

Viewpoint

Potential of Renewable Energy Resources with an Emphasis on Solar Power in Iraq: An Outlook

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Abstract: This study presents an outlook on the renewable energies in Iraq, and the potential for deploying concentrated solar power technologies to support power generation in Iraq. Solar energy has not been sufficiently utilized at present in Iraq. However, this energy source can play an important role in energy production in Iraq, as the global solar radiation ranging from 2000 kWh/m² to a 2500 kWh/m² annual daily average. In addition, the study presents the limited current solar energy activities in Iraq. The attempts of the Iraqi government to utilize solar energy are also presented. Two approaches for utilizing concentrated solar power have been proposed, to support existing thermal power generation, with the possibility of being implemented as standalone plants or being integrated with thermal power plants. However, the cost analysis has shown that for 50 kW concentrated solar power in Iraq, the cost is around 0.23 US cent/kWh without integration with energy storage. Additionally, notable obstacles and barriers bounding the utilization of solar energy are also discussed. Finally, this study proposes initiatives that can be adopted by the Iraqi government to support the use of renewable energy resources in general, and solar energy in particular.

Keywords: electric power in Iraq; concentrating solar power; renewable energy sources in Iraq; solar energy in Iraq; power scenario in Iraq

1. Introduction

The global demand for energy, particularly clean energy, is increasing rapidly. The protection of the environment through the control of pollution, particularly greenhouse gas emissions, has become a major concern worldwide. Although energy from fossil fuels remains available and will not disappear any time soon, the era of abundant low-cost energy will not last long. Hence, exploring alternative energy sources, particularly renewable energy, and addressing the environmental issues associated with energy sources has become necessary [1].

By 2040, power generation based on renewable energy sources is expected to account for 50% in the European Union, approximately 30% in China and Japan, and over 25% in the United States and India; by contrast, coal will account for less than 15% of the electricity supply outside Asia [2]. Power plants use conventional coal or gas to generate base-load electricity, which results in pollution and contributes to the greenhouse effect.

Concentrating solar power plants (CSPPs) uses the sun as a heat source to drive an engine and to produce heat energy. This process is associated with traditional forms of power generation based on fossil fuel combustion, which also depend on heat engines to convert thermal energy into electrical energy. The use of solar thermal power is not new. Solar energy was first generated in Germany in 1907. In the United States, the sun was initially used as a heat source for power generation after the oil crisis of 1973. The first commercial station was established in the late 1980s in California [3]. Then, a decline in fossil fuel prices caused the federal and state governments to dismantle the policy

framework that supported the advancement of concentrated solar power (CSP). In 2006, the market for renewable energy reemerged in Spain and in the United States, in response to government measures, such as feed-in tariffs (in Spain), and policies that required utilities to obtain a power percentage from renewable energy, particularly solar energy. By early 2010, the global stock of CSP plants nearly reached a capacity of 1 GW. Projects that are currently in development or that are under construction in over 12 countries (including China, India, Morocco, Spain, the United States, and South Africa) are expected to produce a total of 15 GW in 2030 [4]. In Germany, the feed-in tariff has been in force since 1 August 2004, and it was modified in 2008.

Concentrating solar power plants (CSPPs) can prevent the emission of 7,600,000 (tons/year) of CO₂ by 2020, under an assumed capacity of 4000 MW. For example, a single 50 MW parabolic trough power plant can cut annual heavy oil consumption by 30 million L, and thus, eliminate 90,000 tons of CO₂ emissions [5]. The increase in carbon fossil fuel prices after the global economic crisis in 2008 has escalated the need for sustainable energy, which is not subjected to price and supply fluctuations under political influences. Solar energy is considered to be an option for providing a low-carbon renewable source, and it is expected to become a competitive source of bulk power for peak and medium-peak loads by 2020 [6]. Although solar power stations, which use solar energy as an input of the Rankine cycle, present several advantages, their efficiency and construction costs may not be attractive options for energy investors.

However, funding for the development and deployment of solar thermal power generation decelerated over the period when the price of natural gas (NG) declined in most parts of the developed world. Fluctuating gas prices significantly affect the focus on solar energy, with attention and investments in solar thermal power technology increasing over the past 20 years. With adequate investments, solar thermal electricity generation can become a major source of low-cost electricity generation. Existing major projects indicate a considerable possibility for the use of solar thermal power technologies in electricity generation, along with wind, hydropower, and optical technologies.

Over the past two decades, the development of renewable energy sources worldwide has grown significantly in response to evidence that links climate change to the burning of fossil fuels. As the price of photovoltaic (PV) cells continuously decreases, the solar energy-intensive CSP industry has strived to achieve significant reductions in costs, to compete with PV energy. In addition, when thermal energy storage (TES) is integrated into CSP, a perfect method for solar-to-electricity generation, which can operate 24 h a day and seven days a week, may be derived. Consequently, CSP integrated with TES is becoming an attractive technology for producing electricity [7].

The paradigm of economic development will be more and more transformed in accordance with the base principles of the circular economy, reduce–reuse–recycle waste-free fuels. In this context, the transition to renewable energy sources is one of the major strategic routes. Hence, in this paper, the potential of utilizing renewable energy resources, in general and for solar energy, particularly in Iraq, is analyzed, discussed, and reported. The potential of solar energy sources is updated, and available solar energy options in the industrial and electrical sectors are reviewed. Solar radiation data and weather parameter values provided by several references have been composed, grouped, and presented, to support future prospects for solar energy adoption in Iraq. This study also aims to promote public awareness and motivation for the Iraqi government to dedicate additional efforts and funds into utilizing renewable energies.

2. Principles of Concentrating Solar Power Plants

The working principle of CSPPs is to initially convert solar radiation into thermal energy through a series of conversion processes, which ends with the generation of electrical output. The produced thermal energy may be converted using air, water, or oil as the working fluids. In solar chimney and solar vortex engine power plants, the working fluid used is air [8]. In concentrated solar power plants, the working fluid used is water (for direct systems) or oil (for indirect systems). The conversion of solar energy to thermal energy, and then to mechanical energy in the case of air, water, or oil,

is typically achieved by using the Rankine cycle principles. Solar power generation plants can be based on four types of receivers: linear (parabolic troughs and Fresnel collectors) and focus point (solar towers and parabolic dish systems [9,10]. Several studies worldwide have shown that CSP plants are highly economical for generating solar electricity. These plants utilize concentrated solar radiation to achieve the grades necessary for processing thermal power plant dynamics or high heat. However, the applications of these plants are limited to land areas with high direct solar radiation [11]. Radiation from the sun can be converted into thermal and electrical energies. Solar thermal energy conversion can vary from low temperatures ($T < 100\text{ }^{\circ}\text{C}$) to medium temperatures ($100\text{ }^{\circ}\text{C} < T < 400\text{ }^{\circ}\text{C}$), to high temperatures ($400\text{ }^{\circ}\text{C} < T < 4000\text{ }^{\circ}\text{C}$), depending on the working medium temperature. Low-temperature solar energy conversion uses one flat collector with water and air. Medium-temperature conversion uses vacuum tube collectors, and collectors with concentrates. High-temperature conversion uses solar plants and CSP furnaces [12,13]. CSP stations use thermal energy from a heat storage tank, or gas as an energy source during the night, and on cloudy days [14,15].

3. Comparison among CSP Technologies

Solar energy technology can provide approximately 7% of the projected total electricity needs of the world by 2030, and 25% by 2050 [4]. Numerous CSP plants have been constructed, 68 of which are currently operating and producing 4569.55 MWe. Moreover, 28 other CSP plants are being built, and they are projected to produce 2313.5 MWe. An additional 41 stations are planned to be built in the future, and expected to produce 6831.08 MWe. Table 1 lists the data about different types of CSP plants worldwide that have been built, are being constructed, and that are being planned to be built [16]. Parabolic trough technology is the most mature CSPPs design, and solar tower technology ranks second (Figure 1).

Table 1. Types of concentrating solar power plants (CSPPs) in the world [17,18].

CSPPs	Active	Capacity (MWe)	Under Construction	Capacity (MWe)	Planned for Future	Capacity (MWe)
Parabolic troughs	49	3933	14	1130.1	24	2759
Solar towers	12	472.4	9	1119.9	15	4062
Fresnel reflectors	6	171.6	3	61	1	10
Parabolic dishes	1	1.5	2	2.5	1	0.08
Total	68	4569.56	28	2313.5	41	6831.1

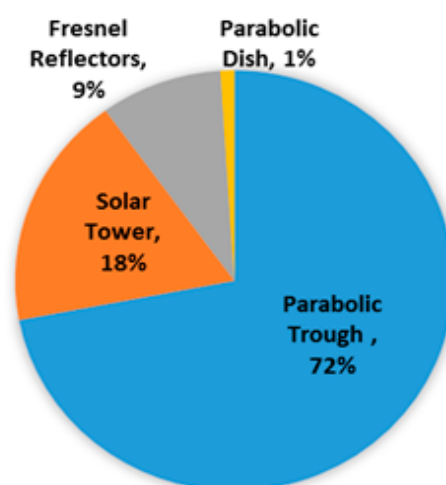


Figure 1. Operational CSPPs in the world by technology.

The CSP market is expected to increase significantly [19]. Several characteristics and prices of active CSPPs worldwide, based on the literature, are provided in Table 2 [15,20–22]. The land area necessary for constructing CSP plants depends on the concentrator type. A large area is required to install a solar tower power plant. For a parabolic trough power plant without heat storage, a land area of approximately 25 m²/kW is necessary. For a solar tower power plant without heat storage, a land area of approximately 45 m²/kW is required [3].

Table 2. Characteristics and prices of active CSPPs [15,20–22].

Type of CSPP	Solar Power Tower	Parabolic Trough	Fresnel Reflectors	Solar Dish System
Plant capacity (MW)	10–150	10–200	10–200	0.01–1.5
Max efficiency (%)	22	24	20	30
Specific power (W/m ²)	300	300	300	200
Demonstrated annual solar efficiency (%)	8–10	10–15	9–11	16–18
Land use (m ² /MW ha)	8–12	6–8	4–6	8–12
Basic plant cost (\$/W)	3.62	3.22	3.0	2.65
Capital cost (\$/W)	2.4–3.62	2.9–3.22	2.8–3.0	2.65–2.9

4. Potential of Solar Energy in Iraq

Iraq is known to have lengthy periods of daylight. On an annual basis, Iraq collects over 3000 h of solar radiance in Baghdad. The hourly solar intensity varied between 416 W/m² in January, to 833 W/m² in June [23]. In fact, Iraq outperforms Spain for the observed levels of sunshine [24]. The potential of solar technologies is considerably large, although its utilization is nearly nonexistent. Compared with other regions, the desert in western Iraq has the highest solar irradiance for electric power generation, compared to the annual global average horizontal surface irradiance of 170 W/m². The German Aerospace Center found that the deserts in Iraq produce a mean power density of 270 W/m² to 290 W/m², achieving a peak power density of 2310 kWh/m²/year [25,26]. Approximately 31% of the surface of Iraq is composed of deserts. However, Iraq has the advantage of remaining one of the top current energy resources suppliers in the world, in terms of fossil fuels [27]. For this, the Iraqi authorities are not keen in utilizing solar energy. Thus, the importance of renewable energy is not being recognized by the government and the people of Iraq. Therefore, the development of technologies that pertain to renewable energy in this region are necessary, and will only be achieved through the initiatives of concerned individuals and non-governmental organizations, instead of official policies. During the last decade, the energy issue has developed into a multidimensional question. Although Iraq has abundant fossil fuel sources, energy shortage has begun after the full-scale destruction of the country in 1991. Moreover, fossil fuel sources are limited, and they are expected to be used up in the coming hundred years. Amidst this scenario, solar energy is the only uninterrupted resource that will also help to reduce CO₂ emissions from various fossil fuel and biofuel sources. Solar energy should be immediately considered, due to this climatic benefit, which can help to mitigate the effects of global warming [28].

5. Overview of Iraq's Climate

Iraq is located between 29 and 37 north latitudes, spanning an area of 437,072 km². It is the 58th largest country in the world, and it is located within the southern part of the northern district of the central region [29]. However, this site is affected by the incidence angle of the rays of the sun on Earth, as well as by the amount of radiance and the number of daylight hours, which lengthen on warm summer days (approximately 14 h) and shorten on cold winter days (approximately 10 h). The Mediterranean Sea is the most influential body of water near Iraq, where climatic weather depressions occur over half a year during winter, causing rainfall and changes in temperature. The gulf is influenced by weather depressions caused by the west wind in the winter passage; these depressions

bring warm moist winds and rains that affect the central, and even the northern regions of Iraq. The climatic characteristics of Iraq vary according to the four seasons, which are unequal in terms of length. The two main seasons are summer and winter, whereas the other two shorter seasons are spring and autumn. During summer from June to August, the sun is nearly vertical or perpendicular to the northern half of the globe. Rainfall is also scarce in certain parts of Iraq during summer, because of the dominant high-pressure orbital, given that this season is characterized by a low relative humidity, and the dry summer season in Iraq is hot [30,31].

The climatic properties during winter are concentrated in the months of December to February, and they can be divided into two parts. (a) The temperature drops during winter in all parts of Iraq; it may drop to below zero degrees during some winter nights in many areas in central and northern Iraq. In addition, decreasing degrees of monthly heat rates move northwards. (b) During winter, winds pass through Iraq during flight depressions in the Mediterranean Sea, and western and northwestern winds blow from high-pressure areas toward low-pressure areas. Moreover, northwesterly winds prevail throughout the year, whereas southeastern winds cause rainfalls during hurricanes, or depressions after the passage of northwestern winds, and winds blow east or northeast during some winter days when the temperature significantly drops [32]. Iraq has a solaririty ranging from 1800 kWh/m²/year to 2390 kWh/m²/year of direct normal radiation [33], which places the country in a highly promising status, and at the forefront of countries that produce electricity using solar energy. Table 3 presents a comparison of solar irradiation on horizontal, vertical, and optimally inclined planes of some cities worldwide where CSP plants are installed, including several cities in Iraq, as reported by the Solar Electricity Handbook (2016) [34].

Table 3. Solar irradiation on horizontal, vertical, and optimally inclined planes, and at optimal inclination for some cities where STPP plants have been installed, and some proposed cities in Iraq (data obtained using the software provided by Ref [34]).

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 Bernardino	USA	5294	3637.5	5875.8	56
Phoenix	USA	5280	3685.8	5895.8	57
Seville	Spain	4868.3	3.443.3	5410.8	53
Badajoz	Spain	4705.8	3405	5268.3	51
Newcastle	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		5011.6	3227.5	5402.5	56
Al-Anbar		5000	3136.66	5347.0	57
Karbala		5104.16	3236.6	5492.5	57
An Nasiriya		5129.16	3219.16	5505.8	59
Al Basrah		5035.8	3086.6	5276.66	60

From the data presented in Table 3, all of the given cities in Iraq evidently have excellent solar irradiation. Iraq is located in a zone with 2000 kWh/m² to 2500 kWh/m² annual average daily energy from global solar irradiation. The global and normal solar distributions are given in Figure 2 [35].

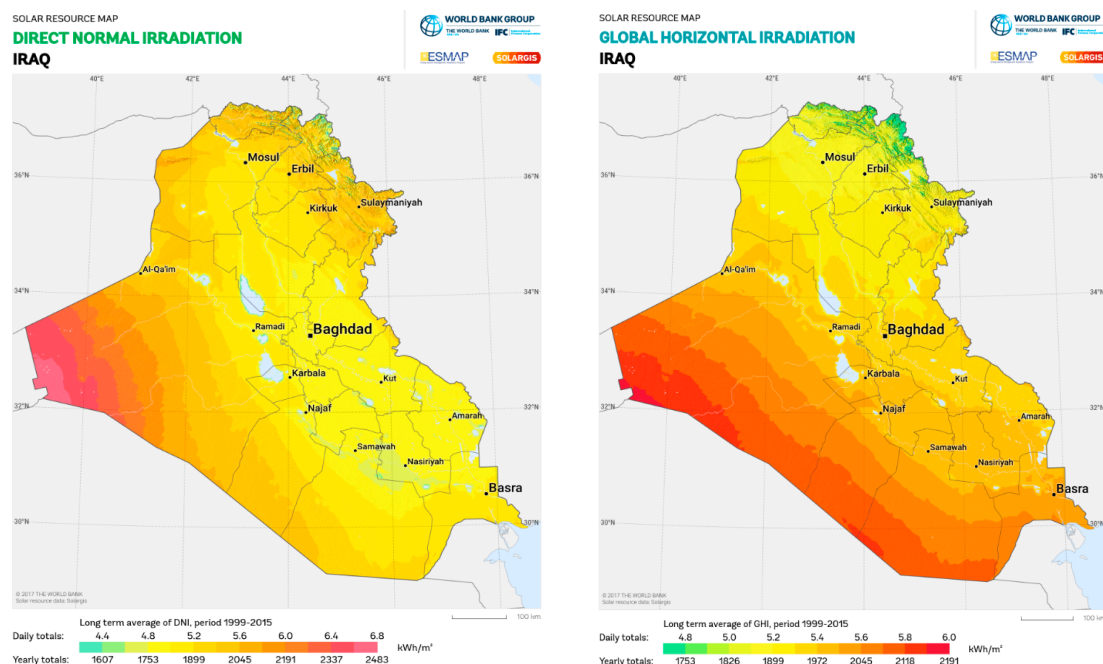


Figure 2. Iraq direct and global solar irradiation [35].

6. Factors for Deploying CSP Technology in Iraq

As noted by numerous researchers [15,36] the deployment of CSP in a country requires four important factors, namely,

- High direct normal irradiation,
- Nearby water sources,
- Geographic conditions (land area requirement), and
- Available transmission.

These four elements are essential, which makes finding suitable locations for CSP difficult. A good solar resource level is fundamental for deploying CSP plants. The hourly solar intensity in Iraq reaches 833 W/m^2 in June [23]. The water supply for energy generation and irrigation in Iraq is obtained from the Tigris and Euphrates Rivers. All of the rivers flowing through the north of Iraq are tributaries of Tigris. Both the Tigris and Euphrates originate from Turkey, with the Euphrates also passing through Syria. Water availability is certainly a limiting factor in Iraq, but not as much as it is frequently believed to be. For example, the amount of water used in a CSP plant is comparable with that used in the agricultural sector for the same land area. Table 4 presents the water requirements for CSP technologies.

Table 4. Water requirements for CSP technologies [37,38].

Technology	Water Requirement (L/MWh)	Remark
Parabolic trough	3000–3500	Wet cooling
Power tower	2240–2800	Wet cooling
Fresnel reflectors	2900–3500	Wet cooling

A CSP plant requires flat land, which may also be a limitation. The dish and Fresnel systems are more modular and easier to adapt to an irregular terrain. Parabolic troughs and solar towers are more difficult to adapt to such terrain. An approximate land surface of 115 ha is required for each 50 MWe plant (Concentrating Solar Power Projects, 2016). This area per 50 MWe is sufficiently large enough to prevent the shadowing effect caused by shade cast between solar collectors on a mounting area during the full sunny hours, which can reduce the efficiency of the system; it can also provide the space

required for the conventional thermal components of a plant [39]. Such plants can be established in the central and southern parts of Iraq, such as Babylon, Diyala, Baghdad, Missan, Thi-Qar, and Basrah. However, the availability of water presents a challenge that should be considered. The multinational engineering and design firm Parsons Brinckerhoff (PB) reviewed the electrical network and other plans of Iraq, and identified potential areas for CPS development. They considered the distance-to-grid connection (<25 km), the technical adequacy of the terrain, and financial and permission difficulties. PB proposed the establishment of a potential number of CSP plants, as indicated in Table 5 [40].

Table 5. CSP plant potential in Iraq [40].

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

Solar resources exhibit inherent intermittence; in the long term, however, solar energy is reliable and can be predicted to a manageable level. To extend the operating hours of the CPS technology, and to secure a reliable peak load supply, support can be provided by TES systems, or by hybrid operation with a fossil fuel system. TES systems can extend the operation time by up to 100% solar share, although an economical trade-off has to be realized. A typical value is 7.5 h of thermal storage.

To ensure a high level of CSP performance, periodic cleaning of the solar field mirrors is necessary. Iraq is a dusty area, and thus, frequent cleaning of glass surfaces with water, steam cleaners, or reverse vacuum cleaner systems is required. The frequency of these operations will depend on the plant location (i.e., proximity to desert areas, wind regimes, and rainfalls). Parabolic dishes can operate independently of electricity networks in remote sunny locations; hence, these networks are suitable for supplying power to people living in isolated and remote villages in the national grid.

7. Overview of Energy Profile Resources in Iraq

Various raw materials are available in Iraq, and they distributed over different geographical areas in the country. Most of these raw materials have not been used previously. Oil is a significant raw material for the economy of Iraq. The approved oil reserves in this country total approximately 115 billion barrels, whereas undiscovered oil reserves are relatively fixed. Thus, Iraq is the second largest oil reserve country in the world, after the Kingdom of Saudi Arabia. The aforementioned evaluations show that oil reserves in Iraq can reach 300 billion barrels [23]. Since oil was discovered in 1920, a considerable fraction of the produced oil was exported. Until the 1950s and late 1960s, a small percentage of oil was allotted for local use in electricity generation and transport. During the 1960s and 1970s, an industrial movement started in the brick and cement manufacturing sector [27]. “NG in Iraq has a fixed reserve of approximately 1.3 trillion m³, representing 8.1% of the global fixed NG reserve.” On the basis of this NG reserve estimation, Iraq ranks 10th among the NG-rich countries in the world. Many other raw materials, which do not have considerable significance and shares in the Iraqi economy, are also available; these materials include white clay, sulfur, and phosphate [23].

7.1. The Electrical Power Scenario in Iraq

Iraq is experiencing a serious lack of electrical energy, because of its increasing energy needs (Figure 3).

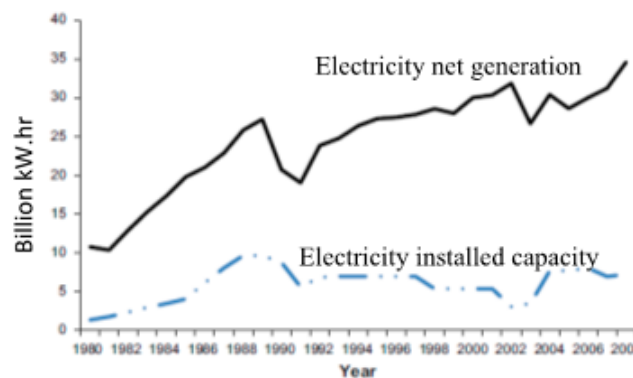


Figure 3. Projection of the peak demand in Iraq until 2008 [23].

At present, Iraq needs additional power, due to its increasing population and demands. The population of Iraq increased from 14 million in 1980 to 32 million in 2010, and it is predicted to rise to approximately 64 million in 2050 [41]. The Iraqi population growth rate has increased from 2.75% in 1980–1985 to 3.23% in 1995–2000. Furthermore, the growth rate has decreased to 2.72% in 2000–2005, and is anticipated to reach 1.09% in 2045–2050 [42]. Thus, an increased amount of power is required to support economic development, and to overcome daily power shortfalls. The Ministry of Energy reported that the highest requirement in 2008 was 12,000 MW of power, but barely 6000 MW was provided. These deficits will probably increase to 21,000 MW by 2020. The base case forecast is presented in Table 6. The prediction was based on looking at the economic prospects for Iraq, and it came to the conclusion that there is likely to be an extended period of economic growth of around 7% per annum in real GDP. The Base Case load forecast was then derived, using a bottom-up approach based on sectorial GDP growth, and income and price elasticities, to relate the electricity demand growth by sector to GDP growth. These rates are similar to those that are specified by the International Monetary Fund in their 2013 forecast. They have been developed through discussions with the Ministry of Electricity (MoE) [40]. At present, far away from hydropower, renewable energy sources do not contribute for any proportion of the generated power [43].

Table 6. Base case demand forecast in Iraq (MW) [40].

Year	Domestic	Commercial	Industrial	Governmental	Agricultural	Total
2009	6162	1333	1889	1802	63	11,248
2010	6618	1440	2027	1933	64	12,083
2011	7068	1549	2167	2067	66	12,918
2012	7542	1663	2312	2205	69	13,791
2013	8054	1776	2470	2355	74	14,729
2014	8562	1909	2649	2401	80	15,600
2015	9101	2061	2828	2447	86	16,524
2016	9456	2177	3009	2494	93	17,229
2017	9825	2299	3190	2542	100	17,956
2018	10208	2418	3373	2591	108	18,698
2019	10606	2537	3555	2641	115	19,454
2020	11020	2654	3749	2692	123	20,237
2021	11450	2768	3956	2743	131	21,047
2022	11896	2878	4177	2796	138	21,886
2023	12467	2985	4453	2858	146	22,908
2024	13043	3086	4741	2919	153	23,942
2025	13727	3210	5040	2980	160	25,117
2026	14628	3386	5345	3040	167	26,566
2027	15537	3573	5647	3097	174	28,028
2028	16460	3769	5951	3154	180	29,514
2029	17393	3976	6253	3208	187	31,018
2030	18332	4195	6553	3261	194	32,535

The lack of reliable electricity supply is one of the hindrances towards the development of Iraq. Although power stations are producing more electricity than before, the electricity that they provide remains insufficient to satisfy requirements. Power cuts occur daily, and the use of support diesel generators is prevalent. The re-construction of the recent electricity system, with adequate fuel resources and non-interrupted power supply, will provide strong support for the government and for private industrial developments. To fulfill the demands of power generation, Iraq requires 70% additional net power generation capacity, with the exemption of hydropower [44].

7.2. Energy Production versus Energy Consumption in Iraq

Net electricity generation (conventional thermal electricity and hydroelectric power) has expanded from 12.86 billion kWh in 1980 to 34.6 billion kWh in 2008; by contrast, net electricity consumption (electricity losses, electricity export, electricity imports, and net generation) has expanded from 10.167 billion kWh to 33.5 billion kWh. The installed electric capacity has expanded from 1.3 GWe in 1980 to 7.2 GWe in 2008 (Figure 3). Hydroelectric power is approximately 13% of the total installed power for electricity generation in Iraq. Fossil fuel power stations include steam technology, gas stations, and diesel stations [40]. The consumption and production power in Iraq is shown in Table 7.

Table 7. Consumption and production of energy resources in Iraq [45].

Primary Energy	2011	2012	2013	2014
Consumption of Power in Iraq (toe) *				
Consumption of petroleum products	1,410,387	1,582,761	2,086,323	2,335,098
Natural gas consumption	1,737,467	1,915,174	2,423,362	3,111,405
Production of Electric Power in Iraq (GWh)				
Production of electrical energy from steam stations	15,151.6	13,258.4	16,234.2	20,838.5
Production of electrical energy from gas stations	20,941.0	22,892.0	28,838.0	37,049.5
Production of electrical energy from the diesel stations	1307.4	5171.7	8593.1	6949.1
Production of electrical energy from hydroelectric power plants	3396.7	4392.2	4756.8	2930.8
Energy bought	7233.1	10,170.2	12,201.6	12,250.6

Note: *: tonnes of oil equivalent.

Although a major increment in grid-based electricity facility (i.e., the peak net daily production is 70% higher in 2011 than in 2006) has been observed in recent years, it remains insufficient for fulfilling the current requirements. The obtainable peak net capacity in 2011 was approximately 8 GW, whereas the approximate net capacity necessary to provide for the peak demand was 15 GW; consequently, approximately 7 GW more power (an increase of roughly 70%) is still required.

In an attempt to fill in the deficiencies in electricity supply, approximately 90% of households in Iraq enhance the public network by means of private generators, using both private household generators and shared generators operating at the neighborhood level [46]. The supplied power obtained from these resources is difficult to compute; however, a prediction can be made that in 2011, shared generators have accounted for 3 TWh, in addition to the 37 TWh of consumed energy obtained from the grid. A 2009 survey showed that approximately 900 MW of power from private generators could be obtained from central Baghdad alone [40]. At present, private generators play a vital role in decreasing losses in electricity supply (i.e., by reducing the incidents of blackouts) in Iraq, as well as exhibiting advantages in terms of flexibility and the existing electricity approach in rural regions. The government is providing subsidized fuel for private generators; nevertheless, the electricity prices that they are offering to the consumers are noticeably higher than those of grid electricity. Residential customers are paying 10 to 15 times more for electricity provided for private generation, compared with that from grid electricity. Moreover, diesel generators contribute to local air pollution [47]. In addition, with the use of non-grid generation, the average accessibility of electricity for end users (from all sources) was restricted to approximately 11 h to 19 h per day in 2011, although this was changing throughout the country.

The seasonal demand for electricity is another challenge in Iraq, because it reaches the highest peak during summer, due to an extremely high temperature in many counties. Throughout the summer, peak hourly electricity requirements can be expected to attain levels that are approximately 50% higher than the average demand level, which increases the gap between demand-based and grid-based electricity supplies (operating at capacity) [48].

7.3. Electrical Power Supply Scenarios and Outlook in Iraq

The domestic energy consumption of fossil fuels is dominant in Iraq. Across time, a common trend observed in the Middle East was the use of gas in energy mixes, where gas replaces oil in generating electricity most of the time, and gas is required on a larger scale for industrial applications of energy [49]. In 2010, oil demand for primary energy fell below 50% in the Middle East (except in Iraq). Although Iraq has planned to raise the production and use of gas, 80% of the primary energy demand remains as oil [27].

In the central scenario, developed with the help of the Ministry of Planning and Development Cooperation in Iraq, the annual GDP will increase from approximately 50 TWh in 2010, to over than 200 TWh in 2020, for the generation of electricity in Iraq. Such an increment in electricity production is similar to that expected in the European Union, for the same interval [49]. Current electricity generation in Iraq depends on liquid fuels, with heavy fuel oil, crude oil, and gas oil, comprising 57% of electricity generation in 2010, whereas the proportion of NG is 33%. Enhancements in electricity production, in the near term, heavily depends on the production of power plants from feeding fuels. The total generation of crude oil and refined products increased from over three-fold to 100-fold. In 2015, the electricity production was approximately 70% of the planned production for that year. Such an expansion in the use of liquid fuel indicates a lower share of NG in energy mixes, generating electricity of less than 25% of planned production. After 2015, however, this trend was cancelled, as the amount of available NG increased. The availability of fuel gas with low price indicates its dominance as a fuel baseload that can carry the middle-peak load by 2020, with only the oil-generating capacity being used to satisfy demands during peak periods. The use of liquid fuel to generate electricity reached its peak in 2015, and then it declined. The share of gas will increase to approximately 60% of the mix in 2020, and to nearly 85% in 2025, and this share will be maintained throughout the period. When this increment is followed, gas generation will increase in overall efficiency, and its share is expected to grow from 30% in 2010, to 42% in 2035, due to the large extent of the introduction of gas turbines for operating combined heat plant technologies.

The MoE has made an agreement with various companies to build more power-generating stations. The agreements aim to maintain the dependence of Iraq on oil and NG, in power-generating stations. Table 8 represents the newly contracted stations, and the fuel used (with its sources) [23,48]. As such, the modernization and expansion of Iraq's refinery capacities will bring a significant improvement to the product slate. Also, this will increase the share of gasoline production relative to heavy fuel oils. If this modernization and expansion of Iraq refineries is considered in the plans of energy in Iraq, then this will reduce the country's reliance on imports of gasoline and diesel, but it does not allow for significant exports of oil products [50].

With the current development of NG trends, and extraction procedures for the use of NG as a fuel for power generation, several recent stations have implemented a modification for operation based on diesel fuel and NG fuel. Table 9 presents information on new power stations that operate using both liquid fossil fuels and NG.

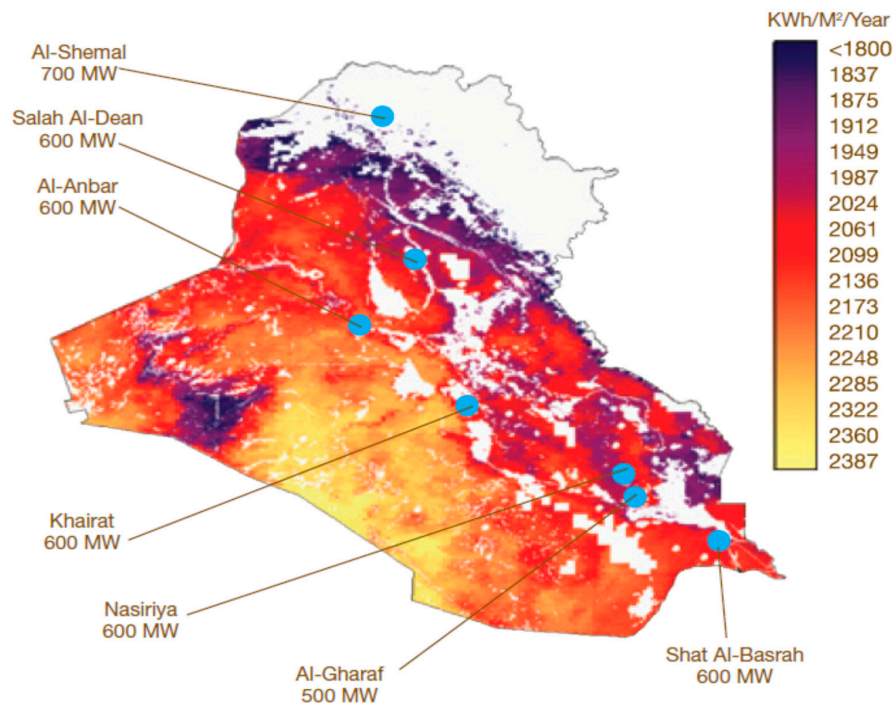
The MoE plans to establish seven new thermal power plants, located as shown in Figure 4. The figure, also indicates the magnitude of solar irradiance in Iraq.

Table 8. Thermal power plants in Iraq that are under construction, with identified capacities and fuel types [23,48].

No	Location	Fuel/Source of Supply	No of Units	Capacity MW/Unit
1	Shat Al Arab	Fuel oil/Al-Basra Refinery	6	125
2	Al-Khairat	Fuel oil/Al-Basra Refinery	6	125
3	Al-Anbar	Fuel oil/Carbala Refinery	4	125
4	Al-Naseriya	Fuel oil/Al-Naseriya Refinery	4	125
5	Al-Doura/ Location 3	Fuel oil/Al-Doura Refinery	6	125
6	Al-Doura/ Location 2	Fuel oil/Al-Doura Refinery	4	125
7	Nineveh	Fuel oil/Al-Kasak Refinery	6	125
8	Al-Dewaneia	Two units of gas and two unit of oil	4	125
9	AL-Qudus	Fuel oil/Gas at future	2	125
10	Al-Amara	Fuel oil/Al- Amara Refinery	2	125
11	Wasit	NA	2	125
12	Al-Samawa	Fuel oil/ Al-Samawa Refinery	4	125
13	Al-Mansouriya	Gas/ Al-Mansoriya field	2	125
14	Al-Najaf	Two units of gas and two units of fuel oil	4	125

Table 9. New power generation stations that use natural gas (NG) [27,48].

No.	Project	Location	Fuel Used	Capacity
1	Al-Garaf station	Thee-Qar	Fuel oil/NG	125 MW
2	Al-Garaf steam station	Thee-Qar	Natural gas	300 MW
3	Al-Khairat steam station	Karbala	Fuel oil/NG	300 MW
4	The North steam station	Al-Mousel	Fuel oil/NG	300 MW
5	The North steam station	Al-Anbar	Crude oil/Fuel oil/NG	300 MW
6	Shat Al-Arab steam station	Al-Basra	Fuel oil/NG	300 MW

**Figure 4.** Locations of suggested fossil fuel power plants according to the Ministry of Electricity, with a total power capacity of 3500 MW [33].

8. A Scenario of Solar Energy in Iraq

One of the most important concerns for the Iraqi electricity sector is with regard to satisfying electricity demands with a constant and persistent power supply. Iraq has excellent solar resources. Although the finest solar irradiance in the Middle East is found in the south, such as in Saudi Arabia and Yemen, the standard solar irradiance in Iraq is the same as that in North Africa. Iraq has a research history of using solar power (which has been reduced considerably over decades of wars and sanctions). At present, solar research activities are supported by the MoE and the Ministry of Science and Technology. The MoE has many off-grid solar research stations, with a few generating tens of megawatts of power. Regardless of the power of the resource, grid-connected solar electricity generation via PV or CSP remains a highly priced alternative, in contrast to fossil fuels [51]. Iraq exhibits excellent solar energy, ranging from 1800 kWh/m²/year to 2390 kWh/m²/year of direct normal radiation [33], which brings Iraq to the forefront of countries that can produce electricity by using solar energy. Similar to other countries, the significance of renewable energy resources, e.g., solar energy, has developed in Iraq [42]. Iraq is forecast to become one of the richest countries in renewable energy resources.

8.1. Current Solar Energy Activities in Iraq

The renewable energy policy in Iraq, and the possibility of using such energy have been discussed at the National Conference of Renewable Energies and their Applications, which was held in the Ministry of Higher Education and Scientific Research in 2013. The conference focused on the utilization of energy and renewable energy sources in Iraq. Solar energy uses in Iraq and the economic feasibility of its utilization were presented and discussed during the conference [52]. However, the use of solar energy in Iraq remains limited to a minimal level. A directive initiated by the Ministry of Industry of Iraq mandated the use of solar energy, including its applications, such as domestic water heating, street lighting systems in Baghdad, and drip irrigation in agriculture. The production of solar flat collectors for water heating, assembled from foreign manufactured items was attempted. Some companies also initiated the manufacturing of solar cells. Several streets in Iraq are currently lit using solar cells. Extremely rare cases of solar cells being used in residential units were identified. To date, no private company has invested in renewable energy in Iraq. Nearly all activities are planned under government sources.

8.2. The Proposed Concentrating Solar Power Plants in Iraq

The MoE in Iraq mandates that a national strategy for integrated power in Iraq should be devised, and the electricity sector is one of the main pillars for this task. Electricity plays a role in the development of society and industry; however, Iraq is currently suffering from a serious lack of electric power supplies.

The strategy of the electricity sector in key aspects in the field of renewable energy sources, as identified by the MoE, is focused on more efficient uses of its potential in the fields of energy production, the reduction of greenhouse gas emissions, reductions in fuel use, and the development of the local industry and new job openings. The goal of Iraq is to increase the participation rate of electric power generated from renewable energy sources by 9.4% of the total national consumption by 2030. The achievement of the goal set by the increase in electrical power generated by renewable energy sources is approximately 2000 MW in 2030. The short-term use of solar and wind energy systems provides electricity that satisfies demands in remote areas in the national grid. To date, Iraq has not yet installed any CSP station [52]. Solar energy can be utilized in Iraq by using two approaches, first, by integration with thermal power plants, and second, as stand-alone solar power plants.

8.2.1. An Integrated Solar–Thermal Plant

The proposed plants can be redesigned to operate in connection with parabolic troughs or solar power towers, in the manner of a solar–thermal combined cycle system. The Ain Beni Mathar Thermo–Solar Combined Cycle Power Plant in Morocco, and the Kuraymat Combined Power Plant in Egypt (Figure 5), may be adopted as reference techniques to increase the efficiency of the plants, and reduce fossil fuel consumption, emissions, and operational costs.

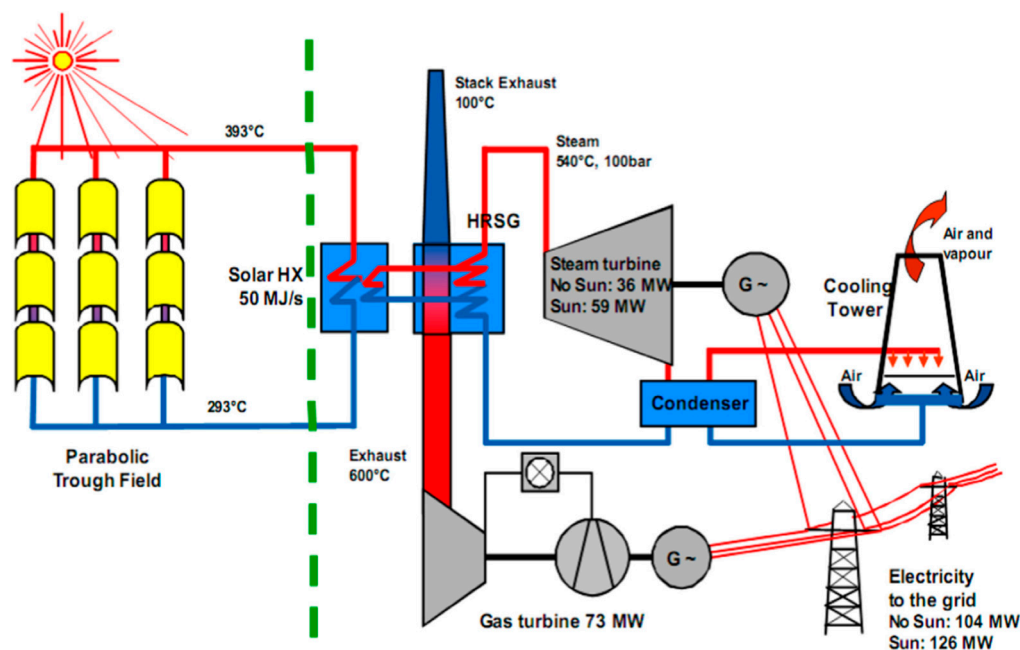


Figure 5. Kuraymat (ISCC) design [53].

8.2.2. A Stand-Alone Concentrating Solar Power Plant

The approach of a stand-alone CSPP implemented in the Enerstar Power Plant in Spain to produce 50 MWe can be adopted for the establishment of similar plants in the provinces of Al-Anbar, Salah-Dean, and Mosul. The justification for this is that the solar radiation intensity in these areas is over 2000 kWh/m²/year, according to NASA data [54]. In addition, the availability of water required to cool the condenser, as well as the open spaces to build these stations are factors.

The Ministry of Foreign Affairs of the United States government funded a project implemented by PB for the benefit of the MoE of Iraq. PB recommended that the most appropriate CSP technology to consider in Iraq would be the parabolic trough. Table 10 shows an estimation of the energy from a standard 50 MW parabolic trough installation without storage in three different locations. This estimation is based on beam radiation data from Meteonorm (a solar database) in Iraq [40,48].

Table 10. Energy production from a 50 MW parabolic trough installation [40,48].

	Baghdad	Basrah	Ramadi
Average direct radiation kWh/m ²	1792	1704	1789
Production GWh/year	109.2	103.8	108.9

8.3. Analysis of Economic Feasibility Compared to Other Solar Technologies

The economic feasibility of a clean alternative electrical power source, and the implementations of a CSP plant, a stand-alone PV plant, and water heating in Iraq are compared and presented in Table 11 [44,47]. After the three technologies were studied and analyzed, the costs per kWh were predicted and provided by PB.

Table 11. Estimated cost of electric power generation by solar energy in Iraq [44,47].

Technology	Capital Cost (\$/kW)	Operation & Maintenance Cost (\$/kW/year)	Overall Energy Cost (US cent /kWh)
CSP Technology, with no storage, 50 MW (grid-connected)	3690	60	0.23
CSP technology, with storage, 50 MW (grid-connected)	7540	107	0.39
Fixed PV system 1 MW (grid-connected)	5430	33	0.40
Stand-alone PV system 0.6 kW (one family)	17,000	917	0.30
Water Heating (domestic)			0.14

The actual costs will vary, due to the complexity of the individual installations, and additional information will be required to provide a more accurate cost analysis. The system costs do not include the additional infrastructure that is required for connecting the projects to the grid. Moreover, investment costs will depend on the land costs. CSP installation costs are expected to decrease as the technology is developed. Parabolic trough technology is considered to be the most technically proven, and a significant potential for reducing current costs exists with further technology development. This condition is the basis for predictions of lower costs of solar–thermal power in Iraq in the future. The cost of PV installations has been reduced by 10% in the previous year. Despite this situation, PV may experience difficulty in becoming economically competitive with other renewable energy sources in Iraq.

9. A Comparison of Various Renewable Energies in Iraq for Power Generation

The possible renewable energies that can be utilized for power generation in Iraq are solar, hydro, wind, and biomass. Hydro power already exists for power generation in various locations in Iraq. Solar, wind, and biomass are not yet utilized, over any small or large scales. Solar, as a resource, is widely discussed, and it is concluded that the best technology is the CSP using a parabolic trough, with and without energy storage. Below is a summarized conclusion for the other three types of renewable energies in Iraq.

9.1. Hydroelectric Power

In its current status, hydroelectric power shares approximately 13% of the total installed power for electricity generation in Iraq. By the end of 2012, the installed power of hydroelectric stations reached 1864 MW, while the generated power was only 855 MW. Existing hydroelectric plants in Iraq are divided into two main categories. The first category includes hydropower plants with storage reservoirs, and the second category includes those with barrages with limited storage. They are presented in Table 12.

Iraq is planning to increase the utilization of hydropower by up to 14 TWh by 2035. The proposed projects, with their capacities and locations, are presented in Table 13.

Table 12. Operational hydropower dams in Iraq [46,55].

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

Table 13. Planned hydropower dams [46,55].

Dam	Al-Fatha	Bekhma	Mendawa	Al-Baghdadi	Taktak	Badosh	Al-Udym	Al-Khazer Comel
Power MW	2500	1500	620	300	300	171	27	24

9.2. Wind Power Scenario

Iraq can be subdivided into three territories, based on the annual average wind speed. The first territory represents 48% of Iraq, and it has an annual wind speed that varies between 2.0 m/s and 3.0 m/s. The second territory represents 35.0% of Iraq, and it has a wind speed that fluctuates between 3.1 m/s and 4.9 m/s. The third territory represents 8.0% of Iraq, and it has a relatively high wind speed of approximately 5.0 m/s [56]. Related studies have shown that the estimated energy densities for the wind territories are: 174 W/m² in Emarra, 194 W/m² in Nekhaib, 337 W/m² in Al-Kout, 353 W/m² in Ana, and 378 W/m² in Naseria. From these results, the average wind energy is approximately 287.2 W/m². In general, the average wind speed in Iraq is greater in summer than in winter. The aforementioned figures of the estimated densities are based on the annual mean of 10 years of measured wind speeds [43]. [57] collected available wind data for 1978 to 2008, which were recorded and reported by various sources, and the results are presented in Table 14.

Table 14. Annual mean wind surface speed (m/s) for some areas in Iraq, averaged over the years 1978–2008.

Annual Average Wind Speed	Mosul	Haditha	Rutba	Baghdad	Nekhaib	Umarra	Basra	Nasiriya
at 10 m height	1.3	3.4	3.7	3.1	3.8	4.0	3.8	4.4
at 50 m height	1.6	4.4	4.5	3.7	4.6	4.8	4.6	5.3

9.3. Biomass Energy Scenario

Iraq is very rich in biomass. Unfortunately, the large availability of oil and gas as fuel resources negatively influences studies and investigations related to biomass in Iraq. Limited numbers of studies by Iraqi researchers have been directed towards utilizing bio-ethanol and methanol in mixed IC fuels, like diesel and gasoline. [58,59]. However, no attempt for biomass-to-electric power conversion has been recorded in Iraq.

10. Restrictions and Barriers to Adopting Renewable Energy in Iraq

Discussions on initiatives to use renewable energy sources in Iraq present many restrictions and barriers that should be overcome before solar energy/wind utilization can be implemented. From the point of view of the authors, the following are important points that should be highlighted.

- Financial and economic constraints: These barriers focus on the high capital cost of renewable energy projects, with the failure of (or lack of) funding mechanisms, as well as on the mistaken belief that investments in projects represent a financial risk despite preserving the environment. Some banks and funding sources may not encourage loans and investments in emerging areas compared with projects involving conventional energy and support; hence, investments in renewable energy may not have the same kind of value, and they may not be economically attractive (cost–benefit analysis) compared to other investment opportunities.
- Institutional and structural obstacles: The production and use of advanced technologies for energy production (e.g., wind power, biofuels, and solar energy) require the concerted efforts of many partners, including manufacturers and user companies; the legislative, executive, and relevant authorities (including the Ministries of Electricity, Energy, Transport, Environment, and Finance (for customs and taxes); scientific researchers; and the specifications and standards organizations. Thus, specifying roles and implementation plans is important, as well as the development of an integrated management system for coordination among parties to achieve energy production from renewable sources.
- Limited policies, attractive private investments, and the lack of government resources allocated to them.
- Poor policies that aim to form partnerships under the renewable energy application field.
- Limited institutional capabilities to develop renewable energy systems, and the difficulty in coordinating among them.
- A lack of public awareness regarding the available capabilities and the renewable energy systems that are used technically and economically.
- Difficulty in applying for a government funding system for renewable energy.
- Limited regional cooperation and coordination in the field of renewable energy projects and funding, as well as a dependence on foreign funding programs.
- The Iraqi market has limited experience and a lack of local expertise in the field of renewable energy resources in general, and for solar energy in particular.
- Accredited testing laboratories are insufficient, in terms of number and capability.
- The Iraqi government has enacted inadequate legislative laws that encourage the production and installation of monitoring devices used in solar energy systems.
- Prices for the production of electricity using common fossil fuels, such as oil and gas, are economical because of the price of energy-related products.

In addition to the aforementioned restrictions and barriers, the most important concern from the perspective of securing energy resources is that the role of renewable energy in the diversification of these resources will be significant, particularly for the generation of electricity and thermal heating as one of the means to promote energy, security, and to preserve oil resources for future generations. After considering all of the aforementioned reasons, many European countries have enacted laws to motivate investors in this sector. In Arab countries in general, and particularly in Iraq, the electricity sector depends mostly on the government to own, operate, and manage power plants, and thus, the priority is to provide services to people, and not to use other techniques, or to involve the private sector. The high cost of building solar power plants compared with fossil fuel stations; the lack of laws and regulations for investors, particularly those related to tariffs and clean electricity rates; insecurity in the current circumstances; and other factors such as the availability of NG and oil in the region,

which are used as fuels to generate electricity at prices that are considerably less than renewable energy stations, have maximized the role of fossil fuel resources, compared with renewable ones.

11. Initiatives and Support of the Iraqi Government

In view of the limitations presented in Section 9, the Iraqi government is recommended to provide a number of initiatives to support and to encourage the use of renewable energy sources. The following are the most noteworthy suggestions.

- Establish open markets and competitions that allow diverse participation, to ensure the sustainability of renewables adoption.
- Perform market functions efficiently, to ensure the diversity of resources.
- Transparency in exchanging energy information among different entities inside and outside the country.
- Provide the financial resources necessary for local investments in energy projects.
- Issuing strategies, as well as national and regional policies, that ensure the commitment of companies toward power transmission and distribution, by purchasing power that is generated from renewable energy resources, and by introducing regulations that can accommodate an agreed-upon percentage of renewable energy.
- Urban planning projects and programs shall include the allocation of lands that are required to establish power generation projects by using renewable energy resources.
- Creation of awareness among the public, particularly about the financial benefits of solar energy, the legal requirements, and the environmental advantages.
- Provision of information related to the implementation of solar energy technology, and technical details regarding building capacity, and support of scientific research into renewable energies.
- Implementation of supportive policies, such as effective laws that can impose pricing and provide practical support to those who implement renewable energy technologies.
- Offer support to reduce the proportion of electricity that is produced by using fossil fuels, via the technological establishment of solar energy. Furthermore, an advancement of the solar energy market with an attractive price for users and suppliers of renewable energy sources is necessary.
- Establish dedicated facilities that produce solar power and renewable energy sources, as well as cut taxes and customs duties on equipment that are related to renewable energy credit loans or grants.
- In a privatized market, each supplier has a defined percentage of power from renewable sources. A trading system allows for renewable energy “certificates” to be bought and sold, and thus, suppliers can fulfill their obligations.
- The plans and implementation of renewable energy projects by the Iraqi Ministry of Energy should be supported, to achieve the main goal of increasing renewable energy-based electricity production by approximately 9.4% in 2030, which will also affect CO₂ emission.
- Encourage private sector investment by introducing special regulations to motivate investment in this area, such as the law of feed-in tariff, and the net metering of energy produced from different renewable resources.

12. Conclusions

This study presents an outlook on renewable energy sources in Iraq, particularly on solar energy which produces 1800 kWh/m²/year to 2390 kWh/m²/year, with approximately 10 h availability per day. The study concluded that solar power production in Iraq is limited to simple applications, such as water heating for domestic use, lighting some streets, and drip irrigation in agriculture. Given the climatic and geographical conditions in Iraq, installing CSP has been proven to be economically feasible in this study. The use of parabolic troughs or solar towers in existing thermal stations is recommended. Solar power plants, using Fresnel reflectors or parabolic dishes, can operate independently of the

grid in remote sunny locations, and thus, these power plants are suitable for supplying power to people who live in isolated and remote villages that are not connected to the national grid. However, the potential for solar energy for electricity production is found to be sufficient if it is utilized efficiently as standalone, and as an integrated system with thermal power plants. A costwise analysis and comparison indicates that 50 MW CSP technology is economically feasible at 0.23 US cent/kWh, when connected to the grid with no storage. The absence of good planning, governance, or initiatives by authorities imposes restrictions and barriers toward renewable energy development in Iraq.

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