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The Future of Renewable Energy in Iraq: Potential and Challenges

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ABSTRACT

Renewable energy (RE) is currently viewed as a planned and effective option to achieve development sustainability, as it provides an appropriate answer to climate change and also meets the power requirements. With regards to the current scenario in Iraq, a grave deficit with regards to electric power has been looming in the country and this serious shortage in equipped power started decades ago. Various prospects exist regarding the adoption of renewable energy in order to deal with the current issue pertaining to power shortage. This present study is a crucial examination of the existing and future electrical power needs in Iraq and the ongoing planning and challenges that are deliberated, for a better understanding of the prospects of utilizing Renewable energy sources for investment as well as to be able to provide energy to all those who need it in Iraq. Hopefully, this study can support researchers in earning an in-depth understanding of previous research efforts on this subject, and in exploring directions for future research.

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1. INTRODUCTION

Globally, there is a rapid increase in energy requirements, especially clean energy [1] There is a global trend toward environmental protection by controlling pollution, especially greenhouse gas emissions. Even though there will still be availability of fossil fuel energy for a while, such availability of affordable and abundant energy will come to an end. In light of this, it is necessary to explore replacement possibilities, in particular, RE, and address the issues of pollution and the preservation of the environment. Worldwide, fossil energy sources (such as natural gas , coal, and oil) are the major sources of fuel for power plants [1], [2] and it is estimated that in excess of 50% of the sources that currently sustain power plants in supplying energy will still be available until around 2040[3]. On the other hand, these sources are also responsible for the continuing emissions of Carbon dioxide (CO2) , which contributes substantially to global warming [4]. The constantly increasing demand pertaining to energy, clubbed with pollution issues pertaining to fossil fuels, led to further practical and scientific initiatives concerning the development of RE sources to cater to the future and current demands pertaining to 'green' as well as 'clean' electricity [5].

RE resources include wind turbines, solar photovoltaic panels as well as biomass. The feasibility to use such resources will rely on their availability and, if so, the extent of availability pertaining to a specific location. As such, every country or region will include its unique outcomes with regards to the deployment of RE sources. For example, in the European Union (EU), wind energy accounting for 14.7% is equivalent to 11.7 gigawatt electric energy generated in 2018, which continues to grow year-over-year [6]. In addition, in 2016, solar power potential around the world was greater than 300 gigawatts (GW), which an increase of 100 GW versus 2015 [7] as per the 'Global Market Outlook for Solar Power, 2017-2021,' report. It was reported that in

2016 only, China could add 34.5 GW to its capacity in the grid, suggesting an increase of 128% versus the installed output in 2015 [8].

Nevertheless, Iraq's present capability with regards to RE is regarded to be modest versus the country's estimated potential to generate via the stations that make use of gas, oil and steam. In 2011, 80% of the energy generated were based on fossil sources, with hydro stations contributed for just 2% (8). Furthermore, the old hydro power stations and water-based generators have been negatively impacted by a series of droughts. There is also the matter of dams constructed in nearby countries, for instance, Turkey's Elisso Dam on the Tigris river, which effectively reduced Iraq's overall water availability share.

Similarly, most of the projects in this country have implemented in recent years in the power generation sector are dependent on the availability of hastily-constructed stations such as gas turbine or combined cycle stations, that were originally fossil fuels-based power plants. Despite all these recently-initiated projects, the country still faces a significant deficit in power generation relative to national demand [3], as the details will show later in this study. Due to the considerable significance of this segment in the country, numerous researches in Iraq focused on the power situation and also the prospects of substitute power options as discussed in as [3], [9]–[12]. Due to the high dependence on fossil fuel as earlier explained, the problem of emitting carbon dioxide gas resulting mainly from the use of fossil energy sources in power plants and factories is one of the most significant environmental problems globally. This is because the emission of these harmful gases leads to very harmful dynamic changes to the present and future of the globe, such as an increase in the earth's temperature as well as melting snow in the polar regions and also health problems related to air pollution [13].To realize the extent of this problem, it is necessary to be reminded that the total global carbon dioxide emissions in 2018 was 33, 890.8 million tons of carbon dioxide[14]. Currently, Iraq is highly dependent on electric power generated using fossil energy sources. Besides this, the gas-burning operations that result from oil refining activities as well as the ageing factories, with their increasing emissions and an unrestricted increase in the number of cars on the road all these factors made a dramatic increase in the emission carbon in Iraq as shown in Table 1.

Table 1. CO2 emissions for the period 2008-2018 [14]

Year	Carbon dioxide emissions (Million tons of carbon dioxide)
2008	82.4
2009	93.2
2010	99.1
2011	104.0
2012	111.1
2013	119.5
2014	115.6
2015	115.6
2016	132.1
2017	133.7
2018	151.4

Given that Iraq is one of the signatories to the Kyoto Protocol on climate change and regulating the amounts of carbon emissions[15],therefore, Iraq should reactivate programs to reduce these emissions, by increasing dependence on renewable energy generating stations, such as solar plants which can substantially reduce carbon emissions. No less than 89% of air emissions linked to the generating of power could be avoided if energy is generated from photovoltaics [16]. Based on the Energy Sector Management Assistance program, every 1 GW of additional RE capacity lowers CO2 emissions by 3.3 million tons annually. In addition to the economic benefits of renewable energies. the global trend in the power generation industry is to install more environmentally friendly generation plants using RE sources, the planning in this country should follow this global trend to ensure operationally efficient and environmentally friendly power generation for the present

and future generations of the country. However, this study focuses on the present and future status of applying RE and also on the opportunities for investors to develop this crucial sector, which has suffered for 30 years or so from a continuing crisis and work towards formulating a long-term holistic solution that will provide Iraq with a modern, sustainable power generation sector that is more dependent on RE sources than fossil fuels. This research also seeks to create greater awareness regarding the vast importance of the sustainable generation of clean and green energy for this country in present and future.

This paper comprises eight sections. Following this section, Section 2 overviews the reality of the energy situation in Iraq, while Section 3 focuses on and explains the types of traditional power plants in Iraq, while Section 4 presents the Iraqi central plans to address the energy situation in Iraq. In Section 5, focus is on the advantages of Iraq's geographical location and climate and their relationship with opportunities to harness renewable energy sources. Section 6 Follows with the details the advantage of Iraqi climate. Overview for application sustainable energy in the world, besides that, review details of the renewable energy application types in Iraq in section 7. In Section 8 the discussion is on the restrictions and barriers faced in embracing RE in Iraq, while the final in section 9 discusses in detail the efforts of the Iraqi government to initiate and support the establishment of a sustainable energy generation sector for the country.

2. THE REALITY OF THE ENERGY SITUATION IN IRAQ

Iraq's population increase is one of the significant factors for the increase in energy demand over the years. In the period from 1998 to 2018, Iraq's population rose from 22.1 million to about 38.4 million, representing a 73.7% increase over two decades [17], rate of increase considered high by global standards. This population increase occurred despite the political circumstances and the military conflicts that occurred in Iraq in the past four decades. Electricity generation in Iraq has a history that dates back to as long as 1911 with the establishment of the first Direct current (DC) generation unit in Basra by the Anglo-Persian Oil Company [11]. During the past decade the Iraqi electrical system witnessed various changes that accelerated its growth and the efficiency the Iraqi grid until 1990, after which this sector witnessed a huge challenge in terms of a substantial deficit in supply relative to overall national demand. The main causes of this dramatic reversal in the country's energy supply ability were the following:

2.1. Physical damages

The electrical system was subjected to direct physical damage as a result of deliberate military strikes, particularly during the second Gulf War in 1991, as many generation plants were targeted and the total generating capacity was reduced to less than 25% of the energy production which was about 9 gigawatts (GW) before the war[18]. This sector was also subjected to sabotage during the 2003 war and finally, the biggest losses witnessed in all service sectors in Iraq where the electrical system suffered from a combination of direct military operations and sabotage during operations to eliminate the Islamic State during the years from 2014 to 2017.

2.2. Damage due to aging

Most of the main generating plants were established in the past decade and before 1990, however the massive damage to the plants in addition to the economic sanctions that Iraq faced during the period from 1990 to 2003, had a huge impact on the maintenance of the generating units and many of them were unable to redesign or maintain economic feasibility from re-maintenance.

2.3. Poor planning

The mismanagement of resources and the weak investment in this sector led to the loss of large sums allocated to this field, for example, the money spent according to the report of the Iraqi Integrity Commission on this vital sector for the period from 2006 to 2017 was estimated to be about USD29 billion. Despite all that expenditure, there is still a significant deficit in this sector.

2.4. Losses in the distribution network

As a result of the politically unstable situation and wars in Iraq and the many cases of abuse of the system, as well as ineffective maintenance of the distribution network, which led to losses estimated at 24%[11]. As a result of the above reasons, this sector is still experiencing a deficit of about 27% in terms of supply relative to demand, as shown in Table 2. It shows that the supply rate is 16,372 MW, while the generation required is 20,667 MW at peak load. This table also shows the amount of Average rate and Required rate of electric power supply in the governorates of Iraq for the 1st of October 2019, as well as the ratio increasing in electric power supply from the same time in 2018. As explained earlier, most of Iraq's generator plants rely on fossil fuels to generate energy as the following paragraphs explain the types and numbers.

Table 2. Showing the average rate of electric power supply, the required rate on 1st October 2019, and the percentage of electric power supply increased over the same period in 2018 [19]

Name of state	Average rate of electric power supply	Required rate	Percentage of electric power supply in 2018
Al-Basrah	2656	3061	14 %
Al- Nasiriya	1044	1292	11 %
Al-Samaua	401	506	9 %
Al-Amara	678	812	16 %
Al-Diwaniya	500	655	9 %
Al-Najaf	709	895	20 %
Al-Hai	767	1002	22 %
Kerballa	702	893	24 %
Anbar	540	727	37 %
Baghdad	4067	4857	11 %
Salahaddin	526	744	10 %
Diyala	666	823	9 %
Kirkuk	657	895	10 %
Al-Mosul	746	1337	17 %

3. TRADITIONAL POWER PLANTS

Iraq, being blessed with abundant oil and natural gas has understandably established conventional power generating plants that use fossil fuels and all the plants are therefore steam- and gas-driven. In the steam-driven plants, steam necessary for driving steam turbines are generated by boilers using a variety of fuels such as natural gas and oil. Initially, fuel for electricity generation was mainly on, which was easily available in many parts of the country through the network of pipelines as well as huge oil storage tanks to support the various power generating plants in Iraq. Different types of oil traditionally fuel the operation of conventional power plants such as crude oil and liquid fuels, with heavy fuel oil. However, each type of oil has a different effect on the efficiency and periodic maintenance requirements for the conventional power plants. Historically, the main advantage of steam-driven plants is their high capacity of generation compare to gas-driven plants. With massive developments in gas turbine technologies that support the high electrical power capacity with high creation speed and more efficiency as shown in Figure 1, the Iraqi government appears to establish more gas-driven plants to address the shortfall of generated electricity relative to demand, especially after 2003.

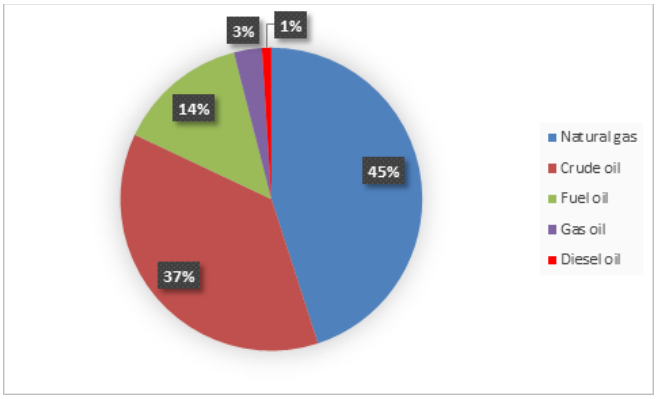

Figure 1. The number of calories (kcal) in percentage required to produce KWH in Iraqi power plants

Another benefit of the gas turbine is its flexibility of fuel source. Traditionally, Iraq uses the natural energy resources available in the country. This includes many flammable gases and light distillate petroleum products like diesel, kerosene (parafilm) and gasoline (petrol). Though, natural gases are the most commonly used source of energy. Crude and other heavy oils are also other fuel sources that fire gas turbines provided their viscosity is first reduced to a level that will allow it to be safely burnt in the turbine combustion chambers. In the Middle East (ME), the use of fossil fuels to generate energy is a very common practice. Over the years, it has been noted that there is a tendency in the ME to use gas in energy combinations, with gas replacing oil

for power generation. Furthermore, gas is needed extensively to generate energy for various industrial applications [20]. For example, in the ME, the amount of natural gas used in electricity generation has been increasing annually. In 2018 878TWh were produced by generation units working on natural gas which was an increase of 37 TWh compared to 2017 [21]. In contrast, the production from power plants that depended on oil decreased from 322 TWh in 2017 to 311 TWh in 2018 although the load demand increased for the same years [21].

Historically, the year 1927 saw the introduction of the gas industry in Iraq commercially. Even though Iraq has massive reserves of natural gas along with crude oil production and free gas considering the fact that it has large potential reserves, the production with regards to marketable natural gas does not correspond to the total yield of natural gas or the massive reserves of Iraq.

For example, Iraq still imports a portion of its gas requirements from Iran to operate electrical plants. Based on the Organization of the Petroleum Exporting Countries (OPEC) report in 2018, it was estimated that the Iraqi gas reserves were 3,729 billion Cu.m and on the basis of this, Iraq is ranked eleventh among the countries rich in natural gas. According to the Ministry of Oil (MoO), about 70% of Iraqi gas is gas associated with the extraction of oil. However, based on the MoO's report in January 2010, Iraq produced 2,875 million Cu.m of gas but burnt 1,594 million Cu. m of it, which was a substantial loss compared to other countries. Based on the above, the Ministry of Electricity (MOE) contracted several firms to construct new oil- and gas-driven energy generating units Table 3 shows the new plants and their fuel sources. Recently, following the discovery of large reserves of natural gas and official directives to use the gas as fuel for power generation, several of the newly-constructed plants are designed to work with diesel and natural gas [12].

Table 3. New stations and their fuel sources

Location	Capacity MW	Fuel
Shat Al-Arab	125 * 6	Fuel oil/Al-Basra refinery
Al-Khairat	125* 6	Fuel oil/Al-Basra refinery
Al-Anbar	125 * 4	Fuel oil/Carbala refinery
Al-Naseriya	125* 4	Fuel oil/Al-Naseriya refinery
Al-Doura/location 3	125* 6	Fuel oil/Al-Doura refinery
Al-Doura/location 2	125* 4	Fuel oil/Al-Doura refinery
Nineveh	125* 6	Fuel oil/Al-Kasak refinery
Al-Dewaneia	125* 4	Two units of gas and two unit of fuel oil
AL-Qudus	125* 2	Fuel oil/gas at future
Al-Amara	125* 2	Fuel oil/Al-Amara refinery
Wasit	125* 2	N/A
Al-Samawa	125* 4	Fuel oil/Al-Samawa refinery
Al-Mansouriya	125* 2	Gas from Al-Mansouriya field
Al-Najaf	125* 4	Two units of gas and two units of fuel oil

Table 4 shows the locations of these new power plants, which generate power using liquid diesel and natural gas. However, as these newly-constructed power plants are using fossil fuels, they continue to cause the same undesirable environmentally harmful effects on human health and air quality [12].

The participation rates of gas and steam turbine units in the Iraqi power system for the period from 2013 to 2019 based on MOE reports are shown in Table 5. It can be seen that the percentage of gas turbine units averaged 45.8 % for all types of generating units in the whole country. The variations in the percentage per year are dependent on several factors including how available is the natural gas which comes from Iran; the state of the natural gas transmission pipes or some financial issues related to buying the natural gas within the Iraqi ministries involved. With regard to the percentage of the steam turbine units in the same period, it was around at 27.4 % due to the policy of the MOE to focus on the gas turbine units.

Table 4. New locations of power generation using NG

Project	Location	Fuel used	Capacity
Al-Garaf station	TheeQar	Fuel oil/NG	125 MW
Al-Garaf steam station	TheeQar	Fuel oil/NG	300 MW
Al-Khairat steam station	Karbala	Natural gas	300 MW
The North steam station	Al-Mousel	Fuel oil/NG	300 MW
The North steam station	Al-Anbar	Crude oil/Fuel oil/ NG	300 MW
ShatAl-Arab Basra steam station	Al-Basra	Fuel oil/NG	300 MW

Table 5. Percentages of gas and steam turbine generating units for the period from 2013-2019[22]

Years	Actual generation amount MW for gas turbines	Percentage of participation in whole grid**(%)**	Actual generation amount MW for steam turbines	Percentage of participation in whole grid **(%)**
2019	5745	41	2968	21
2018	5521	42	3270	25
2017	5810	49	3518	29
2016	5293	50	3227	31
2015	3981	43.1	3002	32
2014	4229	46	2379	26
2013	3292	49.4	1853	28

4. GOVERNMENTAL PLANS TO ADDRESS THE ENERGY SITUATION IN IRAQ

Depending on the nature of the system in Iraq, the management of the power network is one of the tasks of the Iraqi MOE as it is responsible for the generation and transmission of power and for the future development plans pf the country's power network. The Iraqi MOE plans are focused on addressing the following issues:

Maintenance of old systems and recycling some of them, such as the Baiji power plant that was established in 1960[23]. However, this is trend has suffered from technical difficulties due to the need to replace many components of the system and control systems as well as the issue of economic feasibility. Dependence on the installation of gas-powered generating plants or recently-combined cycle power and diesel plants, due to the relative ease and speed of installation, but the capacity of these implemented plants remains limited to within (200 MW) [19]and also requires regular maintenance cycles at relatively short intervals. Purchasing generation capacities from Iraq's neighboring countries, for example, Iran and Turkey, via transmission lines between the two countries, or by ship, carrying generating plants in Basra seaport. However, this issue suffers from difficulties related to the transport infrastructure, as well as terrorist operations targeting this transportation line, besides the high economic cost.

Purchasing generation capacities locally by contracting some local private companies, which represents 2% of the supplied capacity [19]. Iraq's MOE signed an implementation agreement with Siemens in 2019 for a series of projects that could be worth as much as US$14 billion which would overhaul Iraq's power generation sector. Via supply the Iraqi electrical power system with 11 GW, which is equivalent to about 50% of the current production value, and this ambitious project includes the development of infrastructure through the construction of 13 sub-stations of 132 kV stations (Iraq's MOE). The ambitious project will need four full years to implement it and it will work mostly within the traditional generation plants. The expansion of the transmission lines, as the length of the 400 kV transmission lines increased from around 4,353 km in 2010 to 5,505 km in 2017. However, for the same period as above, 132 kV transmission lines decreased from 12,608 km to 11,882 km due to the military conflicts and sabotage that occurred in Iraq [19].

In relation to the above, Table 6 shows the types of generation plants in the Iraqi power system in terms of their designed capacities and the actual participation in the Iraqi network in 2019. Through schedule 6, the difference between the designed capacities and the actual capabilities of participation is noted, and for the reasons outlined above in terms of the aging of the system and the physical damage that resulted due to Iraq's political conditions. Despite the many efforts made in this country to develop this sector, it still suffers from shortcomings and significant losses in the generation networks.This leads to instability of the system's

operation and the need to rely on alternatives such as local generators in return for a financial fee, during interruptions of the main power supply. However, such supply lacks efficiency and is not comparable with the ideal supply of electricity in terms of level, voltage, and frequency value. Such a situation is a burden to the affected members of the public and he industrial sectors as well in addition to the chaos and damage to electrical appliances.

Table 6. Capacity Generating Plants and the Actual Participation Rate in the Iraqi Network for the year 2019[19]

Power Generation plant	No. of units	No. of operating units	Capacity of the largest designed unit (MW)	Total Capacity (MW)	Total Capacity of operating units (MW)	Average of production In 2018 (MW)	Average of production In 2019 (MW)	Percentages (%)
Steam Plants	31	22	610	7305	5575	3270	2968	21
Gas Plants	198	155	292	15694	13414	5810	5745	41
Hydroelectric Plants	29	23	187.5	1864	1214	208	567	4
Total	258	199	-	25334	20059	8999	9280	66
Diesel of Ministry of Oil						102	67	1
diesel of Ministry of MOE	110	66	23	2037	1487	274	687	5
Total of Diesel Unites	322	66	-	2327	1562	376	754	5
Imported energies	24	24	250			3627	4030	29
System total	604	289		27661	21621	13002	14064	100

The geographical location of Iraq provides the country with many characteristics that will help in understanding why there are opportunities for the development of the energy sector. The next section will describe these characteristics in greater detail.

5. IRAQ SITE FEATURES

Based on Iraq's geographical location and climate, the country has various advantages in terms of natural resources such as a wide range of climate. To next two sub-sections will describe these in greater detail.

5.1. Geographical location of Iraq: The total land area of Iraq is more than 430,000 km2, but the exact figure differs depending on the source, whether it includes both land and water areas. Iraq's Gulf coastline is relatively short at 58 km (see Figure 2). The country has four geographical zones [24]which are briefly described below:

5.2. Desert plateau: This zone occupies nearly 40% of the country. It is described as "a broad, stony plain with scattered stretches of sand to the west and south-west of the Euphrates River. A network of seasonal watercourses (wadis) stretches from the border to the Euphrates River."

5.3. Northeastern highlands:This zone covers almost 20% of Iraq and "stretches south from the border between Mosul and Kirkuk towards the Iraqi borders with Turkey and Iran and contains mountain ranges as high as 3,600 m. "

5.4. Uplands region:This zone covers nearly 10% of the country. Iraq is geographically located in a transitional region that lies between a desert plateau and the highlands, between the Tigris in the Euphrates and North of Samarra, which lies North of Hit. This forms a natural region which extends into Syria and Turkey.

5.5. Alluvial plains:30% of Iraq is made of alluvial planes. This region was formed because of the combined deltas of the Euphrates and Tigris Rivers. The alluvial plains in Iraq extend from North of Baghdad to the Gulf region.

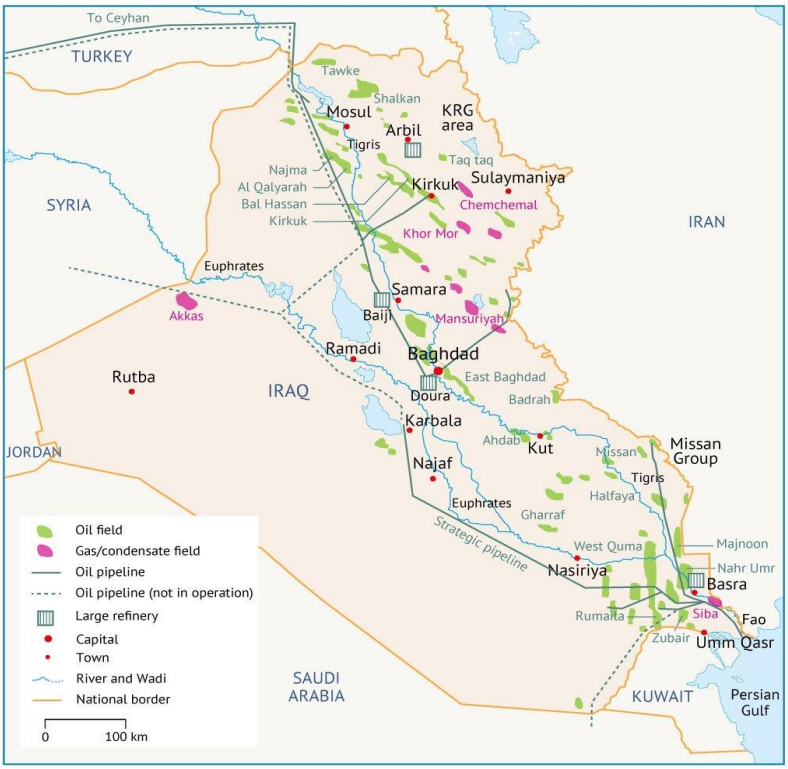

Figure 2. Map of Iraq and neighboring countries

Iraq's population grew at a rate of 2.75% in the period from 1980 to 1985 to 3.23% in the period from 1995 to 2000. The growth rate then declined to 2.72% in the years from 2000 to 2005 and is expected to reach 1.09% in the period from 2045 to 2050. On the other hand, actual population density differs significantly from five inhabitants/km2 to more than 170 inhabitants/km2 in the western desert province of Al-Anbar, and in the fertile lowlands of Babel (Babylon) respectively. Nearly three-quarters if the country's population live in urbanized hubs. A wide range of raw materials can be found in Iraq, and the majority of them are widely distributed, with many raw materials still to be fully exploited. Oil is of the greatest importance to the Iraqi economy. Iraq's estimated overall oil reserves are 115 billion barrels. Together with the undiscovered oil reserve, Iraq is recognized to have the world's second largest oil reserve after Saudi Arabia. Based on the OPEC Report, it is estimated that the country's oil reserves touch 145,019 billion barrels. At the 2018 oil production was 4,410 bbl/day, as presented in Figure 3. All of these factors give Iraq various opportunities to use many energy sources to enhance the power generation sector [25] .

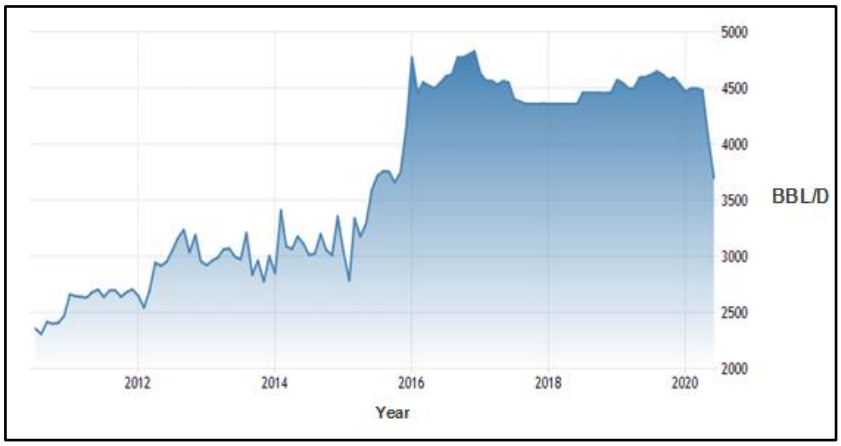

Figure 3. Production of oil

6. OVERVIEW OF IRAQ'S CLIMATE

Iraq is geographically located at Lat/Long of 33°, 44°, in the southern direction of the North District in the Central region. Iraq spans over a 437,072 km2 area and is ranked 58 in the world, based on its size [26]. Owing to the geographical location of Iraq, it is affected by the incident angles of the sunrays and experiences higher radiance levels during the long summer days (14 h) and short winter days (10 h).The climate in Iraq is significantly affected by the Mediterranean Sea, which gives rise to the climatic depression during winter, leading to temperature and rainfall variations. The Gulf is also affected by the climatic depressions arising from the west winds in winter, which are accompanied with the warm winter rains in the northern and central regions of Iraq. The climate in Iraq shows different characteristics during the 4 seasons, which have different durations. The main seasons in Iraq are winter and summer, in addition to the short seasons of spring and autumn. During the Iraqi Summer from June to August, the sun is at almost 90º to the northern hemisphere. Some areas of the country receive little rainfall in summer, due to the dominantly high-pressure orbital, and also because summer is typically low in relative humidity, while the dry Iraqi summer is also hot [27], [28].

Iraq shows a typical winter from December to January, which is characterized by 2 distinctive changes: (a) A significant temperature decrease is noted in Iraq, where the temperatures can even reach sub-zero levels during the winter nights in the north and central region of Iraq. Furthermore, there is a decrease in the monthly heat rate, as one moves towards the Northern regions of Iraq; (b) During the winter months, the winds blow across the country when depression is noted in the Mediterranean Sea. The North-western and western winds blow from a high-pressure region to the low-pressure regions. The north-western winds flow throughout the year, whereas the southwestern winds carry precipitation during the hurricanes or cause depression due to the movement of the north-western winds. The wind blows in the eastern or north-eastern direction during the winter season, which leads to a significant decrease in the temperatures [29].

Because of the climate and geographical location of the country, the country receives direct normal radiation ranging between 1,800 kWh/m2/year and 2,390 kWh/m2/year [30]. As a result, Iraq shows a lot of potential to produce electricity based on solar radiations. Table 7 has presented a comparison of the amount of solar energy that can be harvested when the solar irradiations are incident on the vertical, horizontal or optimally-inclined planes in many global cities, including a few in Iraq, based on the data presented by the Solar Electricity Handbook (2016)[31]. The data presented in Table 7 indicated that all the cities in the country showed excellent solar irradiation levels.

Table 7. Solar irradiation levels on the horizontal, vertical and the optimally-inclined planes, at optimal inclinations for many global cities which installed STPP plants, including a few Iraqi cities

Location	Country	Solar Irradiation on Horizontal Plane (WH/m^2/year)	Solar Irradiation on Vertical plane (WH/m^2/year)	Solar Irradiation on Inclined Plane (Wh/m^2/year)	Optimal Inclination
San Bemardino	USA	5294	3637.5	5875.8	56
Phoenix	USA	5280	3685.8	5895.8	57
Seville	Spain	4868.3	3443.3	5410.8	53
Badajoz	Spain	4705.8	3405	5268.3	51
New castle	Australia	4590	3154	5031	57
Abu Dhabi	UAE	5533.3	3186.6	5847.5	66
Cairo, Egypt	Egypt	5290	3227.5	5647.5	60
Mosul	Iraq	4841.6	3319.1	5319.1	54
Mosul	Iraq	5011.6	3227.5	54025	56
Al-Anbar	Iraq	5000	3136.66	5347.0	57
Karbala	Iraq	5104.16	3236.6	54925	57
An Nasiriya	Iraq	5129.16	3219.16	5505.8	59
Al-Basrah	Iraq	5035.8	3086.6	5276.66	60

From the information reviewed above, the importance of Iraq's location for many applications in the field of electric energy is evident, especially with regard to the renewable energy sources.

7. SUSTAINABLE ENERGY (SE)

Since renewable energies offer many benefits to the environment, a global trend has been set to increase dependence on such sources. By 2040, in the European Union, it is estimated that 50% of the energy

sources will be derived from renewable energy sources, while in China (the second largest global economy), 30% of energy sources would come from alternative energy sources [32].

This global trend is pushing research and industry centers and sources of financing and investment to active participation in this field, as it represents an important opportunity in the right direction. With the deficit in the energy supplied in Iraq, as well as the country's geographical location, the energy sector is an investment opportunity that will lead to the creation of a many jobs, something which would be welcomed especially with the high rate of unemployment and poverty in Iraq due of the country's mismanagement of resources. Generally, the types of renewable energy generation units vary according to the mechanism, source, and efficiency of these units. These sources are listed below as follows: Hydroelectric Power; Solar Energy; Wind Power; Biomass and biogas; Geothermal energy and Other renewable sources[33], [34].

One of the other advantages of these energies, is their independence of energy sources and being far removed from the disturbances that occur, for example, in the oil markets, as well as other political problems, and this provides reliability to these sources[35]. Globally, hydropower is the oldest and most commonly used due to the large capacities obtained from it, which could be more than 1000 GW [36] but in the current period, there is an increase in the installation of wind-powered generating plants, especially in the European Union, where the global production reached 539 GW in 2017. According to the report of the International Renewable Energy Agency (IRENA) , the same applies to solar energy in the Middle East, as well as in China and India[37]. Figure 4 shows the rate of participation of these energies globally and we note that hydropower is the most extensive, given that it is the oldest in use and generally the dependence on these sources increases annually as production increased to about 1000 GW within six years. We also note that the least capacity is from Geo Thermal energy due to the inherent difficult of its technology.

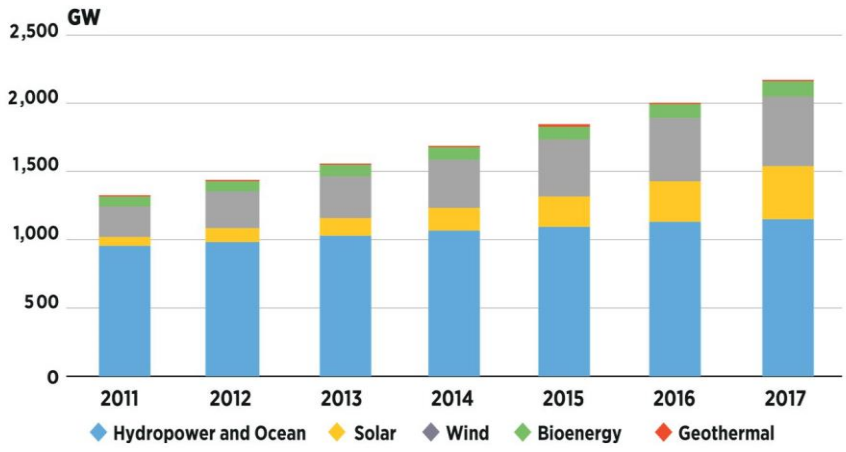

Figure 4. Total Renewable Power Generation Capacity (2011-2017)

However, given the geographical location of Iraq, which is Lat/Long: 33°, 44° and a geographical area estimated at about 437,072 Km2, the possibility of using these sources varies according to the location of installation where the efficiency varies according to the chosen location. The section that follows will review details of the renewable energy application types in Iraq.

7.1. Hydropower Energy in Iraq

Historically, Iraq is a country that is rich in water resources, where the first organized civilization known to mankind was established at a time when Iraq was known as Mesopotamia and through which flow two of the world's greatest rivers, the River Tigris and the R Euphrates River, the main artery of civilization. From this standpoint, the Iraqi government has worked to take advantage of these features in the construction of dams on the Tigris and Euphrates, such as the Mosul Dam on the Tigris and a modern dam on the Euphrates. The Iraqi government has also taken advantage of these dams (as well as the regulatory side of the water) by establishing electrical power plants. Table 8 shows the number of design capacities for all water plants in Iraq[3],where there are five main plants with a design capacity of 2109 GW on the main dams, and there are also four power plants with a design capacity of 164 MW (total schedule) on organizational dams, and these main plants were established at different times, starting around the middle of the last century[11].

Table 8. Operational hydropower dams in Iraq [3]

Type	Plant	No of Units	Installed Unit Size (MW)	Installed Storage Capacity (MW)
With Storage Reservoir	Mosul Main	4	187.5	750
	Haditha	6	110	660
	Dukan	5	80	400
	Darbandikhan	3	83	249
	Himreen	2	25	50
With Limited Storage	Mosul Regulating	4	15	60
	Samarra barrage	3	28	84
	Hindiyah barrage	4	3.75	15
	Kufa barrage	4	1.25	5

However, the actual participation rate of these units remains below that, Table 9 shows the participation rate of these units in the electrical network from (2010-2019). From the table below, we note the significant fluctuation in the participation rate of these units, and this is due to several reasons, including the dry seasons that Iraq experienced in recent years, as well as obsolescence of operating units.

Table 9. Percentage of hydropower power units participating in the network[38]

Percentage of Participation (%)	Year
10	2010
8	2011
9.5	2012
8.1	2013
3.7	2014
3.1	2015
4	2016
2	2017
2	**2018**
4	**2019**

There were ambitious plans for the Iraqi government that were laid out in advance to develop production for these water plants, as the goal in 2035 was to reach 14TWH [3]. However, the setback suffered by these units as a result of the above reasons, as well as the high cost of construction and maintenance and the urgent need of the local population for electrical energy influenced the central planning approach to establish gas-powered plants and a " combined cycle " plants due to the ease and speed of installation, and high production rates, as evidenced by the design capacity of an implemented unit in the Kirkuk gas-powered plant, which was able to achieve 292 MW.

7.2. Solar Energy in Iraq

Iraq possesses relatively longer daylight hours. The capital of Iraq, i.e., Baghdad alone receives >3,000 h of solar rays. The country received a solar intensity ranging between 416 W/m2/h (in January) and 833 W/m2 per hour (in June) [39]. Iraq received higher solar radiation levels than Spain, which received the highest amount of solar radiations in Europe [40]. With regards to the different regions, the western desert region in Iraq receives the maximal amount of solar radiations which can be used for generating electrical energy, compared to the yearly global solar irradiance average noted in the horizontal regions of 170 W/m2. These characteristics are important and must be considered before designing any solar unit in the area. The German Aerospace Center in its report stated that "the deserts in Iraq produced a mean power density of 270W/m2 to 290W/m2, attaining a peak power density of 2310 kWh/m2/year" [41], [42]. It is important to note that nearly 31% of the surface of Iraq is desert. These large areas of desert with long daylight hours suggest two things: first, the opportunities for investment in solar technology, and the second, an additional cost for the cleaning process of photovoltaic (PV) cells. Potentially, solar technology can be huge in Iraq, but currently its use is practically non-existent.Many researchers started investigating the solar energy-based avenues after Iraq was plagued by an energy crisis in 1973. Numerous studies determined the designs and equations which represented the solar radiation intensities in Baghdad. Several practical and theoretical studies were conducted during the Iraqi energy crisis, for examining if the domestic water heaters and coolers could be powered using solar energy [43]. Some theoretical models were developed for representing the solar water heaters. The results of these studies highlighted the compatibility between the theoretical and practical outcome [44], [45].

After that, the later studies moved their attention to the search for feasible approaches enhance the effectiveness of solar-powered applications to generate energy [46]. Mohamed-Rascal (2008) [47] investigated the possible utilization of solar energy to produce hydrogen. A few experimental studies were carried out for investigating the ability of Trombe walls to utilize solar energy during the winters in Iraq [48], [49]. In their study, Chaichan (2009) [50] presented the effectiveness of the solar salt gradient pools and the use of "stored energy" for warming the rooms. Data pertaining to viable solar radiation would help to better understand efficient use of solar energy. Evaluating this data in Iraq is significant in order to reap the benefits of renewable energy resources [51]. The correlation amongst temperature, humidity and duration of solar radiation was mathematically calculated by Ahmed (1988) [52]. In their study, the relationship constants were determined for three different regions in Iraq. The monthly and annual solar radiation maps from various six cities that located in the areas of the south, center and north of the Iraq, is shown in figure 5. In general, the daily/ monthly solar radiation was great, especially in the period Jun-Sep in these cities [53].

A summary is provided for the basic properties pertaining to solar radiation in Iraq with regards to the northern regions, there has been a variation in annual radiations by 300%, which lied in the range of 7 MJ/m2 (December to January) and 23 MJ/m2 (June). While in the southern regions, there was 200% variation in solar radiations, in the range of 13 MJ/m2 (December to January) and 27 MJ/ m2 (June to July). With regards to the central regions of Iraq, there was 250% variation in annual solar radiation, which is also considered to be the average annual variance between the southern and the northern regions. There was a considerable decrease in solar radiation from the northern to the southern regions, which would tend to increase during the winter periods and decreased in summer season. During the summer season (June to August), a uniform distribution with regards to solar radiation was seen in Iraq. From the eastern to western regions, there was a general decrease in solar energy to the lowest point, which could lead to inaccurate evaluation. The solar radiation was evaluated by considering the relationship that has been derived from the data, as defined by the meteorological stations in the country's urban centres and cities. These regions experienced lesser solar radiation versus the surrounding regions because of higher levels of pollution prevalent in these regions. Therefore, it can be said that the actual solar radiation levels would certainly be higher versus the measured values when we consider the pollution levels [54].

Numerous researchers performed experiments by employing PV cells in Iraq; however, these studied did not give adequate results. In general, the PV cells are mainly employed to power community street lights. However, these lights did not seem to be effective due to the dusty weather condition in Iraq. Due to this, the use of PV cells has been decreased. Despite such issues, the PV cells can be optimally employed for home rooftop systems or community water pump plants, where people do not have access to power grids [55].

In the last 10 years, the problem of electric power in Iraq has evolved into a multi-dimensional challenge but the country has somehow managed to remain as one of the leading power providers globally, in respect of fossil fuels [55]. However, following the extensive devastation of the country in 1991, power shortage has emerged Furthermore, fossil fuel reserves will eventually be depleted, most likely in the next century. In such a situation, solar energy remains the single uninterrupted resource that will at the same time reduce the carbon footprint from different fossil fuel and biofuel sources. As such, immediate consideration should be given to solar energy because of this climatic benefit, which can significantly mitigate of the impact of global warming [56]. In light of the above, necessary technologies should be developed pertaining to RE in this region. However, it appears that this will most likely be initiated by concerned individuals and Non-Governmental Organizations (NGOs), rather than official policies. The main limitation which affects the construction of a concentrated solar power (CSP) plant is the presence of a flat area. It was noted that the Dish and Fresnel systems were modular and could adapt to the irregular terrain. A flat piece of land, approx. 115 ha, was needed for constructing a 50 Me power plant (Concentrating Solar Power Projects, 2016), which offers space for placing the thermal components of a solar plant. Furthermore, this also prevents the "shadowing effect" due to the shade that is cast on sunny days.

Table 10. The recommendations made by the Parsons Brinckerhoff (PB) Researchers[61].

Region	Resource (kWh/m^2)	Area for Plant (ha)	Possible No. of CPS Plants	Installed Power (MW)
Central Iraq (Babylon, Diyala, and Baghdad)	2100-2200	318	28	1400
South Iraq (Missan, ThiQar, and Basrah)	2100-2200	203	18	900
Governorate of AL-Anbar	2200-2300	504	44	2900

This shade is generally cast between the solar collectors constructed on a mounting surface and can decrease the efficiency of the complete system. Some researchers recommended that such solar plants must be constructed in the southern and central regions of Iraq, particularly in Babylon, Baghdad, Basrah, Diyala, Missan and Thi Qar [57]–[60]. Table 10 presents the recommendations made by the PB researchers related to the number and locations of the CPS plants [61].

According to [62], "Iraq is located in a zone with 2000 kWh/m2 to 2500 kWh/m2 annual average daily energy from global solar irradiation." The normal and global solar distributions are presented in Figure 6.

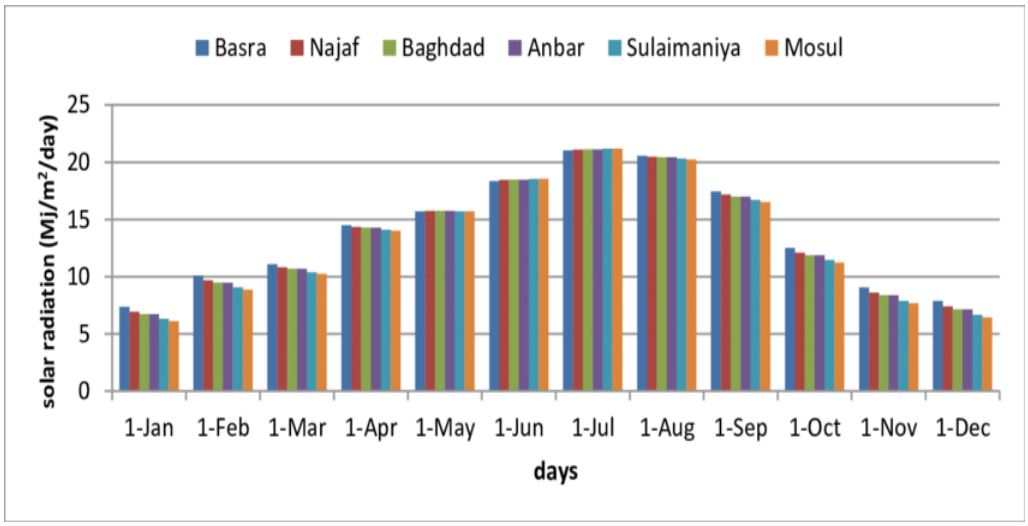

Figure 5. Average daily solar radiation for various six locations in Iraq

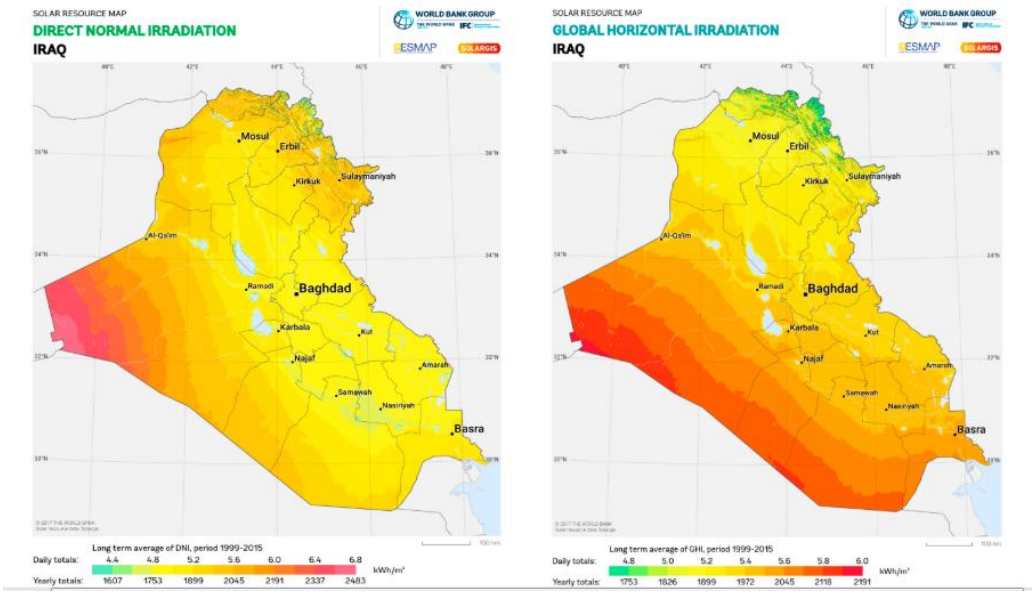

Figure 6. Iraq's direct and global solar irradiation [62].

However, if water was available on the land, it needs to be considered. Parsons Brinckerhoff (PB), which is a multinational engineering and design company investigated the power network in Iraq. In their report, they identified some probable locations where the CPS could be constructed. They considered the technical appropriateness of the terrain, the "distance-to-grid connection (<25 km), financial and the permission-related issues.

7.3. Wind Energy in Iraq

Owing to its geographical location, Iraq does not experience very high annual wind speeds [10]. Some researchers investigated the potential of using wind energy as a renewable source of energy in Iraq. In total, they selected and studied 23 different plants. According to these studies, the maximal wind speeds differed between 5-10 m/s.

It was noted that the summer winds showed a higher velocity compared to the winter winds. This was very advantageous as there was a higher demand for electricity during the summer months for ventilation and cooling purposes, compared to the winter months [54]. The wind velocities in the country have to be investigated in three different regions. Region 1 constitutes 48% of the total area in Iraq and faces wind velocities of 2-3 m/s. Region 2 constitutes 35% of the total area in the country and is affected by wind velocities ranging between 3.1 and 4.9 m/s. Region 3 comprises 8% of the total area in the country and is affected by higher wind velocities, i.e., >5 m/s. The researchers stated that the densities for the above wind territories were:

174 W/m2 in Al-Emarra, 194 W/m2 in Al-Nekhaib, 337 W/m2 in Al- Kout, 353 W/m2 in Ana, and 378 W/m2 in Al-Naseria. Based on these values, they calculated the average wind velocity of 287.2 W/m2 [55].

The British Wind Energy Report stated that a majority of the wind turbines generated wind energy when the wind velocities were between 3 and 4 m/s (8 miles/h). They also generated a maximal amount of 'rated' power when the wind velocities were ≈15 m/s (30 mph) and had to be shut down for preventing further damage when the wind velocities were ≥ 25 m/s or above (50 mph) Figure 7.

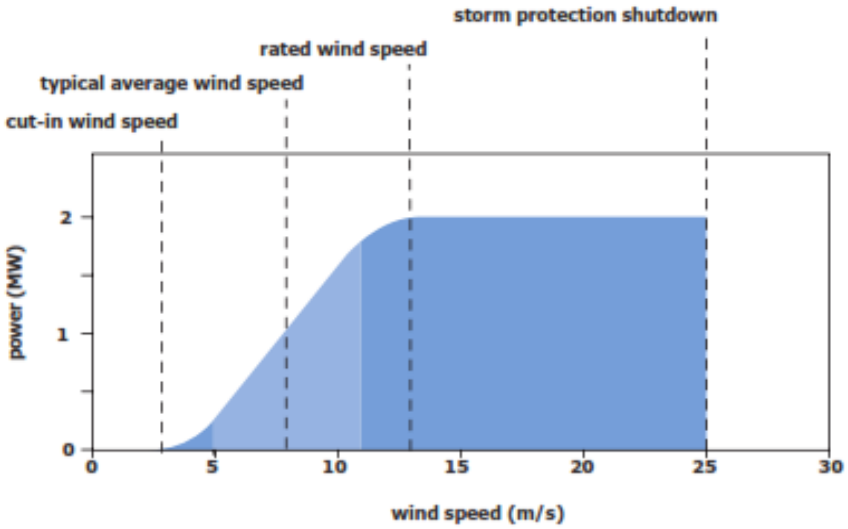

Figure 7 Typical power curve of a wind turbine[10]

An earlier study highlighted the effect of the wind speeds on the amount of wind energy produced. They noted that the amount of power generated using the winds was the function of the cubic power of the wind speeds [63]. To clarify, if the winds blew at twice the original speed, the energy generated from these winds would be 8-times the original amount. Hence, the wind turbines that were located at the sites with an average wind speed of 8 m/s generated 75-100% more electric power compared to the sites which faced an average wind speed of 6 m/s. The installation of wind turbines is not very cost-effective in Iraq in comparison to other countries since the wind speed and the turbine performance was based on the available wind speed, which should match the turbine specifications and the higher ratio of mechanism failures. A lower wind speed requires the development of a complicated design [10]. For increasing the wind speeds, the wind turbine towers should be longer. This is a major design-related challenge which requires additional costs, especially since Iraq has a lesser experience in designing and manufacturing such structures (i.e., Iraqi engineers are not experienced in this field).

7.4. Biomass Energy in Iraq

Biomass can be defined as 'solid biomass, liquid biofuels, biogas and municipal waste, and each of these terms can be described as follows. The first term refers to organic, non-fossilized material that is of biological origins; the second term pertains to bio-based liquid fuel that can be sourced from biomass transformation and is chiefly employed for transportation applications; the next term refers primarily to methane and carbon dioxide generated via anaerobic digestion of biomass as well as combustion to generate

heat and/or power; the last term refers to the waste generated by the commercial, residential and public service as well those incinerated via specific installations to generate heat and/or power)" [56], [64].

Converting sugar-cane and corn into bio-diesel has proved to be the most successful example of biomass conversion into energy. Dates and sugar-cane (besides various varieties of canes cultivated in Al-Ahwar) are also used for the production of bio-ethanol. The various plants mentioned are easily available to Iraq and in abundance. At present, Iraqi agriculture in Iraq leaves much to be desired, suffering from obsolete technology, insufficient farm credit, and the generally poor state of irrigation and the overall agricultural infrastructure [65], [66]. Such a sorry state of the agricultural sector in Iraq explains the neglect of biomass as an energy source. These researches verify the benefits of augmenting traditional Iraqi diesel and gasoline with ethanol and methanol. A drawback of Iraqi diesel is its excessive sulfur (almost 10000 ppm), whereas the disadvantage of Iraqi gasoline is its low octane number. Both these issues can be addressed by utilizing bio-ethanol or methanol [66], [67]. Although Iraq has abundant gas and biomass however this sector needs more adequate support. Furthermore, the substantial reserves of recently-discovered oil and gas has also been a reason for neglecting biomass as a potential energy source.

7.5. Geothermal energy

In other fields, geothermal energy is employed as a source of heat as well as for cooling homes by employing heat pump technology. Furthermore, agriculture applications as well as warming swimming pools could employ geothermal energy [68]. However, there is higher cost associated with the power generated via geothermal energy versus the use of other renewable technologies. Numerous countries utilise geothermal energy to generate electricity as well as other applications mentioned above.

One of the best sources of renewable energies that have been neglected throughout the world, including Iraq, is found in the crust of the earth. Some researchers have stated that 1% of this geothermal energy was equal to 500-fold of the existing capacity of fossil fuels in the world [69]. A report presented by International Renewable Energy Agency (IRENA) stated that in 2018, the global geothermal energy capacity was 13.277 MW, which increased by 539 MW from 2017. A majority of the geothermal energy production was carried out in Turkey (+219 MW) and Indonesia (+137 MW), along with other countries like the USA, Mexico and New Zealand. Additionally, Iran, which is Iraq's neighbor established the Meshkinshahr geothermal power plant with a 55 MW capacity. They further plan to increase the capacity of this plant to 200 MW [70]. However, further efforts need to be carried out in Iraq for harvesting this source of energy.

7.6. Other renewable sources

There are other types of renewable energies, which are less common than the previous types mentioned in this research. The following are the most prominent of these types:

7.6.1. Ocean (or Marine) energy

"Ocean energy systems" are defined as "all sorts of possible technologies which could lead to energy formation out of many related renewable resources such as tides, waves, currents, temperature gradients and concentration gradients" [71]. Of these mentioned resources, wave energy has attracted attention Wave energy is an effective form of energy. The major advantage of this type of energy compared to the conventional RE energy types or solar radiation was that it had a higher energy density. The energy levels for this form is dependent on the wave configuration, i.e., their length or height. Based on the estimation and after considering the open ocean waves, the wave energy was seen to be ≈ 107 MW [70]. Globally, tidal energy is estimated to be around 100 GW [72]. In 2011, South Korea developed the world's biggest ocean project. The ocean-based (i.e., tidal) energy projects were also developed by other countries like USA, Canada, France and the UK [71]. The Oman Sea near Iraq possesses sufficient wave energy levels of 2.6 kW/m. The Arabic Gulf showed lesser values (6.1 kW/m) since it was away from the open ocean [72]. Additionally, the Iraqi coastline was 58 km from the Arabic Gulf.

7.6.2. Mini-hydro power

Hydropower plants can convert water energy into electric energy. A mini hydro-electric project can be developed on a smaller scale on the canals or smaller rivers in the country. This form of energy is a clean energy source. The water that is used for generating electricity can be further used for irrigation and similar purposes [73]. A microscale hydroelectric project shows a capacity of ≈100 kW, whereas a mini-scale hydroelectric project shows a capacity ranging between 100 kW and 1 MW. These projects can generate sufficient electric energy for a house, farm ranch or even a village [74]. However, this energy source still needs to be investigated further. In the past few years, the mini hydroelectric power plants have become an important source of RE. However, they need to be constantly regulated for controlling the significant variations noted in

their input flow values (occurring in the small feeder rivers which provide water to these plants) for ensuring an uninterrupted power supply [75]. In Iraq, the main dependence is on generating electricity from huge dams instead if d Mini-Hydro power plants, and this trend can focus on establishing large projects. However, at the same time, this policy wastes the opportunity to use the Mini-Hydro power and there are needs to support the local farmers with financing and training to bring and use the mini-hydro power technique, especially with the absence of the private generators in Iraq villages.

8. CONSTRAINTS AND OBSTACLES WITH REGARDS TO THE ADOPTION OF RE SOURCES IN IRAQ

Deliberations on efforts to utilize RE resources in Iraq reveal numerous limitations and obstacles that need to be surmounted prior to the implementation of solar energy/wind utilization in energy generation in Iraq. We perceive that the significant aspects that need to be focused on are:

8.1. **Financial and economic limitations:** These pertain to the high capital cost of RE initiatives, compounded by the absence of financing support and also misled by the mistaken notion that investing in projects is financially risky even though it leads to the preservation of the environment. It is also unfortunate that a number of banks and funding sources are reluctant to provide loans for investing in novel projects in comparison with conventional energy, thus, funding RE projects fails to have the same value attraction and economic pull (cost–benefit analysis) as other more familiar investment options.

8.2. **Structural and institutional factors:** these issues affect the adoption of RE sources in Iraq. Where several authorities, collaborators, organizations, manufacturing companies, legal authorities, executives, along with other important ministries such as Energy, Electricity, Environment, Transport and Finance (for controlling the taxes and customs), researchers and other standards and specification bodies, need to work in tandem for exploiting the different renewable energy sources with the help of modern technologies for generating energy. Therefore, stipulating functions and implementing plans for each one are important, and also developing a whole unified management mechanism to coordinate multiple parties to produce RE with best possible way.

8.3. **Regional cooperation:** in this framework, there is poor regional coordination regarding RE projects. Where there are successful experiences in countries neighboring Iraq, such as the experience of the Kingdom of Saudi Arabia in the field of solar energy, but the process of transferring experience, funding, and the joint connection is not at the level of ambition Weak rules

9. IRAQI GOVERNMENT INITIATIVES AND SUPPORT

In light of the constraints mentioned, recommendations are for the specialists in electrical energy to make available some initiatives for the purpose of supporting and encouraging the use of RE sources. Below are a number of suggestions can highlight more points such as : Launch open markets and competition that encourage participation diversity, to ensure that RE options are sustained. Furthermore, ensure the efficiency of market functions, so there will be diverse resources. Additionally, transparency of energy information exchange among various parties within and outside Iraq. Ensure availability of needed funds to be locally invested in energy projects. Also, establish appropriate strategies, and also national and regional policies, that will commit companies to invest in power transmission and distribution, by buying generated power from RE resources, and by regulating and accommodating mutually-accepted proportion of RE. Town planning authorities should allocate land for the establishment of power generation plants driven by RE resources. In additional, enhancing public awareness, especially regarding the financial advantages of solar energy, the legal implications, and the environmental friendliness.

Disseminating information on the use of solar energy technology, and technical details with regard to building capacity, and promoting scientific research into RE. and implementing supportive measures, like explicit legislation to dictate price structures and offer real incentives to parties who adopt the use of RE technologies. Use of solar energy technology. Additionally, there is a necessity to grow the solar energy market by offering a favorable price for users and suppliers of RE. Also, build dedicated facilities that generate solar power and RE sources, and also reduce or abolish taxes and levies on materials and parts that are related to RE through credit loans or grants. Establish a privatized market, with individual providers having a specific proportion of power from RE sources, and establish a trading system allowing for RE "certificates" to be traded, and therefore, energy providers can meet their commitments. The initiatives and implementing of RE projects by the Iraqi Ministry of Energy needs support to attain its primary objective of enhancing RE-based power

generation by about 9.4% in 2030, which will positively impact the carbon footprint. Also, promote private sector investment by enacting specific laws to encourage investment in RE, such as "the law of feed-in tariff," and "the net metering of energy produced from different renewable resources."

10. CONCLUSION

There has been an increase in the global trend for transitioning towards a low carbon energy source. However, the picture is different in Iraq, since the carbon emission levels and energy demand have significantly increased in the past few years due to the changing lifestyles of the Iraqi people. In this study, we focus to understand the issues that face the application of RE units in Iraq, the country's electric power system is reviewed in terms of the types of generation units, the fuels used for their operation, past and present situations for these units, and future planning to upgrade this power grid. This paper shows the massive damage inflicted by this power network that has struggled to serve the power demands of the 40 million people of Iraq. Moreover, the Iraqi grid is highly dependent on fossil fuels (except for less than 10% for older units that use hydropower units). The promising opportunities for RE plants such as solar energy have also been discussed in this paper due to Iraq's geographical location, which offers the country the potential to use solar power plants effectively. In addition to that, the restrictions and obstacles in the use of clean energy units have also been reviewed, as well as ways to overcome these obstacles. The Iraqi specialists in electrical energy need to create policies for encouraging the use of clean and renewable forms of green energy to overcome the gap between the energy supply and demand. At the same time, the energy must be safe for the environment. Hence, harnessing some or all the different RE sources for fulfilling the energy requirement in Iraq would be an effective step.

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