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Environmental considerations, sustainability opportunities and Iraqi government's energy policies: a comparative study

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Abstract

The steady increase in demand for energy in Iraq requires the inclusion of the renewable energy in any future plan. This work assesses the feasibility of electric generation from renewable energy and its impact on the environment compared to its utilization by Iraqi government. Long-range Energy Alternatives Planning System (LEAP) and Photovoltaic Systems (PVsyst) were utilized for this purpose. LEAP was configured based on the current scenario compared with other available scenarios. PVsyst was supplemented by NASA data to assess the energy potentials from solar energy. The results showed that Iraq has sufficient renewable energy potential due to its topological factors. Solar energy potential for 14 different areas in Iraq was estimated, and it was in range of (2200–3300 kWh). The wind speed at 10 m above ground level for many regions in Iraq is also suitable for electricity generation. The environmental impacts of the energy production based on the current scenario were compared with renewable and natural gas. Results showed that the renewable energy scenario mitigates the CO and CO_2 emissions, while the natural gas scenario increases the emission of CO. It is concluded that renewable energies could enhance the electricity production and reduce greenhouse gases with proper policies for future energy plans by the Iraqi government.

Keywords Sustainability · Renewable energy · Energy policy · Iraq · LEAP · PVsyst

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1 Introduction

Electricity is considered as the engine that runs the wheels of everyday activities in all life sectors: agriculture, economic and social (Zhu et al. 2020; Hodgson 2010). Therefore, the provision of reliable and secure sources of energy is crucial for any country to ensure the sustainability and the security of energy provision (Aberilla et al. 2020). Energy provision and its resources became an attractive and fateful issues in various stages of life (Droste-Franke et al. 2020) and vital areas of research, and also the environmental impacts of energy consumption globally enhanced the research activities in direction of introducing new green technologies for energy production (Aberilla et al. 2020; Lowitzsch et al. 2020; Huang et al. 2018; Gasch and Twele 2011). The energy supply, sustainability and environmental interdependence are obviously strong and appear under the issues of the climate change and the energy policy considerations (Griffiths 2017; Al-Maamary et al. 2017). This interdependence bounds the energy policies and the climate change with a real nexus that ensures energy security, strict policies, human's luxury and safety (Chen et al. 2016; Marquina 2010; Raymond 2006). The renewable energy sources, especially wind and solar energies, are deemed as most preferred alternative sources due to their low impact on the environment (Al-Dousari et al. 2019; Griffiths 2017). The renewable resources are still considered as the most promoted resources for energy provision; however, the meteorological conditions such as dust and wind speed are limiting their production capacity (Shaban et al. 2020; Aghahosseini et al. 2020; Hammad et al. 2018).

While the energy demand in Iraq , as a developing country, is increasing insanely, the renewable resources are regarded as an intractable choice for the government (Nematollahi et al. 2016; Hamdan 2014). The depletion of oil and gas resources is another reason that should motivate the Iraqi government for utilization of renewable resources as it could provide the security and diversity in energy supply (Chen et al. 2016; Li and Yao 2020; Kazem and Chaichan 2012). Similar to most countries in the Middle East, Iraq has a great deal of non-fossil resources such as renewable resources (Saeed et al. 2016; Abed et al. 2014) and nuclear energy option (Saeed et al. 2020; Khadduri 2003; Marouf 1992; Marouf et al. 1993; SAEED 2018). The government policies regarding energy production and environment sustainability should empower the Iraqi government to provide a good mix of energy resources that ensure the vital balance between the environmental measures and economic ambitions (Saeed et al. 2016; Abed et al. 2014; Al-Karaghouli and Kazmerski 2010; Kubba 2022). In addition, Iraq owns the required infrastructural and reputable scientific centers for research (especially engineering) (Alhijjaj 2009; Khadduri 2003; IAEC 1990; Al-Majid 2018). The current situation of electricity generation in Iraq is reported briefly in Table 1.

According to the Integrated National Energy Strategy (INES) proposed by the Iraqi government in 2012 and planned with cooperation of Booz&Co (Uqaili 2013; Wijeratne et al. 2019), Iraq intended to diversify the electricity generation capacity by utilizing the renewable resources including 5% of the total hydro-power (Saeed et al. 2016; Uqaili 2013; Wijeratne et al. 2019). This work aims to show how a deliberate utilization of renewable resource potentials should motivate Iraqi government to increase investments in renewable energy resources, as several studies and assessments approved its feasibility (Saeed et al. 2016; Abed et al. 2014; Hamdan 2014; Kazem and Chaichan 2012; Chaichan et al. 2012; Al-Karaghouli and Kazmerski 2010; Alhijjaj 2009; Darwish and Sayigh 1988; Khalisi 2014). Consequently, the renewable energy could help Iraqi

Table 1 Total electricity supply in Iraq from 2011 to 2018 (CSO 2018)

Years	Production capacity (MWh)					
	Gas	Diesel	Hydropower	KRG stations	Import and investments	Barges
2011	2.06164E7	4.07966E7	3396691	1.31059E7	5872124	1360970
2012	2.27906E7	4.60176E7	4392150	1.78743E7	8201976	1968258
2013	2.8838E7	5.8422E7	4756787		1.02301E7	1971545
2014	3.70495E7	6.7768E7	2930797		1.22506E7	
2015	3.48693E7	6.86883E7	2546137	2046212	1.1058E7	
2016	4.63645E7	8.00303E7	3371234		1.19649E7	
2017	5.08976E7	8.5508E7	2176083		1.36444E7	
2018	4.83642E7	8.21302E7	1817702	618520	2.17934E7	

government to overcome the rapid shortage in electricity supply effectively, especially in remote areas, and prevent the increase of green house gas emissions (Saeed et al. 2016; Istepanian 2014; Al-Majid 2018; Uqaili 2013; Zhang et al. 2020).

2 Theoretical background

Recently, the sustainability in energy and environment obtained a great concert by the scientists, governmental and economical institutes, and this is to review the general policies for energy production in a global context (Griffiths 2017; Raymond 2006; McPherson and Karney 2014; Al-Chalaby 2005). Globally, several agreements and understandings have been issued among the countries under the United Nations (UN) sponsorship (Najarzadeh et al. 2021; Kennedy and Basu 2014). The first official response to the climate change issue was in 1997 through Kyoto protocol agreement which sets a goal to reduce 5.2% of the greenhouse gases (GHG) coming from energy consumption by 2012 (Maamoun 2019; Saeed et al. 2016; Dessens et al. 2016; Chen et al. 2016). Many other attempts to save the environment such as the United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Environment Program (UNEP), both appeared as international organizations, place a high priority on environmental issues (Odeyemi 2020; Kennedy and Basu 2014; UNEP 2014). Inline with climate conservation trends, many commitments and obligations have been decided through these organizations to limit or reduce the emissions of some gases that affect the climate by redraw the official energy policies for long-run provision (Rogelj et al. 2013; UNEP 2014; Dessens et al. 2016). However many countries started to review their energy policies to contribute effectively in climate conservation, such as Germany and other European countries, but the actions are still below the global ambitions (Kuramochi et al. 2021; Dell'Anna 2021; Aldieri et al. 2021). Numerous studies have discussed the possible achievement of global inspiration in the mitigation of GHG emissions to consider whether the current commitments are inline with the global goal for decreasing the earth surface temperature to 2 °C (Grigoroudis et al. 2016; Rogelj et al. 2013). In spite of the positive impact of these commitments on global warming potentials, the adopted scenarios are not desirable in terms of cost (Zemigala 2021; UNEP 2014).

Interest in renewable energies appeared later than European countries in the energy policies for Middle Eastern governments (Devlin 1992). This includes the sustainability in environment and energy (Juaidi et al. 2019; Hassan et al. 2021; Baseer et al. 2019; Chaichan et al. 2012). Iraq and most of Middle Eastern countries started to review or state new energy policies for management and diversification of their energy sources (Al-Kayiem and Mohammad 2019; Tofigh and Abedian 2016), and this also includes the sustainability development in urban and city design (Ameen and Mourshed 2019). Officially, the first time that renewable energy included in Iraqi government energy plan was in 2005 through the Integrated National Energy Strategy (INES) (Saeed et al. 2016; EIA 2019, 2017; Uqaili 2013). Although Iraq has not witnessed any vital project in the field of renewable energy, even after 10 years have passed since the issuance of the first official plan which included the renewable energy utilization (MoE 2018, 2020). Iraqi government seems careless to take serious steps toward new energy plan that considers the global ambitions to reduce GHG emissions that results from fossil fuel consumption (Saeed et al. 2016; Chaichan et al. 2012; Al-Chalaby 2005; Kubba 2009, 2004). It is necessary for the Iraqi government to make instant moves in putting the necessary policies and instructions for energy production and management in a manner that will be commensurate with the effects resulting from energy consumption.

3 Energy overview of Iraq

3.1 Oil and gas

Iraq owns good potential resources of fossil and non-fossil energies like renewable energy (Saeed et al. 2016). Iraq has strengthened its rank among the top oil producers throughout the world despite the tremendous challenges that it has faced during last decades. With an increment of 1.5 million barrels nowadays, Iraq is producing (4.7) million barrels per day ranking fifth among the main oil-producing countries (EIA 2017; BP 2019), as shown in Fig. 1. Also, the proven reserve of natural gas in 2017 was estimated at (3.5 trillion cubic meters), mostly associated with gas production in parallel with that of oil in super-giant fields (EIA 2017; BP 2019).

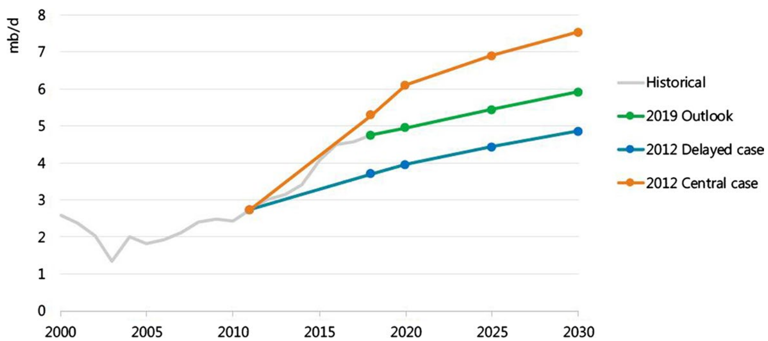


Fig. 1 The oil production outlook; a comparison of the proposed scenarios in Iraq Energy Outlook 2012 (EIA 2017)

3.2 Electricity production

Iraq, as one of the developing countries, passed through the increment criteria of electricity demand to provide the essential requirement for its development plans (BMI 2014; Kubba 2022). Thus, during the last 5 decades, Iraqi officials were motivated to introduce new electricity production capacities to the system network to match the steady increase in energy demand (Saeed et al. 2016). However, their plan will never take into account the security and diversity for a long-term permanent supply (Kazem and Chaichan 2012). Up until now, the Iraqi government has completely adopted the energy technologies that make use of fossil fuels due to the abundance of the fossil fuels in Iraq (World Bank 2020). Figure 2 shows the main electricity generation technologies that contribute to the total electricity production capacity (World Bank 2020). It shows that Iraq depends completely on fossil fuels for electricity generation except the hydroelectricity power which has alternatively been initiated to produce electricity (World Bank 1949; Kubba 2022). During the Iraqi government plans in (1948–1958), several dams were built in Iraq for the purposes of agriculture and flood prevention (World Bank 1949; Kubba 2022, 2009).

From 2003 onward, the increase in oil prices and the international support to the new sequential governments has boosted Iraq's annual budget (World Bank 2020), as shown in Fig. 3. Yet, most of the electricity generation infrastructures were ruined and their production capacities tumbled to almost half, due to Second Gulf War (Kubba 2004). The new Iraqi governments after 2003 were unsuccessful in rebuilding the necessary infrastructures to fulfill the electricity demand by population or other sectors (Saeed et al. 2016; BMI 2014).

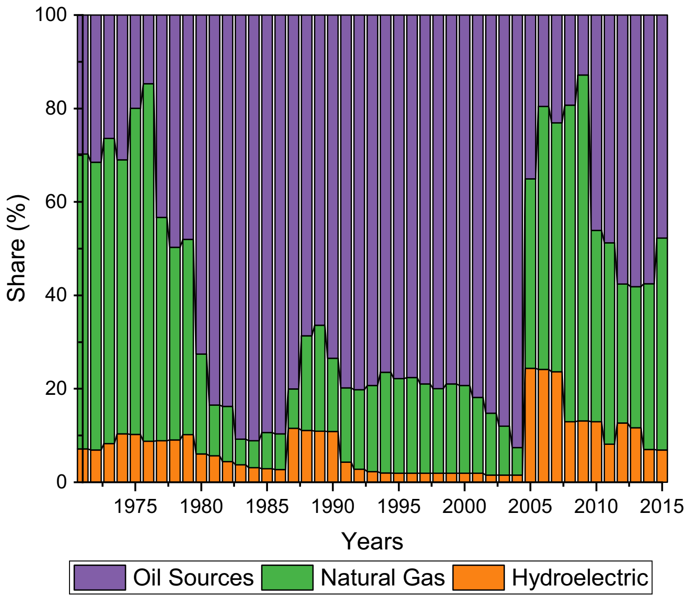


Fig. 2 Energy mix for public electricity generation sector in Iraq (World Bank 2020)

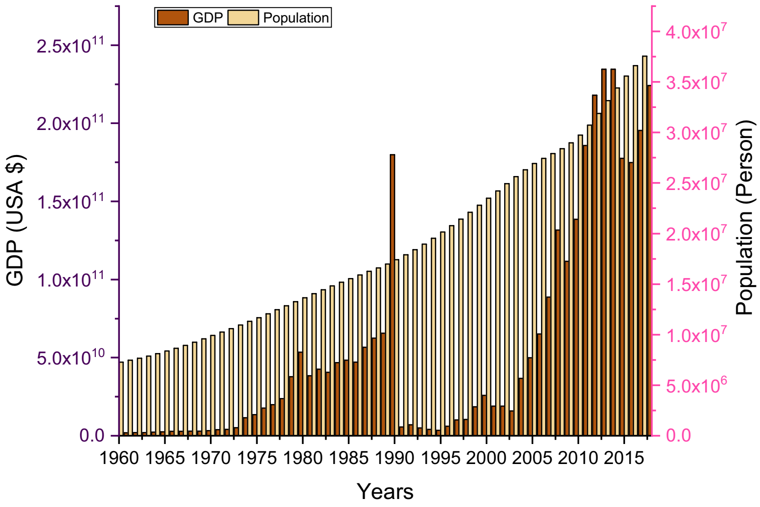


Fig. 3 The gross domestic production of Iraq in 1980–2018 (World Bank 2020)

4 Research tools and methodologies

4.1 Long-range Energy Alternatives Planning (LEAP)

The Long-range Energy Alternatives Planning System (LEAP) is an elegant software developed at Stockholm Environment Institute (SEI), Massachusetts, USA (Shin et al. 2005; Heaps 2014). It is consisted of an interconnected set of modules to provide a forecast and multi-estimations of energy demand, consumption, economics and environmental impacts based on energy technologies (Heaps 2014). In addition, it provides multi-scenario cases which draw the energy policies on the ground of available resources for energy supply and its environmental impact (Nieves et al. 2019; Talaei et al. 2019; Saeed et al. 2016; Song et al. 2007). Recently, LEAP has been used widely by researchers in energy policy and in accordance with the energy-environmental combination context, especially in developing countries (Handayani et al. 2020; Zhang et al. 2020; Hu et al. 2019; Pan et al. 2013; Huang et al. 2011). This model has been used in water supply, urban planning and transportation issues (Lin et al. 2019; Sadri et al. 2014; McPherson and Karney 2014; Huo et al. 2007) as it is supported by the Technology and Environmental Database (TED) which provides adequate information about the technical and economic characteristics with the environmental impacts for wide range of energy technologies (Heaps 2014; Shin et al. 2005).

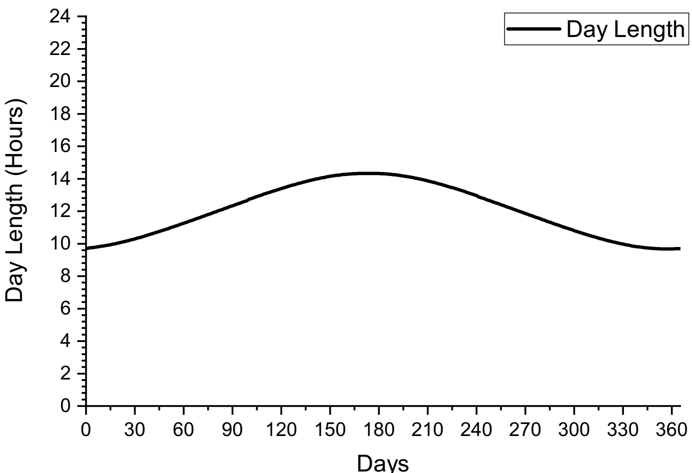
4.2 Photovoltaic Systems (PVsyst) model

The present study has employed photovoltaic systems (PVsyst) model packages to examine the feasibility and availability of solar energy in Iraq. PVsyst is used to design and analyze data for PV systems in an integrated theme. It provides multi-criteria of the PV system contribution in electricity production, such as grid-connected, grid-not-connected (standalone), pumping (irrigation) and DC-grid PV systems (Hernández-Callejo et al. 2019).

PVsyst model has built-in modules that help receive hourly weather data from many official portals such as the National Aeronautics and Space Administration (NASA), especially when the onsite data are unavailable (Malvoni et al. 2016). These data patterns include the solar irradiation, wind speed, temperature, humidity and precipitation conditions for any desired location (Hernández-Callejo et al. 2019). This tool utilized typical annual weather data, in terms of inputted or online data files, to represent the long-term solar resource to identify the appropriate data for a PV system based on the proposed project specifications at the location (Wijeratne et al. 2019). The simulation results of PV systems by PVsyst model match correctly with the onsite data obtained from the installed project through annual monitoring (Srivastava et al. 2020; Sundaram and Babu 2015). Iraq geographical location is quite suitable for solar energy exploitation, as it is located in the southwestern side of the Asian continent extending between (29.50–37.22 °N) and (38.45–48.45 °E) (Shubbar et al. 2016; Jassim and Goff 2006). This classifies the climate of Iraq as continental, subtropical and seasonally (Jassim and Goff 2006). Also, it gives Iraq a suitable day length ranged from (9.7–14.3 h) to an average of (12.04 h) per day, as shown in Fig. 4.

4.3 Data collections and scenario selection

This study considered many input data to assess and analyze the current and future demand on energy, energy consumption, government policies, available resources and the real capabilities hinged on previous and current estimations. The main input data were collected from official organizations such as Ministry of Electricity, Ministry of Plan, World Bank and the U.S. Energy Information Administration (EIA) (EIA 2017; CSO 2018; MoE 2018; World Bank 2020). The required input data for these work estimations such as annual solar irradiation and other meteo input data were imported from NASA Meteonorm V7.1 built-in by PVsyst software. Also, the input data for wind energy resources were collected from the Energy Sector Management Assistance Program (ESMAP) project (World Bank 2020).



Mean	Minimum	Median	Maximum
12.04247	9.675	12.045	14.326

Fig. 4 The maximum, minimum and mean of day length in Iraq

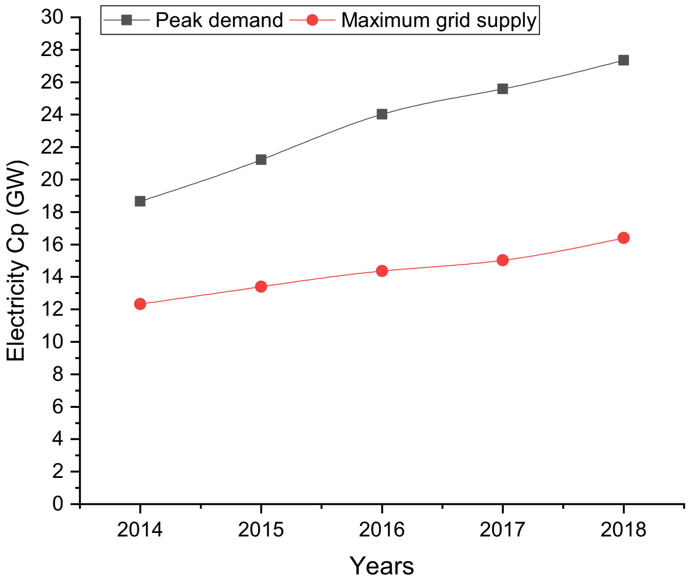


Fig. 5 The peak demand and the maximum power supply from the national grid in Iraq (2014–2018) (EIA 2019)

Table 2 Total estimated electricity consumption in Iraq based on households usages

Appliances	Urban	Rural
Consumption by households (kWh)		
Refrigeration	500	500
Lighting	400	340
Others	800	500
Cooking	400	0
Cooling	20,000	15,000

4.4 Setup of LEAP

Considering the change in annual growth rate of population and GDP in Iraq, as shown in Fig. 3, LEAP has been configured to calculate the predicted increase in energy demand, GHG emissions based on the current government policies and selected scenarios. The electricity production in Iraq has never matched the population demand on electricity since 1990, even with INES plan in 2012 (Saeed et al. 2016; Uqaili 2013; Wijeratne et al. 2019), as shown in Fig. 5. However, this work is focusing only on the population demand on electricity, while the data about other activities such as industry, transportation and commercial are not clear due to the vague policies of the government (Istepanian 2014; Kubba 2009).

This research depends on the total electricity consumption for each household in Iraq. The base year of the calculation was 2020, in which the total number of households in Iraq is about (6.6 million) and the mean number of household members is (7); being the mean everyday consumption based on the general appliances that used by most of Iraqi households as shown in Table 2.

where the rate of urban households accounted 75% and the rural ones to be 25%. Also, two another scenarios (SC_{Diesel}, SC_{NG}) were introduced to explain the impact of the government energy policies on the environment based on the merit order of each energy technology that runs on fossil fuels and are preferred by the government. Another scenario (SC_{Solar}) proposed was the introduction of 8 GW of electricity capacity from solar energy between (2025 and 2050), with an interval of 2 GW for each 5 years. The proposed capacity of electricity production from solar energy was in line with the estimations and assessments that conducted by PVsyst model at different areas of Iraq. This is to show the environmental impact of the renewable energy contribution in total electricity production by the Iraqi government. LEAP model contains all types of energy technologies attached with their environmental impacts. Therefore, it calculates the total GHG emission of an entire system of energy based on Eq. (1), as shown below (Saeed et al. 2016; Shin et al. 2005; Song et al. 2007):

$$\text{Emission}_{t,y,v} = E_c\{t, y, v\} * E_f\{t, v\} \quad EI_D\{t, y - v\} \tag{1}$$

where E_c is the energy consumption, $E_f\{t, v\}$ is the energy technology's environment measure, $EI_D\{t, y - v\}$ is the degradation (the factor that indicates the change in energy intensity based on its age), t is the technology type, y is the time in years, v is the vintage (life cycle or the start year of the technology).

5 Results and discussion

5.1 Electricity demand estimations

The demand on energy, especially the electricity by the population in Iraq, is growing rapidly like the rest of the world. Considering the annual growth rate of (3.0%) of the GDP in Iraq, an estimation of the increase in demand on electricity performed by using LEAP model. Figure 6 illustrates the estimated increase in demand on electricity by the population sector according to the basic needs for electricity, as mentioned in Table 2. The estimation for 2020 year is in good agreement with EIA energy outlook in Iraq for the year 2019. Based on the simulation for the base year 2020, the demand on electricity is expected to be (145.2 TWh) which could be supplied by (26.5 GW) of capacity, while the real capacity of electricity generation was only (17 GW) at 2020 excluding the total lose in distribution grids (MoE 2020). LEAP results show that the demand on electricity by population will rise to (351.4 TW) by 2050. This requires the installation of (61 GW) of generation capacity and its provision from fossil fuel which will be possible for Iraqi government over the next 30 years, but not for long periods of time due to depletion of fossil fuel resources. Thus, the security of electricity provision is not warranted in the long run. Also, the environment impact of electricity generation will continue to increase which alarms the population life safety.

5.2 The environmental evaluation

The renewable energy potentials in Iraq exceed the amount of electricity generation proposed in this study. But this scenario regarding the minimum availability of the renewable energy potential considered some obstacles about the project procedures for solar farms in Iraq. Figure 7 shows the expected emission of CO_2 gases from the electricity generation

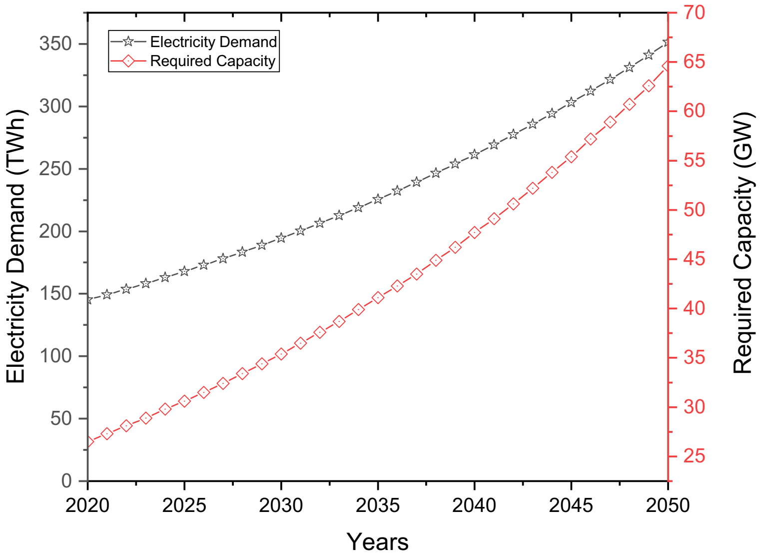


Fig. 6 The estimated increase in demand on electricity for years (2020–2050)

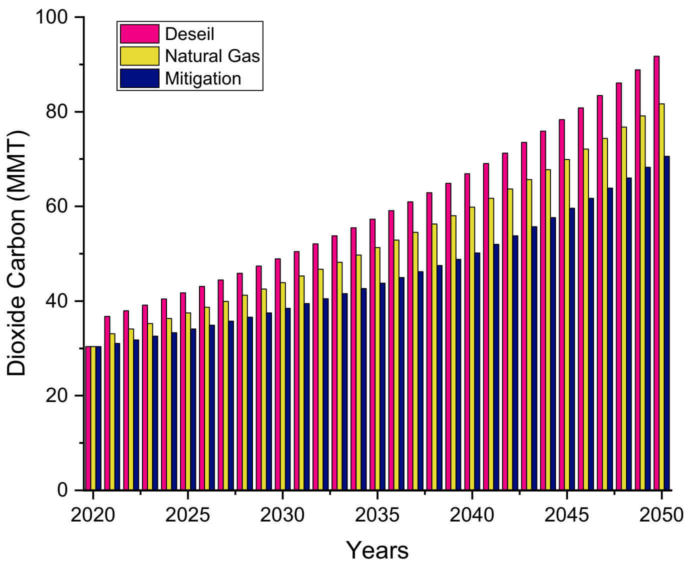


Fig. 7 The estimated CO_2 emission from electricity consumption for years (2020–2050) based on four different scenarios

starting from 2020 to 2050. In 2020, the total emission of CO_2 from electricity generation is (30.3 MMT) given the expected demand on electricity. The provision of electricity depending on the government energy policy for the next (30 years) will influence the total emission of CO_2.

According to the (SC_{Diesel}) scenario, where the addition of new capacities depends on diesel generators, the total CO_2 emission by 2050 will increase to (91.7 MMT). However, shifting to natural gas generators, based on (SC_{NG}) scenario, the resultant CO_2 emission from electricity generation will increase to (81.7 MMT) by 2050 scoring diminishing of (10.1 MMT) of CO_2. Moreover, this reduction in CO_2 emission in (SC_{NG}) scenario, where natural gas in dominant, occurred by an increase in CO emissions, increasing from 9.06 MMT at 2020 to 24.98 MMT by 2050, as shown in Fig. 8. According to (SC_{Diesel}) scenario, the CO emissions will increase from 9.06 MMT at 2020 to 23.3 MMT by 2050; however, based on SC_{solar} scenario the CO emissions will increase from 9.06 MMT at 2020 to 21.01 MMT by 2050, as shown in Fig. 8.

Furthermore, introducing only 8 GW of renewable energy to the system will mitigate the total CO_2 emission by 21.1 MMT by 2050, as shown in Fig. 7. Figures 7 and 8 clearly show that the only way to reduce the environmental impact of electricity generation is by diversifying the energy technologies with renewable ones available in a large scale in Iraq.

5.3 Renewable resources availability

Iraq is characterized by the elevated terrestrial conditions such as mountains, hills, valleys and deserts. This makes the wind velocity quite available for energy production at many regions. Figure 9 shows the annual average of wind speed at (10 m) above ground level in Iraq measured for the duration of (1985–2005). It is clear that the wind velocity at mountainous region of Sulaymaniyah, Erbil and Duhok provinces exceeds (12 m/s). This weather condition is highly suitable for electricity generation from wind energy. Moreover, the average of wind velocity at regions of Anbar, Karbala, Wasit, An-Najaf, Maysan, Al-Muthanna and Al-Basrah is ranged between (4 and 6 m/s) at 10 m above

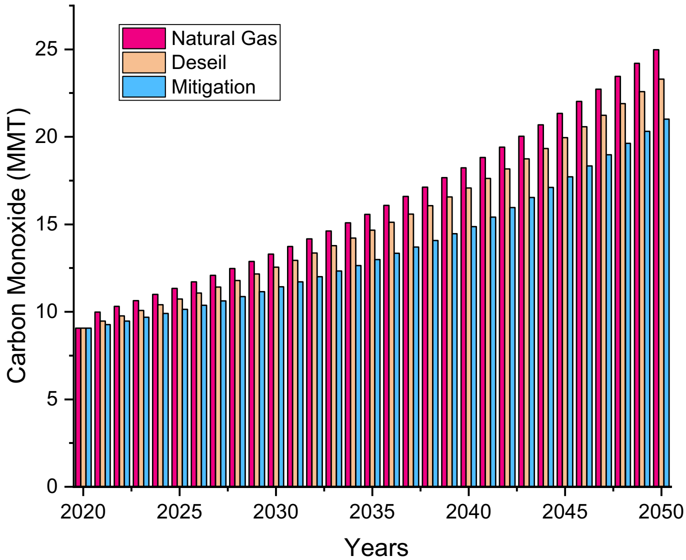


Fig. 8 The estimated CO emission from electricity consumption for years (2020–2050) based on four different scenarios

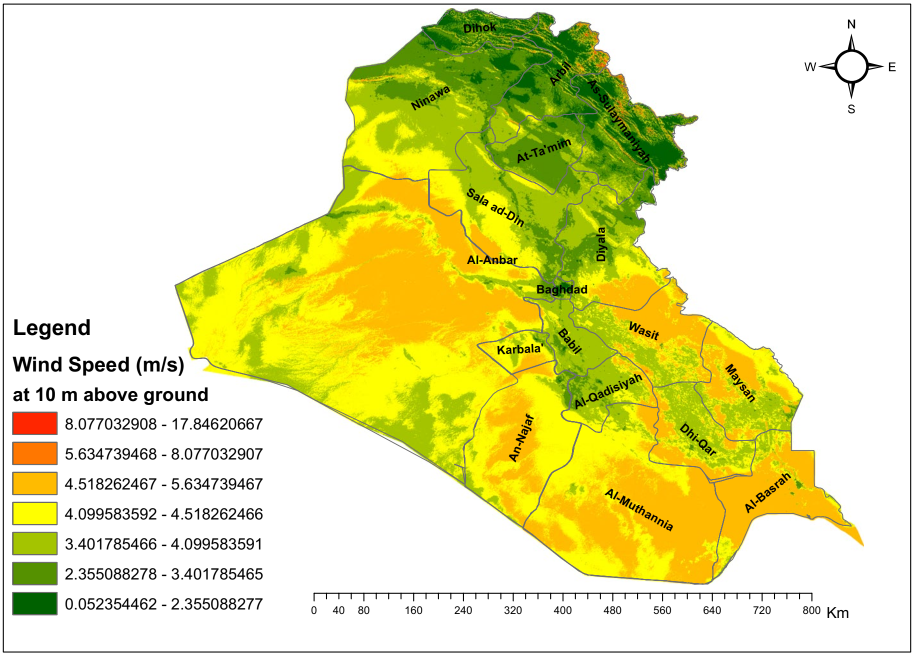


Fig. 9 The average annual wind speed at 10 m above ground level for (1985–2005)

ground level, which is valuable for electricity production especially at remote barren areas remote areas to the west and southern west parts of the country.

Besides the wind energy resource, Iraq is characterized by a huge daily quantity of irradiation for about (10–14 h) per day, as shown in Fig. 4. On the other hand, the most populated cities in Iraq such as Baghdad, Mosul, Anbar and Basrah are surrounded from the western side by deserts. This minimizes the impact of building new huge solar farms on the land use in Iraq. Figure 10 illustrates the available annual and monthly energy output from solar energy at Baghdad city.

Figure 10 clearly shows the possibility of complete reliance on the solar energy for (10–12 h) daily without reliance on any kind of energy storage technologies. However, the energy output from solar energy at many of Iraqi cities, especially those located at the southern and southern-west part of Iraq, is higher. This study performed an assessment for the northern and middle parts of Iraq where the solar irradiation is lower than other parts. The results declared the availability of promoted capabilities that could be provided by solar energy projects at these regions.

The available potentials from solar cell for some cities of Iraq situated north and middle part of Iraq are illustrated in Fig. 11. In these areas, the solar irradiation rate is almost lower than that of the southern and western-south regions of Iraq. It shows that the electricity production from solar energy in these regions is sufficient to daily electricity demand during the year, except the months of December and January. The electricity production from solar energy in these regions ranged from (2200 to 3300 kWh) which is feasible to provide the total demand on electricity in these regions.

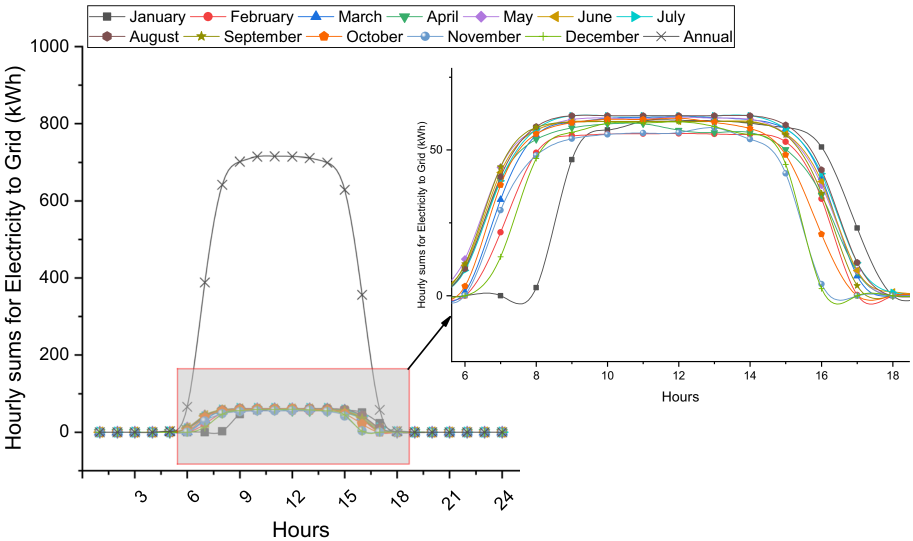


Fig. 10 The hourly and annual sum of electricity power potential from solar energy at Baghdad city

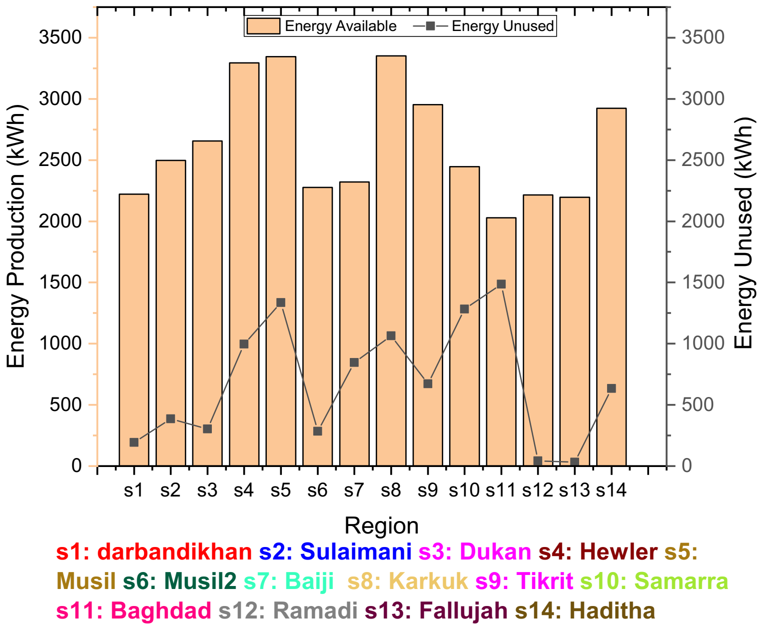


Fig. 11 The hourly sum of electricity power potential from solar energy at different regions of Iraq

6 Conclusion and policy implications

To summarize, the present study indicated and estimated only the demand of energy by the households and potentiality of electric production from renewable energy resources in

Iraq by using LEAP and PVsyst software supplemented with NASA meteorological data. Fourteen different areas across the northern and middle parts of Iraq, with the lower irradiation compared with other parts of the country, were examined. The results were thought-provoking; the availability of energy in all areas was higher than the energy demand by households. Moreover, the irradiation period is between 10 and 14 h per day throughout all the year. The environmental consequences were also studied. Iraqi government policies for electricity generation mainly depend on fossil fuels in all sectors in which CO_2 emission is high. However this assessment covered the population consumption and future demand on electricity, but the estimations were tragic. It showed CO_2 emission from electric generation was (30.3 MMT) in 2020 from population demand on electricity, while this amount is expected to treble and reach (91.7 MMT) by 2050 if Iraq government continues to use fossil fuels for electricity generation. However, utilizing the renewable energy should reduce the amount of CO_2 emission to (60 MMT) by 2050 by only providing (8 GW) electricity from renewable resources. Therefore, this study recommends the Iraqi government to diverse its plan for power generation through tight plans and proper energy policies. Further studies are required to explain the impact of other energy consumption sectors to provide more general figure of energy crisis in Iraq. Also, it is time to switch from fossil fuels to renewable resources which is sufficient to provide the household demands on electricity to decrease the green house effects as a result. Further studies are necessary to evaluate and assess the real demand on electricity and other types of energy for other sectors such as commercial, industry, transportation and agriculture to help the authorities in energy plans and policies in accordance with the global ambitions for environment sustainability.

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