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Journal

Energy Efficiency, 17(3)

ISSN

1570-646X

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Publication Date

2024-03-01

DOI

10.1007/s12053-024-10203-2

Energy Efficiency (2024) 17:19
https://doi.org/10.1007/s12053-024-10203-2

ORIGINAL ARTICLE

Forecasting long-term energy demand and reductions in GHG emissions

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Received: 4 August 2021 / Accepted: 20 February 2024 / Published online: 5 March 2024

Abstract This work projects the long-term energy demand and assesses the effects of using renewable-energy technologies on greenhouse gas (GHG) emissions in the Marun Basin, Iran. Energy projections are made with the Low Emissions Analysis Platform (LEAP) model. Demographic and macro-economic data, per capita energy use in the urban and agricultural sectors in the Marun Basin, were gathered and input to the LEAP model to simulate the energy system in the period 2016–2040. This work's results show that under the Business As Usual (BAU) scenario the electricity demand trend in the domestic sector would increase from 1783 MWh in 2016 to 2341 MWh by 2040. The fossil fuels consumed by the urban sector would increase from 738 million barrel of oil equivalents (BOE) in 2016 to 968 million BOE in 2040. The CO_2 emissions under the BAU scenario would increase from 27.33 million tons in 2016 to 35.87 million tons in 2040. A scenario was created to provide electricity service by means of residential solar panels (RSPs) to rural areas currently not connected to the national power grid. The LEAP model's results show CO_2 emissions would be reduced by 17%, and 20% of the domestic diesel use would be replaced by electricity generated with solar panels.

Keywords Energy demand forecasting · Low Emissions Analysis Platform (LEAP) model · RSP scenario · GHG emissions · Renewable energy resources · Residential solar panels

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Introduction

Energy security and permanent access to its resources are essential for economic and social development. Therefore, forecasting energy demand is imperative for energy planning. Energy demand depends on factors such as globalization and industrialization (Suganthi & Samuel, 2012), economic development, and urbanization, population size and age structure (York, 2007), the Gross Domestic Product (GDP), the rate of population growth (Kebede et al., 2010), and industrial development (Yu et al., 2015). Zhang et al. (2017) and Wang et al. (2020) stated that energy demand forecasting is complex because of the strong feedbacks between living standards, economic development, and energy use. Meeting future energy demands must go hand in hand with environmental protection, as recommended by the Sustainable Development Goals of the United Nations

Development Organization. One of the environmental concerns related to conventional energy production is the emission of greenhouse gases (Loáiciga, 2011), most notably CO_2, a phenomenon that has been widely studied with the LEAP model. In various studies, energy consumption and the resulting greenhouse gas emissions have been investigated using the LEAP model; For instance, estimation the CO_2 emissions in Taiwan (Huang and Lee, 2009), analyzing energy supply and demand and GHGs emission in Xiamen city, China, (Lin et al. 2010), examining supply and demand scenarios in the Maharashtra region of India until 2030 (Kale and Pohecar, 2014), developing a reference energy system and energy consumption forecast for the time period (2011-2015) in Iran (Amirnekooei et al. 2012), can be mentioned. It is noteworthy the total global energy demand is projected to increase by 50% by 2030 compared to 2005 (International Energy Agency (IEA) (2019)).

The use of conventional energy for electricity generation poses challenges to emerging energy substitution (Yang et al., 2021), yet, there is significant impetus to replace fossil fuels with renewable and clean energy (United Nations Framework Convention on Climate Change, (2020)). Wang et al. (2010) reported a pathway to achieve sustainable development in Shandong province, China, by developing more energy-efficient technologies, improving energy efficiency and conservation, and modernizing the industrial sector. Masson et al. (2014) applied the Town Energy Balance scheme to show that solar panels would reduce the energy needed for air-conditioning by 12%. Park et al. (2020) evaluated the effects of photovoltaic, solar thermal, and photovoltaic thermal systems on GHG emissions using TRNSYS18 in high-rise buildings in South Korea. Gyamfi et al. (2021) reported that biomass energy consumption reduced CO_2 emissions in E7 countries (i.e., China, India, Brazil, Mexico, Turkey, Indonesia, and the Russian Federation) in 2000–2018. Azam et al (2021) argued that expansion and improvement of renewable energy is vital to reduce adverse climate-change impacts and to achieve sustainable economic growth.

Iran is among the top 10 producers of greenhouse gases because of its dependence on fossil fuels to power its industrial, residential, and transportation sectors (Mollahosseini et al, 2017), which imposes significant costs on the country (Aryanpur et al., 2019). Kachoee et al. (2018) applied the LEAP model to show that the share of fossil fuels in electricity generation in Iran would rise by more than 90% and the CO_2 emissions would reach 670 million tons in 2040. The latter authors estimated that renewable energy could reduce the GHG emissions by 295 million tons and the use of fossil fuels in electricity generation by 33% by 2040. Other studies dealing with the development of renewable energy in Iran have shown, for instance, the potential for electricity generation from waste in the City of Tehran (Nojedhi et al., 2016), or assessed the environmental and economic effects of grid-connected photovoltaic power systems on the annual GHG emissions and electricity generation (Farangi et al., 2020), and calculating the thermal demand of buildings outfitted with solar and wind energy supply instead of natural gas (Noorollahi et al., 2021). Energy use in Iran is primarily by the residential, commercial, and industrial sectors (Energy balance sheet; Iran Ministry of Energy (2015)), and its major source of electricity generation is natural gas (Energy Information Administration (EIA), 2018). The reliance on fossil-fueled energy has had severe impacts on economic and social development, and on the environment in Iran (Golabi, 2011). Afsharzadeh et al. (2016) proposed that Iran must restructure the existing energy system by expanding its use of renewable energy sources. Table 1 lists a summary of energy demand forecasts made with several models applied to in a variety of case studies. It is seen in Table 1 that previous research indicates that studies on energy demand forecasting have often been made at the national scale, while the energy use and energy sources vary across regions of a country. Therefore, the long-term energy policies may vary across regions within a country. The consideration of energy-use diversity within a country is key to the achievement of the national energy goals.

Iran is the leading emitter of CO_2 in the Middle East, and the seventh in the world, with an estimated annual emissions of about 650 million metric tons (World Bank, 2018). In order to achieve the national goals of economic and social development (sixth 5-year development plan) and to meet internationally agreed goals (such as those established in the Paris Agreement), it is necessary for Iran to reduce its greenhouse gas emissions. The use of renewable energy sources is the obvious alternative to reduce greenhouse gas emissions in Iran.

This work's study region is the Marun basin in Khuzestan province, Iran. The Marun basin relies exclusively on Marun dam's power plant as a source of electricity and water supply. Therefore, the water

Table 1 Literature review of energy system modeling

Authors	Case study	Time period	assumptions	Models	Objective
Raza et al. (2022)	Pakistan	2020–2070	Techno-economic parameters such as population, urbanization, industrialization, GDP	LEAP	Forecasting energy demand and CO_2 emissions and overcoming the energy crisis caused by dependence on imported fossil assets and lack of integrated energy planning
Aizad et al. (2018)	Pakistan	2012–2030	Stranded costs are assumed to be zero, discount rate is 5%, and the salvage value is 10% of capital cost of power plants	LEAP	Analyzing renewable energy policy in Pakistan and examining and finding pathways to secure energy supplies
Sarkodie and Strezov (2019)	China, India, Iran, Indonesia, and South Africa	1982–2016	Foreign direct investment net inflows, GDP per capita, CO_2 emissions, total greenhouse gas emissions, and energy use	Panel data regression with Driscoll-Kraay standard errors, *U* test estimation approach, and panel quantile regression with non-additive fixed-effects	Examining the effect of foreign direct investment inflows, economic development, and energy use on greenhouse gas emissions
Hanif et al. (2019)	Fifteen developing Asian countries	1990–2013	Economic growth, fossil fuel consumption, foreign direct investment, population growth	Autoregressive Distributive Lag (ARDL) model	Examining the long-run and short-run impacts of fossil fuel consumption, foreign direct investment, and economic growth on carbon emissions
Wang et al., (2018a, 2018b)	China and India	2017–2026	Primary energy consumption for China and India	Single-linear, hybrid-linear, and non-linear forecasting techniques based on grey theory	Forecasting energy demand
Yuan et al. (2017)	China	2016–2030	GDP, population, urbanization rate, and share of secondary industry	Bayesian approach	Probabilistic forecasts of energy demand at the provincial and national levels
Tsai and Chang (2018)	Taiwan	2013–2050	GDP, industrial structure, population, and household number	Market Allocation (MARKAL)	Analyzing nine long-term carbon reduction pathways from technical perspectives
Ahmadi et al. (2019)	Iran, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates	2000–2017	Oil, natural gas, coal, renewable energy use, and GDP	ANN based on the Volterra-Kolmogorov-Gabor (VKG) method with multiple inputs and one output	Determining carbon dioxide emissions, the most significant GHG, on the basis of shares of various energy sources
Ameyaw and Yao (2018)	United States of America	2012–2021	Historical energy use	Assumption-free own-data-driven technique	Energy demand projections with high accuracy

Table 1 (continued)

Authors	Case study	Time period	assumptions	Models	Objective
Balyk et al. (2019)	Denmark	2010–2050	Costs, efficiency, availability factor, lifetime, existing capacity, expansion potential, losses	(The Integrated MARKAL-EFOM1 System) TIMES	Description of socio-economic pathways to a low-carbon society
Vincent et al. (2021)	South Korea	2017–2035	Maximum demand, energy usage, and the load factor	Wien Automatic System Planning (WASP)	Investigating the effects of the "Renewable Energy 3020" policy
Wang et al., (2018a, 2018b)	Chongming-China	2016–2040	Coal consumption, biomass consumption, input/output electricity, maximum electricity demand, renewable energy generation	EnergyPLAN	Improvement of renewable energy development
Owolabi et al. (2019)	Nigeria	2015–2030	Climate data and cost data	RETScreen	Feasibility analysis to assess the viability of installing grid-connected solar photovoltaic
Noorollahi et al., (2020)	Iran-Hormozgan province	2025–2030	Population and GDP	EnergyPlan	Maximizing the solar energy share for heating, cooling, and electricity demand

and electricity sources and their consumer nodes in this area are known, and long-term demand can be projected under climate change accurately. Also, the synergies and trade-offs between water and electricity sources can be evaluated. Khuzestan province has a special place among Iran's provinces by being its energy. This province is the second producer and consumer of electricity in Iran. It is also one of the five provinces of Iran where greenhouse gas emissions have increased in recent years (Mamipour et al., 2019). Therefore, the reduction of greenhouse gas emissions in this region plays a key role in the overall reduction of greenhouse gases in Iran.

The use of solar energy has been proposed based on the capacity of using renewable resources in the study region as established in previous studies (Kashani et al., 2013). This study is novel in the field of substitution of fossil-fueled energy by renewable energy at the river basin scale. This study's proposed scenario for renewable energy conforms with established possibilities in the study region.

This study's objectives are to project the demand for energy carriers by 2040 and to estimate the emissions of greenhouse gases in the Marun basin, Iran. This study also considers the use of residential solar panels to reduce greenhouse gas emissions in rural regions of Iran. The development of renewable energy would reduce rural emigration driven by the high price of fossil fuels in rural areas (Afsharzadeh et al., 2016). The use of conventional energy in rural regions has raised GHG emissions and causes social calamities (Kardowani, 2001).

Methods and materials

This work implements the LEAP model to forecast the long-term energy demand and greenhouse gas emissions in Iran through 2040 and assesses the effects of using residential solar panels to reduce fossil fuel consumption and GHG emissions. The energy-environment scenario-based LEAP model developed by the Stockholm Environment Institute (SEI) is a user-friendly model that simulates and forecasts energy supply and demand at various temporal and spatial (local, regional, national, and multinational) (Cai et al., 2008).

LEAP features include flexible structure for creating multiple scenarios, optimization, connection to Water Evaluation And Planning (WEAP) modeling, cost–benefit analysis, user access to Technology and Environment Database (TED) for calculating emission factors in some countries, estimating greenhouse gas emissions, and calculating the Global Warming Potential (GWP). Figure 1 displays the framework of the LEAP model (Heaps, 2002).

Demographic, macro-economic, and energy-use data were gathered in this work's first phase. The demographic data, such as the number and sizes of households in the study region, urbanization percentage and its growing rate, macro-economic data such as GDP, average per capita income (Iran's National institute of statistical 2016), and the per capita use of fossil fuels in urban areas and electricity use in the urban and agricultural sectors (National Iranian Oil Refining and Distribution Company, 2016), were applied to create the energy model. Energy use was simulated with LEAP in 2016, which was chosen as the base year in LEAP due to accurate data available for that year. Figure 2 displays this study's flowchart methodology.

Calculation of the total energy demand

The total energy demand is calculated as follows:

$$DE = \sum_{i}^{M} \sum_{j}^{Mi} \sum_{n}^{N} AL_{ijn} \cdot EI_{ijn} \quad (1)$$

in which DE is the aggregate energy use, and AL_{ijn} and EI_{ijn} are the activity level (which represents social or economic activity) and energy intensity (energy use per unit of activity), respectively, in sector i, $i = 1, 2, \dots, M$, by energy consumer $j, j = 1, 2, \dots, M_i$ and fuel or energy source $n, n = 1, 2, \dots, N$.

Calculation of the global warming potential (GWP)

One of the LEAP model capabilities is calculation of the GWP created by fossil fuel emissions. The GWP is a quantitative, normalized, measure of the global atmospheric heating by GHGs. The GWP measures the total energy that a gas absorbs over a particular period of time (usually 100 years) compared to CO_2. The GWP is calculated as follows:

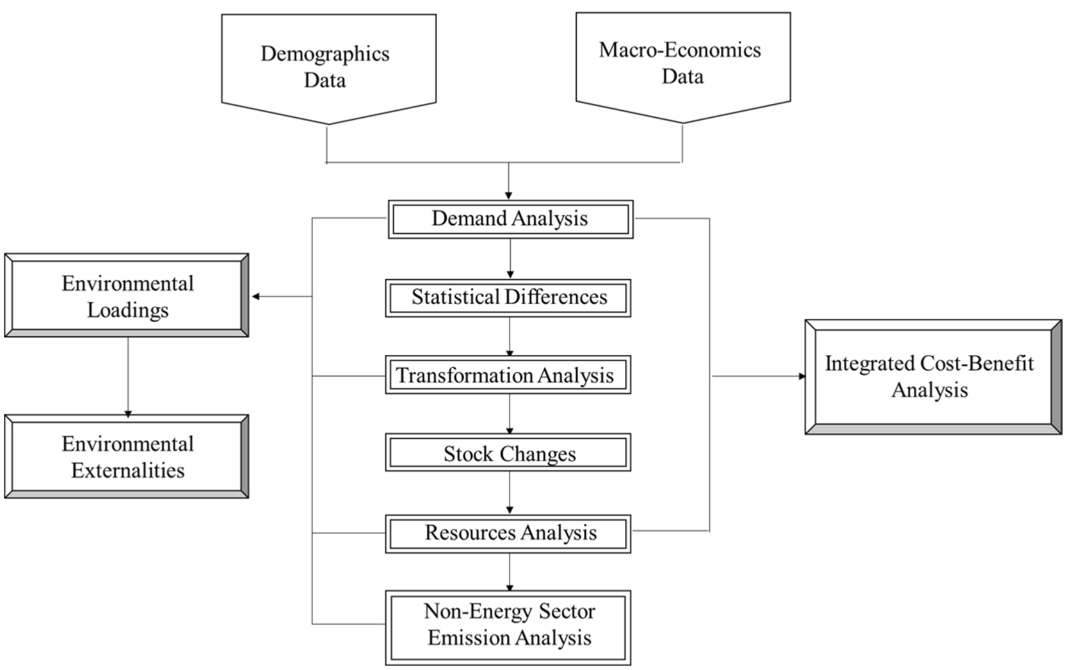


Fig. 1 LEAP modeling framework

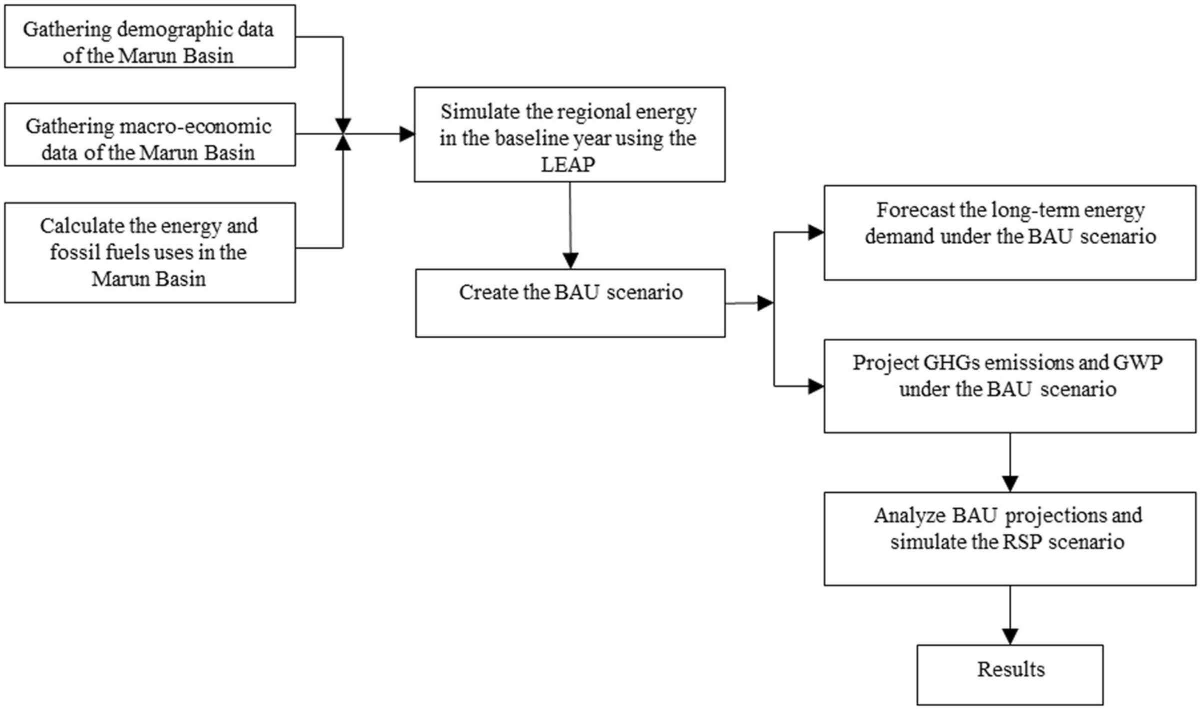


Fig. 2 The flowchart of this paper's methodology

$$GWP(x)=\frac{a_x \int_0^{TH}[x(t)]dt}{a_r \int_0^{TH}[r(t)]dt} \tag{2}$$

in which *TH* is the time horizon (typically 100 years); a_x is the radiative efficiency due to a unit increase in atmospheric abundance of the gas *x* (in W m^{-2} kg^{-1}); $[x](t)$ denotes the time-dependent decay in abundance of gas *x* following an instantaneous release of it at time $t = 0$; a_r is the radiative forcing due to a unit increase in atmospheric abundance of the reference gas (CO_2); and $[r(t)]$ is the time-dependent decay in abundance of CO_2 following an instantaneous release of it at time 0.

The calculations made by the LEAP model are based on an annual time-step, and the time horizon can be medium or long term.

The LEAP methodology in modeling energy demand is a bottom-up, end-user accounting, and in modeling, the supply side implements a range of accounting and simulation methodologies for modeling energy generation. In general, LEAP simulates all energy sectors, sub-sectors, and technologies within an energy system. The LEAP model first projects the energy demand and subsequently it simulates the energy supply to ensure the sufficiency of primary energy resources to meet the projected demand. Also, LEAP is a scenario-based tool that can be used to model different policy options.

The LEAP model calculates the GWPs for the all major GHGs and other materials based on the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports. The Fifth IPCC Assessment Report is applied in this work (Revised IPCC 1996). The characteristics of the 20-year GWP, 100-year GWP, and 500-year GWP are listed in Table 2. The 20-year GWP, 100-year GWP, and 500-year GWP are calculated based on the radiative forcing and lifetime components. It is common to use projections corresponding to the 100-year GWP.

The greenhouse gas emissions and environmental parameters are calculated based on the basis of tier 1-emission factors as detailed by Intergovernmental Panel on Climate Change (IPCC).

Table 2 GWP values (CO_2 is the reference gas)

Greenhouse gas	Unit	20 years	100 years	500 years	Lifetime (year)
Carbon dioxide (CO_2)	Metric tons	1	1	1	-
Methane (CH_4)	Kilogram	85	30	*-	12.4
Nitrous oxide (N_2O)	Kilogram	264	256	*-	121

*GWP values for methane and nitrous oxide were not reported in the IPCC's Fifth Report Assessment

Case study

This section describes the study basin.

The Marun basin

The Marun basin is located in Khuzestan province in southwestern Iran (Fig. 3). This basin is a part of the Persian Gulf and Oman Sea basins and the Jarrahi-Zohreh. Marun sub-basin. It features an area of 3634 km^2 and is located between 50° 5′–51° 11′ eastern longitude and 30° 39′–31° 21′ northern latitude. The Marun River has a length of 422 km, with headwaters in the Saghaveh, Shoor, Lourab, Charoosagh, and Zagros Mountains. Marun dam, the second largest in Iran, is located on the Marun River 19-km northeast from Behbahan city (Tange Takab). Marun dam's height above its foundation is 170.85 m with crown width and lengths equal to 345 and 15 m, respectively. Its reservoir has a 1.2 billion m^3 storage capacity.

The reservoir is operated to supply agricultural water to a district encompassing 55,000 ha and supplies water to the cities of Behbahan, Haftkel, Ramshir, Baghmalek, Ramhormoz, and Shadegan. The Marun dam provides water and electricity to several cities and areas whose main economic activities are agriculture and fisheries. The installed capacity of the Marun hydropower plant is 150 MW, which has an annual energy production of 190 GWh.

Demographic, economic, and characteristics of the study region

The urban population in the Marun basin was 573,000 people dwelling in 167,000 households in 2016 (Iran's National institute of statistical 2016). The last national population and housing census in Iran was conducted in 2016, and, therefore, this year was selected as the base year in this study. The average population growth rate in the study region is about 1% (United Nations Website, (2018)). Also, the urban population in the Marun basin was equal to 57.7% of the total population in 2016 (Iran's National institute of statistical 2016). It is estimated that urbanization will rise by 80% by 2040 year due to migration from rural to urban regions. Also, 30% of the habitants in the Marun basin do not have access to the national power grid and use fossil fuels instead.

The use of fuels is listed in Table 3 (National Iranian Oil Refining and Distribution Company, 2016), where it is seen that 53% of the total fossil fuel consumption corresponds to natural gas, followed by diesel, gasoline, LPG, and kerosene with 28%, 14%, 4%, and 1% consumption, respectively.

Scenarios under study

This section develops the energy simulation scenarios.

The BAU scenario

The amount of energy demand and greenhouse gas emissions in the period 2016–2040 is based on the trend of changes in the current population, and the current pattern of energy use is applied.

The RSP scenario

The RSP scenario is based on the sixth development plan of the Government of Iran that seeks to reduce greenhouse gas emissions by replacing fossil fuels with renewable energy resources for electricity generation.

The Marun Basin is located in southwestern of Iran and has a large number of sunny days during the year. Gorgani Firouzjah (2018) evaluated the potential of deploying solar power as a source of electricity generation and showed that southern parts of Iran

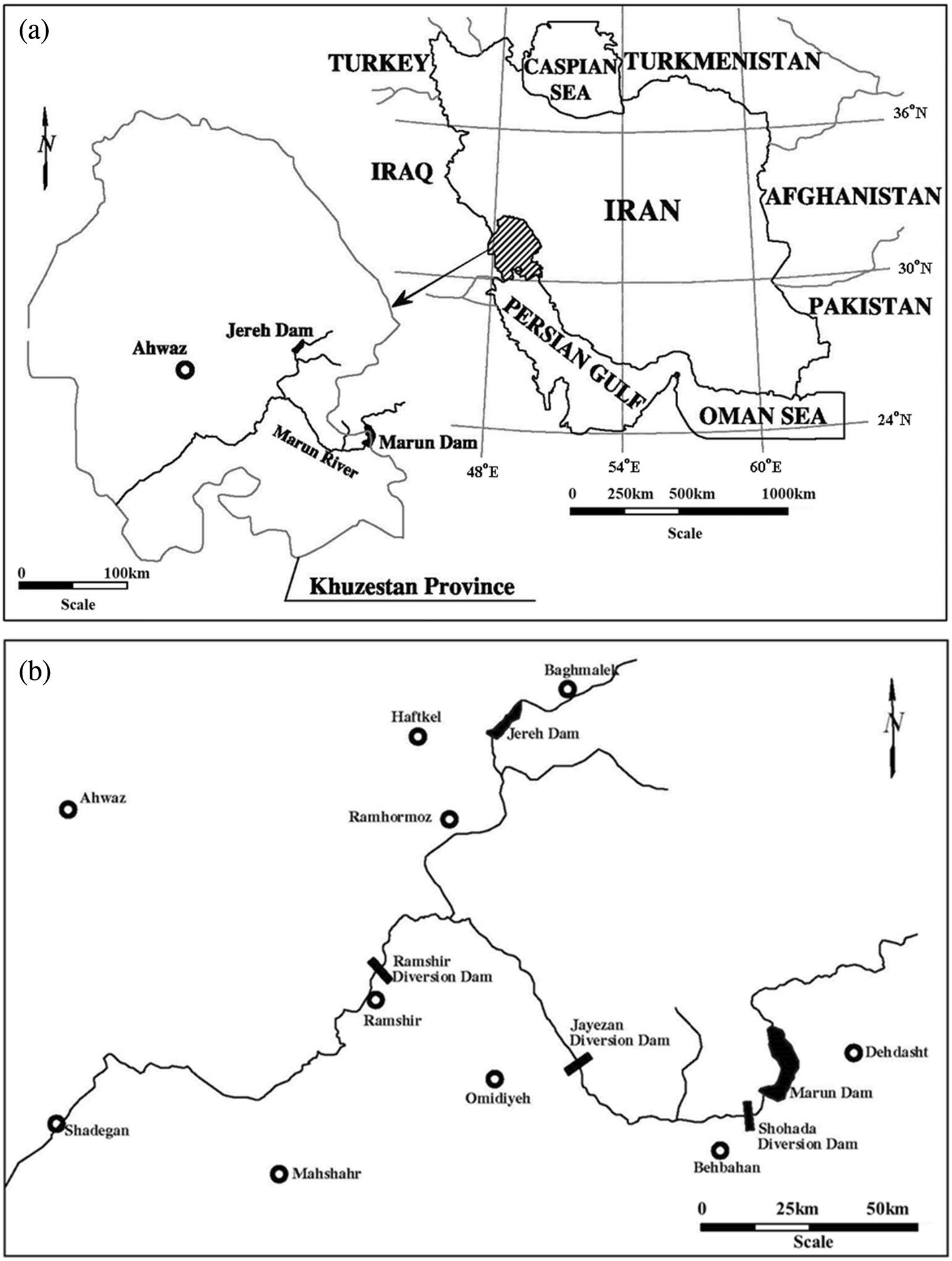


Fig. 3 Location map: **a** regional map and **b** the Marun Basin

are well suited for solar electricity generation. The daily solar radiation that reaches a horizontal surface unit in this region ranges between 3.8 to 4.5 kWh/m^2 (Renewable Energy and Energy Efficiency Organization (SATBA) (2018)). Selecting the best location for capturing sunlight with residential solar panels was

Table 3 Percentage of use for each type of fossil fuel in the Marun basin

Type of fossil fuel	Percentage of use
Natural gas	53
Diesel	28
Gasoline	14
Kerosene	1
LPG (liquefied petroleum gas)	4

based on climatic data gathered at the Behbahan and Ramhormoz synoptic stations in the Marun basin (Iran meteorological organization, Iran weather stations database., 2019). The climatic parameters for Behbahan and Ramhormoz cities in time interval (1994–2016) are listed in Table 4. Comparison the climatic parameters of the two above stations shows that Behbahan city has a higher potential for the residential solar panel application due to the larger number of sunny days, lower relative humidity, and fewer cloudy and dusty days than Ramhormoz city.

The RSP scenario assumes that households meet their electricity needs from photovoltaic (PV) solar panels. This scenario prescribes that the rural regions of Behbahan city would meet their electricity use with residential solar panels thus reducing 20% of its diesel consumption. The scheme of the off-grid PV solar panel system is depicted in Fig. 4 (Hicks, 2017).

The nature of the off-grid PV system is based on the “storage and use” mode. This type of system contains: (a) PV array with charge controller, (b) battery bank, and (c) direct current (DC) generator.

Figure 4 shows how the PV off-grid system operates. The electricity produced in the solar panels is stored in the battery bank through the charge controller. Also, the charge controller reduces the flow to a certain voltage to avoid overcharge. The DC current is converted to alternating current (AC) current by means of the inverter.

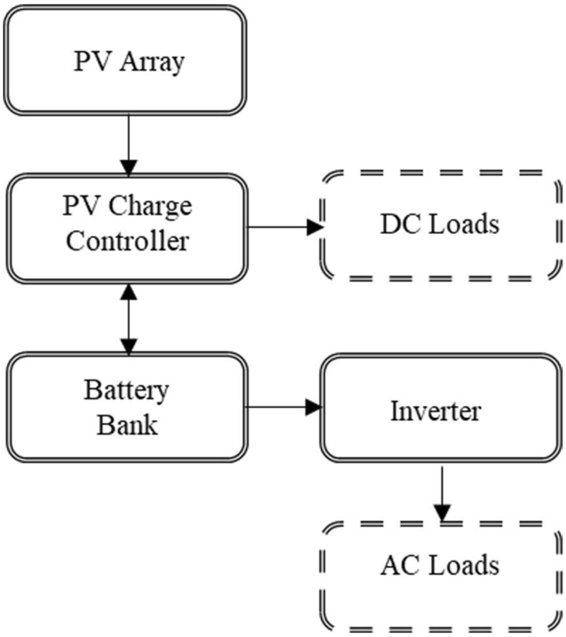


Fig. 4 The scheme of the off-grid PV system

The best places to deploy residential solar panels are those where the national power grid is not accessible or available or it is costly to connect to it. This is the case in the rural regions of the study area (Tan & Seng, 2012). The off-grid photovoltaic system has no requirement of a regional electric grid, no network transmission system and maintenance, no requirement for fuel and fuel-distribution logistics, low maintenance cost, and long lifespan.

The residential solar panels are made of polycrystalline planes with dimensions of one by 2 m which combine silicon crystals, and their efficiency is between 11 to 14% (ICE60364-7–712, 2017), this means that 11 to 14% of the solar electromagnetic energy received by a panel is converted to

Table 4 Climatic data for the Behbahan and Ramhormoz synoptic stations

Climatic parameters	Longitude (degree)	Latitude (degree)	Height (m)	Number of dusty days	Number of cloudy and partly cloudy days in 1 year	Relative humidity (%)	Sunny hours in 1 year
Bebahan	30° 36′	50° 14′	313	65	24	42.6	3248
Ramhormoz	31° 16′	49° 36′	150.5	87	29	39	3155

electricity. The PV panels are installed on roofs or surfaces with a slope facing the sun. The roof or installation-surface slope should be approximately equal to the latitude of the deployment site. The solar panels are commonly rated at 300 W.

It is estimated that 323 solar panels are required to meet the electricity demand in the domestic sector based on demographic data and the characteristics of the proposed solar panels.

Results

Calibration and verification of the model

Before describing the LEAP model results, first, the LEAP model is calibrated and validated. In order to calibrate and verify the LEAP results, the model outputs will be compared with the observed values of domestic electricity consumption (Zam et al, 2021) in the intended time interval (2004–2015). In this research, the time interval (2004–2015) is considered. The LEAP model result for domestic electricity demand in the time interval (2004–2015) with considering 2003 as the base year is given in Fig. 5.

In the next step, the results obtained from LEAP were compared with the recorded values of domestic electricity consumption in the time interval (2004–2015) as shown in Fig. 6. Figure 6 shows that comparison between the results obtained from the LEAP model with the recorded observation values for domestic electricity consumption in the time interval (2004–2015) has a little difference.

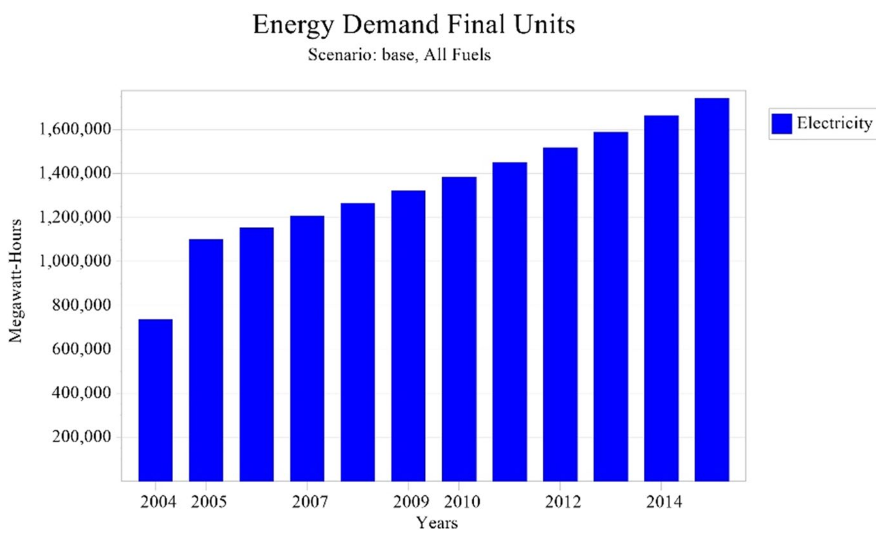


Fig. 5 Domestic electricity demand in the time interval (2004–2015) from the LEAP model

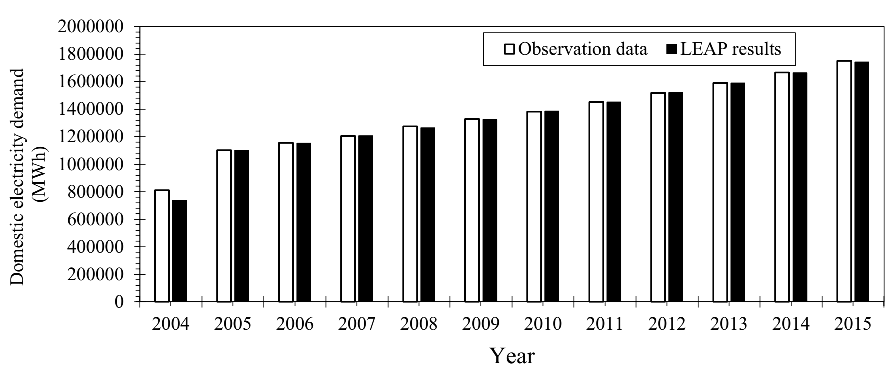


Fig. 6 Comparison of observed domestic electricity demand trends and results from LEAP model in the time interval (2004–2015)

In order to calculate the validity of the results obtained from the LEAP model, two criteria, Mean Absolute Percent Error (*MAPE*) and Mean Square Percent Error (*MSPE*) (Moradi, 2013), were used, which are calculated from the Eqs. (3) and (4), respectively:

$$\text{MAPE} = \frac{\sum_{i=1}^{n} \text{ABS}\left(\left(x_{model} - x_{actual} / x_{model} \right) \times 100\right)}{n} \quad (3)$$

$$\text{MSPE} = \frac{\sum_{i=1}^{n} \left(\left(x_{model} - x_{actual} / x_{model} \right) \times 100\right)^2}{n} \quad (4)$$

in which x_{model} is the values from LEAP model, x_{actual} is the observation values, and n is the number of observation years.

The results show that the values of *MAPE* and *MSPE* criteria are 0.77 and 0.92, respectively, which indicates that the performance of the model is accurate and the results are reliable for the future time interval.

Energy demand analysis and greenhouse gas emissions under the BAU scenario

The projections of electricity and fossil fuels demand for the urban sector calculated with the LEAP model are presented in Figs. 7 and 8, respectively. Figure 7 shows that urban electricity demand would increase from 1783 MWh in 2016 to 2341 MWh by 2040. This means that electricity demand under the BAU scenario would rise by 31% during 24 years. The urban fossil fuel projections shown in Fig. 8 indicate that natural gas consumption would equal 329 barrels of oil equivalents (BOEs) in 2016 and would rise to 514.7 barrel of oil equivalents by 2040. The natural gas consumption would rise from 203 BOEs in the baseline year to 267 BOEs by 2040. Gasoline, liquefied petroleum gas (LPG), and kerosene consumption were 105, 31.9, and 4.3 BOEs, respectively, in 2016 and are projected to rise 139, 42, and 5.7 BOEs, respectively, by 2040. The total fossil fuel consumption would increase from 738 BOEs in 2016 to 968 BOEs in 2040. This means that fossil fuel consumption would rise by 31%.

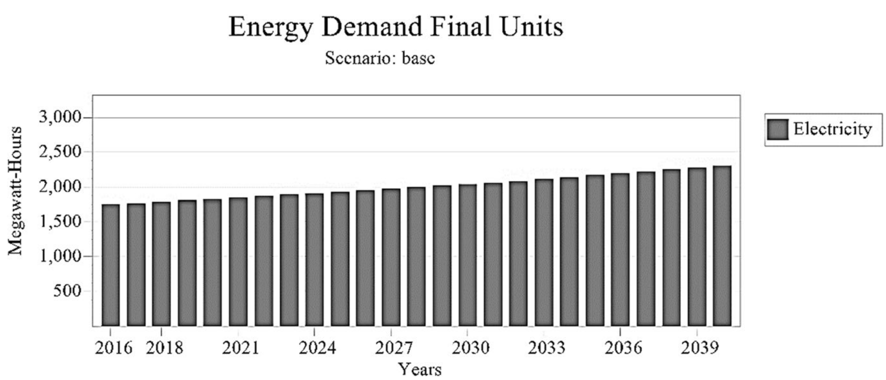


Fig. 7 Forecasts of the urban electricity demand 2016–2040

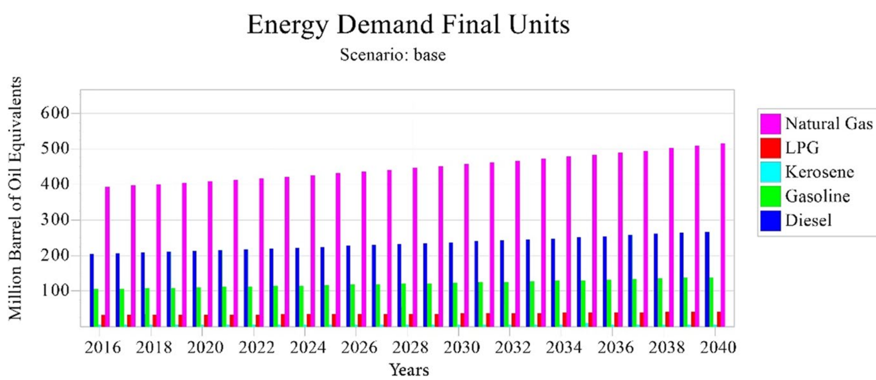


Fig. 8 Forecasts of fossil fuels use in the urban sector

The increase in energy use in the urban sector is due to the rise in population and urbanization. Therefore, population and urbanization play a key role in the energy use portfolio, and any policy to control these two variables would be effective in influencing the trend of energy use in the study area.

The energy intensity level, i.e., the ratio of energy use to economic output reflects economic performance and energy efficiency conditions. Iran has high energy intensity (low productivity) (Taherahmadi et al., 2020) so that the average energy intensity is 40% higher than in the rest of the world (Global Energy Statistical Yearbook (2019), Enerdata).

In addition, the energy use and GDP are intertwined so that energy supply affect economic and social development of a region, and GDP alters the energy demand. Therefore, forecasting energy demand is vital for future planning in the socio-economic and cultural sectors.

Figure 9 indicates that the annual fossil fuels demand growth rate would be approximately 1.1% in the agricultural sector. Natural gas is projected to have the largest growth rate among the fossil fuels due to the larger availability and lower pollution compared to other fuels. The demands for other fossil fuels would also increase but at rates smaller than the growth rate of natural gas. In order of decreasing growth rate the fuels would be diesel, gasoline, LPG, and kerosene. The projected growth rate of fossil fuels use may not appear large; yet, considering the increase of fossil fuels prices in the coming years and

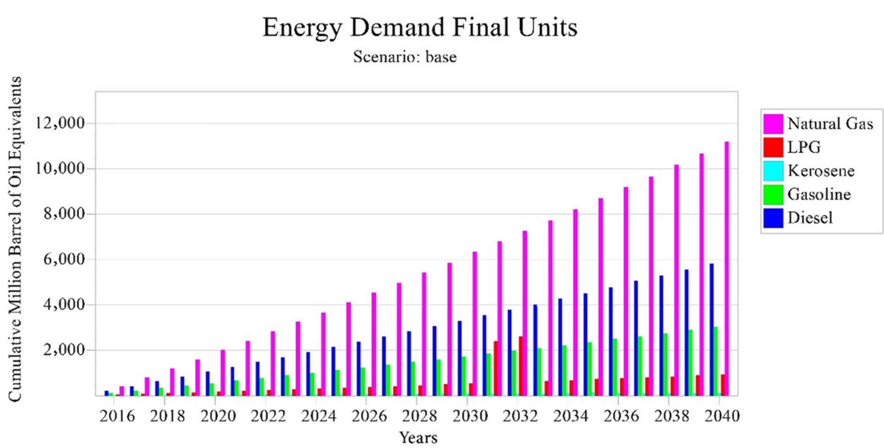


Fig. 9 Projection of cumulative demand of fossil fuels in the urban sector

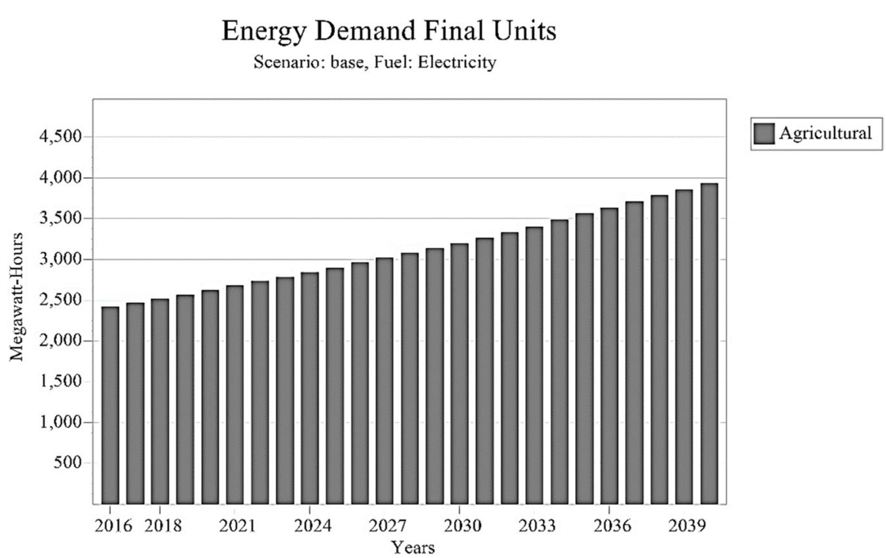


Fig. 10 Forecasts of agricultural electricity demand

the associated air pollution the growth rate must be reduced by means of alternative energy use.

The projection of electricity demand for the agricultural sector with the LEAP model is shown in Fig. 10 where it is seen that agricultural electricity demand per hectare in the Marun basin would rise from 246 MWh per hectare in 2016 to 395 MWh, i.e., about 61% increase. Electricity consumption in the agricultural sector is significant due to the vastness of farm lands. Traditional irrigation methods and old infrastructure for supplying electricity have caused rapid rise in electricity consumption in the study region.

GHG emissions and the GWP

The use of fossil fuels accounts for 86–90% of total GHG emissions in Iran (NCCOI, 2014). The total CO_2 emissions from fossil fuels in the forecast period are shown in Fig. 11. The CO_2 emissions rate with the current use pattern would increase from 27.33 million metric tons in 2016 to 35.87 million metric tons by 2040, i.e., a 31% increase.

The other major air pollutants in the region are carbon monoxide, non-methane volatile organic compounds, nitrogen oxide, and sulfur oxide. The emission rates of each pollutant are shown in

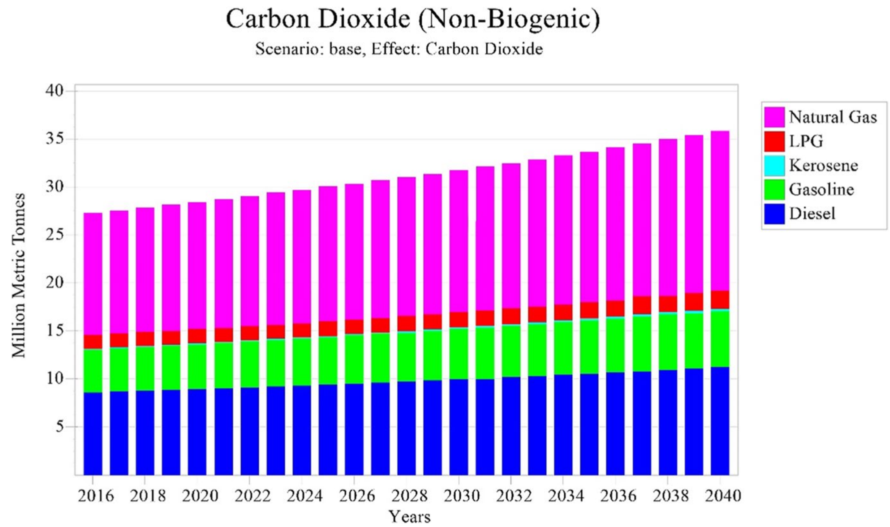


Fig. 11 Projected CO_2 emissions under the BAU scenario

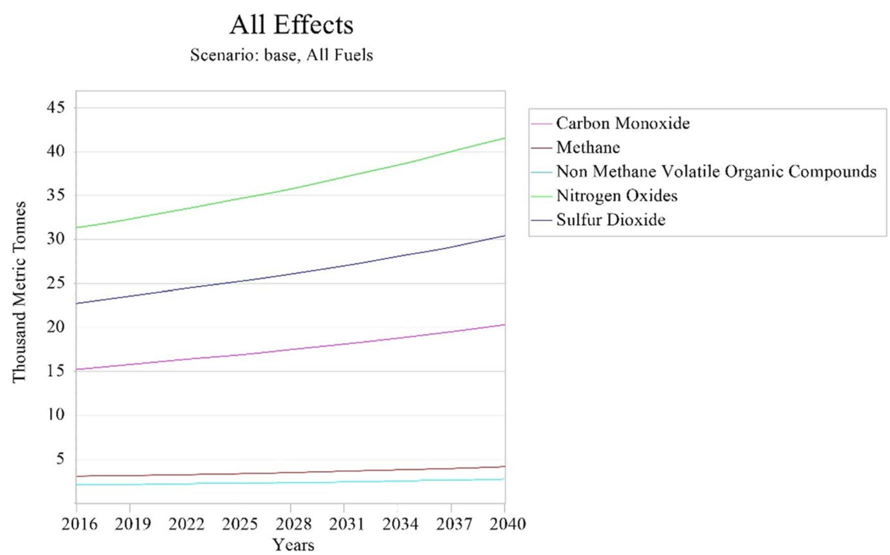


Fig. 12 Projected emissions rate of several air pollutants under the BAU scenario

Fig. 12, where it is seen that nitrogen oxide would account for most of the pollution in the study region after CO_2 and would increase from 32 thousand metric tons in 2016 to 41 thousand metric tons by 2040. The emissions of nitrogen oxide in urban areas cause respiratory illness. Therefore, clean energy would limit the nitrogen oxide emissions in the study region.

Another air pollutant is sulfur oxide, whose emissions and changing rate are significant. Sulfur oxide emissions in 2016 were 23 thousand metric tons and would increase to 30 thousand metric tons by 2040. Sulfur oxide emission is mainly due to diesel fuel burning and is a notorious air pollutant because of its adverse environmental impacts. Carbon monoxide is another air pollutant of concern from a health standpoint due to its toxicity that would increase from 15,000 metric tons in the baseline year to 20,000 metric tons by 2040. The LEAP projections indicate the share of pollutants emissions for gasoline, natural gas, diesel, kerosene, and LPG are 16.4%, 46.5%, 31.5%, 0.67%, and 5.0%, respectively.

Figure 13 depicts the 100-year GWP variation for types of energy in the period 2016–2040 in the Marun basin, where the 100-year GWP for the natural gas would be the largest and grows rapidly during the forecast period. The 100-year GWP expressed as the CO_2 equivalent would increase from 12.76 million metric tons in 2016 to 16.74 million metric tons by 2040. Also, gasoline's 100-year GWP would rise from 8.65 million metric tons to 11.35 million metric tons during the forecast period. The cumulative 100-year GWP values for all types of fossil fuels in the study region are displayed in Fig. 14, where it is shown that the cumulative 100-year GWP values due to fossil fuel consumption was 27 million metric tons in 2016 and would rise to 36 million metric tons by 2040. The ascending trend of 100-year GWP is a harbinger of things to come concerning energy and water resources in the Marun basin. The ascending trend of the 100-year GWP means increasing air temperature and possible reduction of reservoir inflow. The reduction of reservoir inflow would mean smaller reservoir water releases from the Marun dam, and, therefore, declining water supply and hydropower generation.

RSP scenario results

The results of the LEAP model indicate the use of solar panels to supply electricity instead of diesel would reduce CO_2 emissions in the period 2016–2040 by 17% compared with 2016 emissions, i.e., its emissions rate would be 22.68 million tons in 2040, which means a reduction from 29.7 million tons in 2016. The CO_2 emissions under the RSP scenario and avoided value against BAU scenario are depicted in Fig. 15. According to Fig. 13, the avoided value of CO_2 emissions was positive that means the CO_2 emissions have been reduced in RSP scenario. Also, among air pollutants, sulfur oxide would decrease by 31% compared to the BAU scenario in 2016 equal

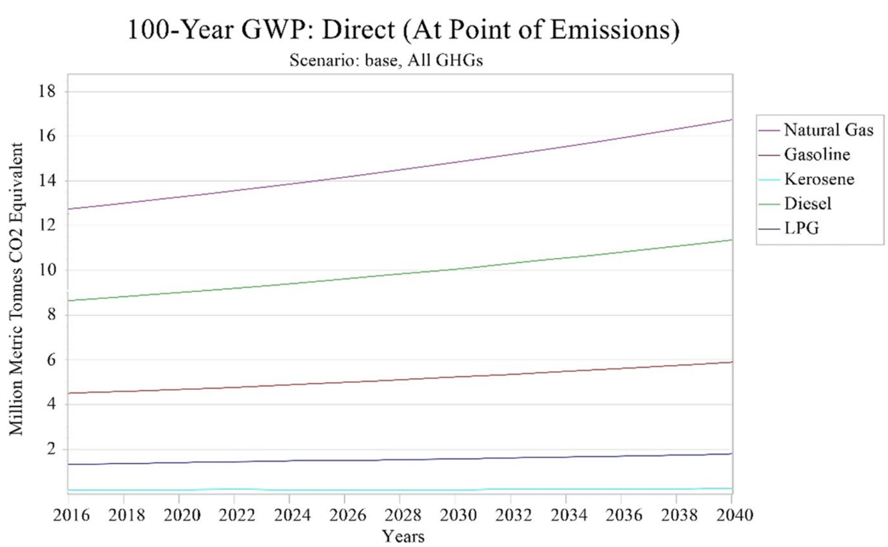


Fig. 13 100-year GWP year projection under the BAU scenario

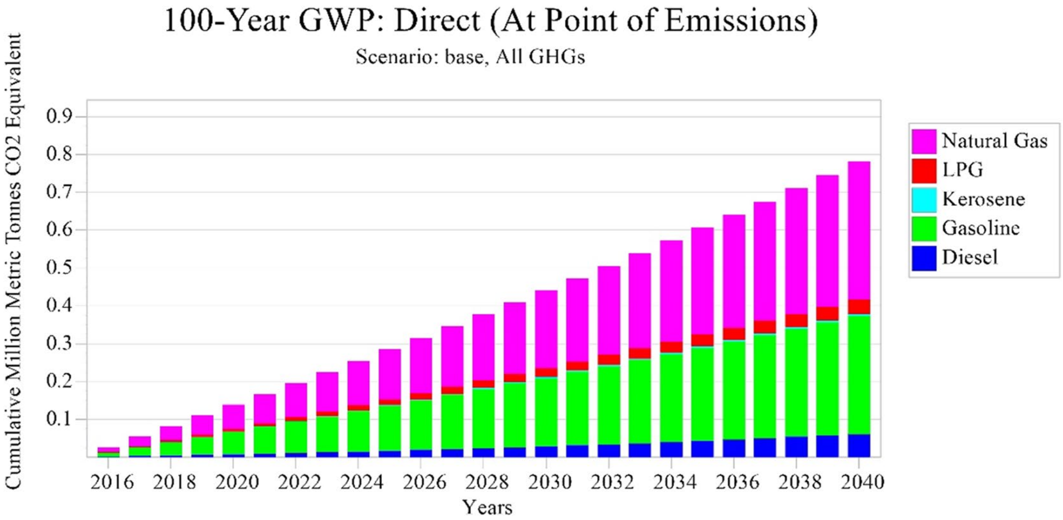
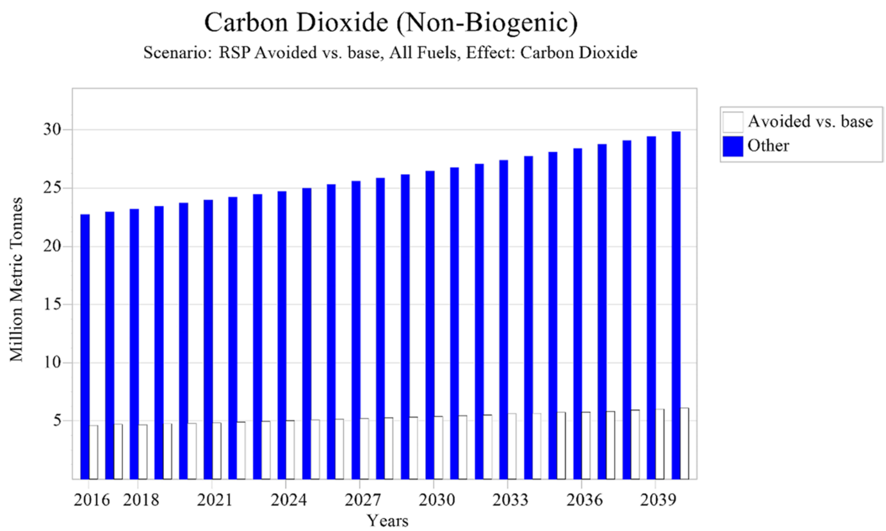


Fig. 14 Cumulative 100-year GWP projection under the BAU scenario

Fig. 15 CO_2 emissions under the RSP scenario and avoided emissions of Co_2 vs. base scenario



to 15.8 thousand metric tons, this being the largest reduction among the air pollutants.

Carbon monoxide with 20% (12.3 thousand metric tons) reduction compared to the BAU scenario would have the second highest emissions reduction after sulfur oxide. These results project significant reduction in CO_2 emissions and other pollutants by replacing 20% of diesel consumption with solar energy.

The only current source of electricity generation in this region is the Marun dam's power plant, whose electricity generation will be subject to variation resulting from climate change. Therefore, reliance on renewable solar energy would reduce greenhouse gas emissions and provide sustainable electricity. Household surplus electricity generated could receive credits, and the surplus electricity can be delivered to the national electric transmission grid thus increasing household income while raising the national electricity production.

Concluding remarks

This study presented long-term forecasting energy demand over a time interval of 24 years (2016–2040) with the LEAP model in the Marun basin, Iran. For this purpose, demographic and macro-economic data were collected in the urban areas and used as baseline conditions in the LEAP model. Next, electricity and fossil fuels use in the urban and agricultural sectors were simulated with LEAP for 2016. This was followed by application of the reference scenario and the rate of change in energy use. Lastly, the energy demand and GHGs emissions were projected for future years.

This paper's results demonstrated that if the current consumption pattern in the demand sectors continues the urban electricity consumption in the forecasting in 2016–2040 would increase from 1783 to 2341 MWh, i.e., a 31% rise. The agricultural electricity consumption would increase from 261 MWh per hectare to 395 MWh per hectare, equivalent to a 61% increment.

The total fossil fuel consumptions in the urban sector would increase from 738 in 2016 BOE to 968 BOE in 2040. This amount of fossil fuel consumption and its growth rate in the coming years implies significant rise in GHGs emissions. Concerning the use of fossil fuel it was herein established that the GWP-100-year value would increase by 31% based on the LEAP projections.

The RSP scenario of replacing diesel fuel use with household solar panels in the Marun region was modeled in LEAP. The results show that CO_2 emissions would be reduced by 17%. Applying the RSP scenario would reduce CO_2 emissions and the cost of providing fossil fuel carriers and electricity transmission to residents.

The trend of energy demand is relevant given that the only source of electricity in this region is hydropower. Hydropower is clean energy generation in that it does not produce greenhouse gas emissions; on the other hand, besides reservoir sedimentation, hydropower generation may be disrupted by declining reservoir inflow associated with climatic change.

Therefore, increasing the reliance on renewable energy sources would be a timely investment in Iran. This study's findings are intended to assist policymakers to identify the potential and capacities of different regions to achieve sustainable development in Iran and other regions of the world.

This study also demonstrated the value of considering rural areas in long-term energy sector planning. A well-balanced distribution of energy resources at the national level is based on the development of infrastructure at the regional and local scale. This work has shown the potential benefits of deploying solar energy in rural areas.

The authors deployment of renewable wind power should be considered in the study area due to its potential there (Kashani et al., 2013) in association with solar-produced electricity to reduce reliance on fossil fuels in the domestic sector.

Limitations

The LEAP approach is data-intensive. Lack of accurate data about the evolution of energy use is a source of uncertainty in LEAP-based modeling.

LEAP implements accounting methods, and the influence of economic factors such as energy prices is difficult to project when evaluating different development scenarios of energy technologies.

Recommendations

One of the most important demographic parameters for projecting future energy demand is population growth. This work projects population growth based on the historical demographic trends in the study region, which may change in the future due to governmental policies. Therefore, it is recommended to evaluate the sensitivity of the model results by low and high rates of population growth.

One of the key capabilities of the LEAP model is cost–benefit analysis. It is recommended that the cost–benefit analysis be performed for the BAU and RSP scenarios.

Solar panels must be cleaned clean to optimize performance. There, it is recommended that a PV-hybrid system be used. Such system incorporates alternative energy sources, such as power generators, for use as an auxiliary power source during cleaning of solar panels and during cloudy days when solar insolation is negligible.

Policy recommendations

This work's results contribute to achieving the goals set for the energy sector in the National Development

Plans (NDP) in Iran. The NDP calls for a reduction of CO_2 emissions and the development of renewable energy sources (Renewable Energy and Energy Efficiency Organization (SATBA) (2018)).

Iran has large deposits of fossil fuels and natural gas and is well endowed in terms of renewable energy resources such as wind power, solar, thermal, photovoltaic, biomass, biogas, and hydrogen energy (Bahrami and Abbaszadeh, 2016). These alternative sources of energy should be considered in the Economic, Cultural, and Social Development of Iran.

This work's results are applicable to local and national policy-making to achieve national development goals, among which the expansion of solar energy is possible given that on average there are 300 clear days annually and there are large areas of available land to deploy solar projects in Iran (Shahsavari et al., 2019). The private sector can be encouraged to in the development of solar electricity in line with Iran government policies using tax incentives and competitive loans. This study reveals the value of local studies on renewable energy because they can be scaled up to reach national deployment with the ultimate result of diminishing the reliance on fossil fuels, reducing greenhouse gas emissions, and improving economic diversification.

Data availability Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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