90%, respectively. Further, a discounted rate of 6% was applied on the capital cost, labor and maintenance costs and chemical cost, purchased electricity cost and biomass cost. Upon looking into the detailed comparison of the parameters, it clarifies that in the past, the product from gasification has been electricity or heat source, and the low value of these products in today's market is insufficient to justify the capital and operating costs. But, if gasification is coupled with the production of a higher value of hydrogen, the combination could be a viable alternative energy technology [51].

Table 4: The cost breakdown of a biomass gasification plant in the 20 years period term. [Re-produced from Ref. [51]].

Further it is important to note that the hydrogen produced in smaller biomass gasification plants would be considered uneconomical. For example, the cost of hydrogen produced from 960 ton of biomass per day in the year 2000 is 20% and 22% more than its cost in 2010 and 2020, respectively. The data of table 3, clarifies that the cost reduction is not only attributed to the large quantity of biomass to be processed on daily basis but also to future advancement and development that could play a major role in the cost reduction of hydrogen to an economical

rate. Additionally, the amount of hydrogen that could have been produced by the gasification plant in the year 2000 would have been approximately 12,000 GJ of hydrogen per day. Such produced amount could be sufficient to fuel 150,000 proton exchange fuel cell vehicles (PEMFCV). Further the amount of hydrogen that could be produced by the gasification plant in 2020 would be approximately 63,000 GJ of hydrogen per day, which could be sufficient to fuel 750,000 proton exchange fuel cell vehicles [51, 64].

5-7: Geothermal Energy

Though the United Arab Emirates have a limited potential of geothermal resources available and scattered throughout the Emirates, this renewable resource has not been exploited at its maximum level [51].

As an example, it is widely known that energy is available in Emirates of Ras Al Khaimah, and Abu Dhabi (i.e. Al Ain). Such geothermal energy resource could be either extracted through hot dry rock. At this location a large mass of dry material extends from near earth's surface to a deep inside the crust or from hot aquifers, at which the heat resource remain within a layer of water deep beneath the ground surface. Nevertheless, no technical study on the potential of such resources to generate the power has been performed neither economic feasibility of utilizing such resources in hydrogen production [51].

5-8: Hydropower

The UAE lacks the hydropower as renewable resource since lack of waterfalls in the country. This renewable resource is considered as one of the mature resources among all other renewable sources. For instance EU countries depend greatly on utilizing hydropower to fulfill approximately 4% of its energy needs [51, 65].

5-9: Wave Energy

Wave energy is also considered a renewable energy resource which is extracted from deep-sea water waves and it could be exploited for small-scale applications such as powering residential houses near shores or energy storage purposes by producing hydrogen energy through electrolysis process at the offshore [51, 66]. Normally, there are various obstacles associated with the production of wave energy that consist of irregularities in the wave amplitude, difficulty in coupling the wave period with the electrical generator and difficulty of constructing power devices and maintaining or mooring them. Consequently, these obstacles could make extracting wave power quite expensive as compared with the fossil fuels [42, 57].

In a recent work that has been published on the potential of wave energy in the UAE, and took wave profile of Dubai as a case study [51, 66]. In this study, wave data of Dubai coasts were taken over the period from 1997 to 2000 in terms of significant height, amplitude, and wavelength and energy period [51, 66]. Fig. 8, demonstrates the average monthly significant height and the mean zero crossing periods. In addition, the monthly average power extracted from the waves was calculated and presented. Here the most reasonable values of the extracted power were evaluated for the months of January, February and March. These months denote the winter season, which is characterized of a relatively low temperature between 15 and 20 °C and high winds reaching 7 m/s. These winds cause a greater significant height in the sea waves. For instance, a maximum power of 0.9 kW/m can be found in the month of February, where

the corresponding significant height, H_s and mean zero crossing period, T_z are 0.6 m and 4.5 s, respectively. In contrast to this value, a minimum wave power of 0.1 kW/m that can be extracted from the Dubai coasts has been calculated to be in the month of September with the corresponding minimum H_s and T_z of 0.21 m and 4.0 s, respectively [51, 66].

Fig. 8: A view of the monthly average significant height, mean zero crossing period, power extracted per unit width of the wave front. [Reproduced from Ref. [51]].

These findings indicated that a maximum possible wave power of 16.9 kW/m could be extracted from Dubai coasts at extreme condition during winter season. This season could be characterized of having a high wavelength, phase velocity and significant height. Moreover, the yearly average wave power distribution over the entire frequency range from $\nu = 0$ to $\nu = 0.3 \text{ s}^{-1}$ was estimated to be 4.5 kW/m. Nevertheless, the general trends of the magnitudes of the measured data are considered to be on the low side. This trend is due to the fact that the measured data were taken in the close proximity of the sea onshore, and the general characteristic of Dubai coasts of having shallow waters and low wavelengths. As a result of it, a marginal benefit from this renewable energy source could be attained [51, 66].

5-10 : Tidel Energy

Tidal energy arises as a result of gravitational and kinematics forces as a consequence of motions of the earth, the sun and the moon, is considered as one of the major renewable energy sources beside the solar, the wind and the hydro energy [51, 67]. The assessment related to tidal energy in the UAE was conducted in 2005, based on the tidal pattern of Dubai's coasts as a case study. Tidal data of Dubai coasts were taken over the period from 1997 to 2000 in terms of tidal range and current speed [51, 67].

Based on the tidal range power approach, the recorded tidal data indicated that the average yearly water depth was estimated to be 7.62 m, which indicated the estimated mean sea level in Jebel Ali for the 3 years period. The neap and spring tides arises twice in a month with respective values of low and high tides from the mean sea level (shown in Fig 9 of ref. [67]). The results indicated that the average neap and spring values were found to be 0.8495 m and 0.425, respectively. These found magnitudes were used to determine mean square range as well as the mean tidal power extracted over the entire month. The recorded data clearly shows that the spring occurred in the second and forth weeks of the month. Also it clarifies that the neap occurred during the first and third weeks of the month [51, 67].

The evaluated results presented in Table 5, which shows that the mean square range, during the entire month was found to be 0.4286 m, which is extremely low for the purpose of tidal power extraction. Further, the maximum and average monthly powers that can be extracted from the tides were calculated to be 0.0964 MW and 0.0482 MW, respectively. Obviously, these values are considered very low and unsuitable for any major applications such as hydrogen production, powering residential, commercial buildings [51, 67].

Table 5: A comparison of the measured and calculated parameters of the tidal range and power. [Reproduced from Ref. [51]].

5-11: Ocean thermal energy conversion system (OTEC):

Ocean thermal energy conversion (OTEC) is also considered to be one of the renewable energy forms. In this technology heat conversion process takes place between the ocean surface, which is exposed to the sun and the ocean depth, which represents the cold temperature reaching 5 °C [51]. By considering a stable temperature gradient between the ocean surface and its depth in locations close to the equator and with marginal seasonal changes, a huge potential of thermal energy can be produced. Though, only a fraction of such energy can be converted into a useful mechanical work or electricity. Still, OTEC system is regarded to be one of the main renewable energy sources in the tropical regions [51].

One of the major shortcomings related with OTEC renewable energy resource is when the conversion process takes place in a remote offshore area and distant from the utilization sites, that leads to a significant energy wastage. In order to remove this shortcoming, conversion of power produced from an OTEC system into hydrogen energy through electrolysis process, could be the most suitable method to commercial realization of the hydrogen economy using only renewable energy sources. In 2005, a technical analysis of hydrogen production through an OTEC system coupled with a PEM electro-lyser was conducted [51,68]. Such an analysis has been carried out at an optimum temperature drop between the working fluid and the sea water, and at various temperature differences between the ocean surface and its depth.

Fig. 9 shows both an ideal and an actual power input and output of the OTEC system which is based on the optimum temperature drop. The actual power output varies from as low as 11 kW at temperature difference of $\Delta T = 5\text{ }^{\circ}\text{C}$ to as high as 258 kW at $\Delta T = 25\text{ }^{\circ}\text{C}$. On the contrary, the actual power input ranges from 1250 kW at $\Delta T = 5\text{ }^{\circ}\text{C}$ to 6250 kW at $\Delta T = 25\text{ }^{\circ}\text{C}$. It is clear that, magnitude of an actual power input is much higher than the actual power output because of great losses posed in the thermal conversion process. However, such a low magnitude of the actual power output is still considered sufficient to power the electro-lyser for hydrogen production [51,68].

Fig. 9. Actual and ideal power output of an OTEC system at various temperature differences. [Reproduced from Ref. [51]].

Lastly, it should be noted that out that OTEC system to produce hydrogen energy is employed in oceans with huge depths, where there is a substantial temperature gradient between the surface and bottom of the ocean. Consequently, OTEC technology cannot be applied in the UAE due to low temperature gradient in both Arabian Gulf and Arab Sea [51, 68].

5-12 : Additional Other RE sources:

(a) Solar Thermal Project

This MW project has been constructed in Ras Al Khaima in UAE [40, 69-70]. The project consists of a circular Solar Islands with a diameter of 5 km and height of 20 m contains steam storage, carrying the thermos- solar concentrator solar power (CSP) panels that are placed on a membrane (as shown Fig. 10). Especially of the platform is that it can float both on high sea or land. The basic idea of this project has been made by CSEM, Switzerland (www.csem.ch), which is the first rotation test of the solar Islands prototype, constructed in the Emirate Ras Al Khaimah (RAK) in the UAE [40, 69-70].

Fig. 10. A view of the 1 MW rotating Solar island Project in Ras Al Khaima, UAE. [Ref. from Ref. [40]].

(b) Solar power for water heating:

As an additional RE resource Burj Khalifa, is using solar power, since April 2010, to meet the bulk of its water heating requirements (can be seen Fig. 11). Burj Khalifa tower, which is considered the tallest in the world (818 m), has been employing solar panels to heat 140,000 L of daily water. Such a huge amount of water will be distributed to homes and commercial entities within the tower. This solar powered water provides energy savings equivalent to 3200 kW per day and 690 MWh of energy per annum [40, 71].

Fig. 11. A view of the top roof of the offices at Burj Khalifa there are 378 collector panels, each 2.7 m² in area (total area of 1021 m²), can heat the entire 140,000 L of water in approximately 7 h of day time solar radiation. [Ref. from Ref. [40]].

The project is a perfect accomplishment to the sustainable development initiatives led by the UAE. The solar heating system has been installed and operated by SOLE UAE Solar Systems, the oldest solar thermal company in Europe. Burj Khalifa provides a remarkable opportunity to use solar energy to meet the water heating needs of residents in the tower. The significant benefits of this project include cost savings on energy uses – not only for the tower but the government utility provider too – as well as reduced pollution levels that leads to a healthier environment. The installed solar panels function as solar collectors, as against photovoltaic electricity generation technology located on the roof of the offices, the annexure of Burj Khalifa 378 collector panels, each of an area 2.7 m² with a total solar collector area is 1021 m², can heat the entire 140,000 L of water in approximately 7 hours of day time solar radiation [40].

As reported in ref. [40], among other major sustainable energy and water use measures, the condensate from all the air-conditioning equipment in Burj Khalifa is reclaimed to cool the potable water from Dubai Electricity and Water Authority. In the next step, the condensate water is then collected in an on-site irrigation tank and can be used for tower's landscaping. On its operational stage, this system will provide about 15 million gallons of supplemental water per year [40].

(c) Hydrogen Power Plant:

Hydrogen power plant can also be useful source for renewable energy. Therefore UAE considering this technology as a possible resource for RE, Masdar officials made a deal with British Petroleum and Rio Tinto for the emirate to construct one of the world's first commercial hydrogen power plants, a 500- MW operation slated to cost at least \$2 billion. This announcement was made at the future energy summit [40].

6. Challenges and Issues for sustainable development of renewable energy sources in UAE

The deployment of renewable energy technologies (RET) in the GCC region including UAE is a process that will unfold over decades. R&D work in the field of RE has been performed over the past few decades in GCC countries including UAE. For this purpose, investments, both at the private and public sectors, have been carried out in—economically expensive— innovative RETs, indicating the intention of GCC countries to play a pioneering role in the RE sector [19].

It is important to note that investments in the renewable energy technologies will need to be sustained and both manufacturing capacity and proprietary intellectual property will need to be developed. R&D institutions and centers of excellence must be further established to promote new thinking and innovation [19].

Keeping in view the challenges and drivers of RET opportunities in GCC countries, it is important to understand the innovation value chain in the RE sector from R&D to commercial deployment. Studies reveal that the innovation value chain was first adopted by Grubb [72]. In this chain, the first three stages (basic R&D, applied R&D and demonstration), as applied to any RET, were considered to be “Technology Push” where the technology is created and developed. While in the next three stages (pre-, supported and fully commercial) were considered to be “Market Pull” where the technology has proven its commercial value [19, 72]. Therefore, in order to push the technology from the laboratory to the market, government policy and programme interventions are initially high and will decrease once the technology becomes more commercially viable. At the same time, business and the financial community will become more willing to investment in the technology once it has proven its reliability and economic profits [19, 72].

According to Grubb work [72], the main challenge in the innovation value chain lies in the middle segment, the technology “Valley of Death,” when taking the new technology from the laboratory to the market which means moving from government funding to private investments. The deployment of RET is as important as the R&D stage. The adoption of RE faces many complications [19, 73].

The two main issues of concern include [19]:

- (1) Renewable electricity still cannot economically compete with fossil-fuel generated electricity and provides no new functionality from an end-user perspective.
- (2) The social, environmental- and even security-costs of fossil fuels are not taken into account. Consequently, more attention is needed to understand the preferences of the private investors, especially the venture capital and the private equity investors [72, 74].

At present, most of the investors in the GCC region including UAE are interested in the commercial side of RETs especially when the unit cost of the technology is in parity with or below other conventional energy technologies. However when the unit cost of the technology is higher than other energy technologies, such as solar power, then the technology “Valley of Death” will be the biggest challenge and the right policy and mechanism must be carefully made in order to bring such technology to full commercial status with time [19, 75].

7. R&D organizations

Though UAE do not have a unified federal energy policy, with the efforts of the Emirate of Abu Dhabi have laid the foundations for a “hub” approach in the country, namely through Abu Dhabi’s state-owned institute Masdar [76, 77]. The Emirate’s financing for renewable energy projects has seen, for instance, 66 local companies participate in the 100 MW Shams 1 CSP plant, the majority of such form of energy did not exist in the past [76, 77].

The local renewable energy investment community has also grown as Masdar and state-

sponsored Taqa have become active global investors, with Masdar notably taking stakes in the London Array (which is considered as the world's largest offshore wind farm), and Gemasolar, the Spanish CSP project that uses breakthrough energy storage technology [76, 78]. Given below are the UAE's organizations which are involved in the R & D of renewable energy resources [20, 21]:

- Masdar Institute of Science and Technology has been established as a postgraduate university, focused on science and engineering of advanced renewable energy, environmental technologies, and sustainability [20]. In addition the institute has already produced the region's first-ever patents in clean technology, some with start-up company potential. The Masdar Institute of Science and Technology, in collaboration with IRENA and other partners, commissioned the UAE Solar Atlas [20].
- The northern Emirate of Ras Al-Khaimah has established a clean-tech campus with Switzerland's École Polytechnique Fédérale de Lausanne and a related clean tech research and demonstration center run by the Swiss outfit CSEM [77].
- Many other UAE universities are conducting research on RETs, environmental sustainability assessments in UAE buildings, and utilization of solar-hydrogen energy. These universities also organize seminars and workshops on renewable energy. In addition, Masdar hosts the World Future Energy Summit every year [76].

By playing a leading role, the Masdar city sustainable development and free zone likewise has brought a bundle of renowned renewable energy industry leaders, like as Siemens and General Electric, to establish their regional headquarters in the UAE [76, 79]. As reported in 2012 [80], Dubai, an Emirate of the UAE plans for 1,000 MW of solar power have further reinforced the "hub" [80]. A detailed description of the potential Renewable Energy options for the UAE are summarized in table 6. The data of the table reveals that both Solar and Wind energies are the mains renewable sources for the UAE, while all other sources have a secondary RE sources being considered by the UAE.

8. Conclusions and Summary:

The current work demonstrates the various approaches of the United Arab Emirates to attain the country's sustainable development by adopting various renewable energy resources. Owing to the advantageous features such as RE resources key role in reducing the carbon dioxide and other pollutants which contributing to global warming [10], the UAE is very keen in adopting and employing such RE technologies. The work overviewed the possible potentials of the UAE's efforts in bringing such renewable resources for the production of its energy needs.

UAE has been playing a leading role in the GCC region for utilizing RE sources for its power generation. According to the presented work, the available RE sources available for UAE include photovoltaic, concentrated solar power (CSP), wind, Fuel cell technology, Bio Fuels, Bio-mass, Tidel and Wave energy etc. The country has got great potential in all these RE resources for meeting its energy demands, which have great impact on the UAE economy. In case if the RE resources available to UAE are properly harnessed efficiently through proper management, planning and implementing its RE policy. The country can meet its target set for

“2030 Plan for RE resources” and it can easily manage its energy demands required for its public usage, industrial utilization and for its future economic development.

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<http://www.rsb.gov.ae/uploads/InfoElecTariffsLargeUsersNov09.pdf> ;
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Fig. 1: The historical CO₂ emission in the UAE. [Taken from courtesy of Ref. [9] CDIAC (2014)].

Fig. 2: A view of the net deficit for all the UAE in natural gas. In 2009 alone, such deficit was recorded as 361 billion cubic feet. [Re-produced from Source Ref. [11] EIA's UAE Analysis Brief].

Fig. 3: The number of RE projects (including planned) per each GCC country upto 2015. [Re-produced from Ref. [20]].

Fig. 4. Efficiency of system over duration of project. [Re-produced from Ref. [24]].

Fig. 5 An arial view solar thermal project (100 MW) at Abu Dhabi (Shams 1). [Adopted from Ref. 40].

Fig. 6: A schematic view of the Fuel cell electrolyte membrane. [Reproduced from Ref. [57]].

Fig. 7: Annual energy production of UAE in terms of Biomass. [Re-produced from Ref. [51]].

Fig. 8: A view of the monthly average significant height, mean zero crossing period, power extracted per unit width of the wave front. [Reproduced from Ref. [51]].

Fig. 9. Actual and ideal power output of an OTEC system at various temperature differences. [Reproduced from Ref. [51]].

Fig. 10. A view of the 1 MW rotating Solar island Project in Ras Al Khaima, UAE. [Ref. from Ref. [40]].

Fig. 11. A view of the top roof of the offices at Burj Khalifa there are 378 collector panels, each 2.7 m² in area (total area of 1021 m²), can heat the entire 140,000 L of water in approximately 7 h of day time solar radiation. [Ref. from Ref. [40]].

Table 1: Renewable Energy Targets set by the different Gulf Cooperation Countries (GCC).

Table 2: The cost comparison for a ten years period. [Re-produced from ref. [27]].

Table 3 : A comparison of the cleaning systems. [Reproduced from Ref. [27]].

Table 4: The cost breakdown of a biomass gasification plant in the 20 years period term. [Re-produced from Ref. [51]].

Table 5: A comparison of the measured and calculated parameters of the tidal range and power.[Reproduced from Ref.[51]].

Table 6: Comparison of potential Renewable Energy options for the UAE.

Fig. 2: In 2009, the net deficit in natural gas for all the UAE was 361 billion cubic feet. Source: EIA's *UAE Analysis Brief*.
[Re-produced from Ref. [5] EIA's *UAE Analysis Brief*].

Fig. 4.

Fig. 8:

Fig. 9:

Fig. 10:

Fig. 11.

Fig. 12.

Fig. 13.

Table -1 to Table -6:

Table 1: Renewable Energy Targets set by the different Gulf Cooperation Countries (GCC).

Country/ State	RE Production Target Plan	Year of Production	Expected RE Production	RE Production by 2015	Reported In
UAE /(Abu Dhabi)	7 %	2020	1500 MWatt	2000 MWatt	Ref. [2], Ref. [19], Ref.[20], Ref. [40] Ref. [42]
UAE / (Dubai)	5 %	2030	1000 MWatt		
Saudi Arabia	10 %	2032	54 GWatt	4000 MWatt	Ref.[20], Ref. [19], Ref. [40]
Qatar	10 %	2030	1 G Watt	3500 M Watts	Ref. [19], Ref. [40], Ref. [43]
Kuwait	10 %	2020	1,150 MWatt	1500 MW	Ref. [19], Ref. [40], Ref. [12]
Oman	10 %	2020	600 MWatt	1000 MW	Ref. [20], Ref. [40], Ref. [12]
Bahrain	5 %	2020	1000 MWatt	1000 MW	Ref. [19], Ref. [20] Ref. [40], Ref. [12]

Table 2: The cost comparison for a ten years period. [Re-produced from ref. [27]].

	Manual Cleaning	Over-Sizing	PIC Cleaning	Based PLC Cleaning	Based
Installation of PV arrays (Initial Investment)	14,400	28,800	14,400	14,400	
Installation of Cleaning System (Initial Investment)	0	0	3,000	3,000	
Design Cost (Initial Investment)	0	0	900	1,400	
Maintenance (10-year period)	29,000 (6 times per year)	14,500 (3 times per year)	10,000 (2 times per year)	10,000 (2 times per year)	
Total Cost~ (US\$)(10-year period)	43,400	43,300	28,300	28,800	

Table 3 : A comparison of the cleaning systems. [Reproduced from Ref. [27]].

System Description	PIC Based Cleaning[24]	PLC Based Cleaning [23]	Evaluation
Electrical	Microcontroller and logic circuit	Programmable Logic Controller (PLC)	Design 1 is cheaper and more compact
Mechanical	Pulleys and Belt	Gears and chain	Design 1 more suitable for offshore application due to material use
Cleaning Device	Wiper	Rotating Roller	Design 2 has shown better removal of dirt
Bird Deterring	Light Emitting Diodes at night and Wiper Movement and buzzer during the day	Sirens	A combination of both would be more efficient
Cleaning Initialization Method	Photodetector	Timer	Both can be easily changed to suit cleaning specifications
Water Supply	Integrated solar Desalination system	Water tank	Design 2 is cheaper and easier to install initially. However , Design 1 over an extended period has proven superior
Component Cost	US\$ 900	US\$ 1400	

Table 4: The cost breakdown of a biomass gasification plant in the 20 years period term. [Re-produced from Ref. [51]].

Parameter	Units	Year		
		2000	2010	2020
Dry ton of biomass per day	Ton/day	960	2038.20	4968.60
Biomass energy input	GJ/h	804.07	1707.15	4161.60
External electricity input	MWe	10.59	22.50	54.81
Total investment cost	10 ⁶ \$	79.71	169.23	412.54
Capital cost	\$/GJ	1.66	1.32	1.29
Labor, maintenance & chemicals	\$/GJ	1.34	1.06	1.04
Purchased electricity	\$/GJ	0.92	0.73	0.71
Biomass cost	\$/GJ	2.90	2.57	2.61

Total cost of hydrogen energy	\$/GJ	6.81	5.69	5.36
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Table 5: A comparison of the measured and calculated parameters of the tidal range and power.[Reproduced from Ref.[51]].

Parameter	Quantity
Density of the sea water, ρ (kg/m ³)	1250
Area of the rotor, A_r (m ²)	1000
Area of the Basin, A (km ²)	1
Spring tide R_s (m)	0.8495
Neap tide R_n (m)	0.425
Ratio of neap to spring α	0.5
Mean Square Range, $\bar{R}^2$ (m ²)	0.4286
Mean monthly tidal power, $\bar{P}_{\text{month}}$ (MW)	0.0482
Maximum tidal power, P_{max} (MW)	0.0964

Table 6: Comparison of potential Renewable Energy options for the UAE.

RE Source	Possible Project	Projects Potentials	UAE's Total Capacity	References
CSP	Shams-1	100 MW	22000 KWh/m ² /y 8.5 GJ/m ² year	Ref. [2], Ref. [40], Ref. [42], Ref. [81]
Photovoltaic Energy	Solar PV Park	100 MW	22.5 MW	Ref. [18], Ref. [19]
	(Noor-1) Solar PV Plant	100 MW		
	Solar Power Plant (Abu Dhabi)	500 MW		
	Solar Power Plant (Dubai)	10-100 MW		
	Solar Roof Project (Abu Dhabi Buildings)	500 MW		
	Float Solar Island	1 MW		
	Solar Power For Water Heating	690 MWh/y		
	Solar Power System	1 MW		

	(Masdar Roof)			
Wind Energy	Masdar Sir Baniyas Island	20-30 MW 30 MW	1789(h/y) 28.8 MW (approved)	Ref. [19], Ref. [40], Ref. [42], Ref. [81]
Hydrogen Energy	Hydrogen Power Plant Hydrogen energy from Solar Energy	500 MW ---	--- 10 9 GJ/year (in 2020)	Ref. [40] Ref. [51], [58]
Bio Fuels	Masdar city	---	3500 (h/y)	Ref. [40], Ref. [81]
Biomass Energy	Gasification plant	12000 GJ per day in 2000	75 x 10 ⁶ GJ/Y 63,000GJ (2020)	Ref. [51]
Geothermal Energy	(02) Geothermal wells at Masdar City	5 MW	supply power to the entire air conditioning of Masdar City	Ref. [81], Ref. [19]
Wave Energy /Tidel Energy	Dubai Costs 0.0482MW	16.9 kW/m 0.0964MW	4.5 kW/m (yearly)	Ref. [81]
Ocean thermal energy conversion system (OTEC)	OTEC technology cannot be applied in the UAE due to low temperature gradient in both Arabian Gulf and Arab Sea.			Ref. [81], Ref. [51]