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Impact of Demand Side Management on Consumption of Residential Consumers with a Photovoltaic System in Libya

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***Abstract*—the increasing demand for electricity continues to be a major challenge which leads to obvious outages. Demand-side management (DSM) is an essential tool towards addressing these challenges. Local electricity consumers in Libya suffer from daily load shedding and they pay prices for electricity that do not vary from hour to hour, but are rather a kind of average price supported by the government. This price has been set as an obstacle to understanding the effectiveness of incentives and different interventions. The main question is whether we can assess energy management and renewable energy interventions in customer behavior. Currently, behavioral changes can only be assessed in terms of total consumption. It is also difficult to assess the effectiveness of renewable energy inputs. Therefore, it is difficult to validate renewable energy inputs (PV) and demand-side management at the residential sector level, apart from following plans, subsidies and other initiatives adopted by the government. In this paper, the possibility of using PV system as a demand side management tool at residential community level has been investigated to see if it would be possible to shave some of the load from peak hours.**

Keywords— Demand Side Management, Load Shifting, Residential Community, Renewable Energy Interventions.

I. INTRODUCTION

The electricity demand or load variation in the power network is varying from time to time. Meeting the electricity demand, especially during peak hours, poses a major challenge. Demand Side Management (DSM) is the procedure of scheduling and implementation of activities designed to impact consumers in such a way that the utility load curve shape could be altered to produce power in optimally. It monitors activities on the consumer's side of the meter to modify the amount or timing of energy use. DSM provides a variety of technical and behavioral solutions to modify electricity use and demand and therefore increases the efficiency and reliability of power systems [1]. Demand side management of the load studies not only technical or economic issues, but also social measures, since these are all related to behavioral issues. The DSM programs have focused on how to manage the consumption pattern of electrical appliances by minimizing the negative impacts on consumers [2]. Load management measures can be divided into direct and indirect. Direct load management (DLM) is based upon technological actions and controls the consumed load by directly switching dissimilar appliances on or off [3]. Indirect load control is a way by which the consumer controls load reduction of power by means of a price signal (economic measures). Different tariffs and pricing mechanisms are introduced in order to encourage consumers to modify their load consumption.

The common load shedding scheme in utilities is based on the necessity to eliminate load quickly in the occurrence of a loss of generation and therefore is undertaken automatically as part of the response from protective relays [4]. Figure 1 illustrates different load shape objectives of demand side management programs. These include: peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape.

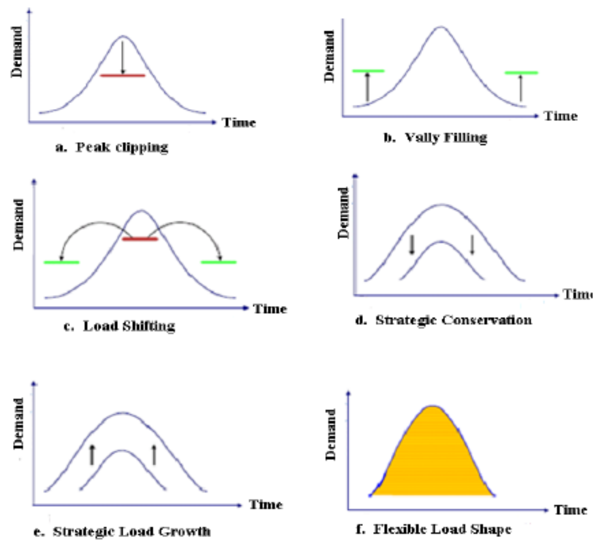

Fig.1. Demand side management load shape curves [5]

In 2020, Libya produced about 30.09 TWh of electricity, of which 99.9% by fossil fuels, and 0.1% by other renewable energy sources. The final consumption of electricity was 25.404 TWh [6]. The peak consumption has reached 7.5 GW in the summer, while the peak winter load reached 7.2 GW, leaving a power deficit of nearly 3.0 GW. Figure 2 shows Electricity net generation and consumption in Libya. The residential sector accounts for the highest share of the demand for electrical energy, which represents 36% of the whole electricity generated, followed by 23% in others,14% represents the commercial/industrial sector as shown in Figure 3.

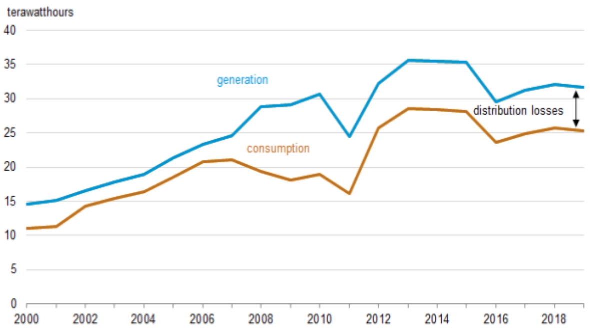

Fig.2. Electricity net generation and consumption in Libya [6]

Libya, which has electricity interconnections with Egypt and Tunisia, started to import meaningfully extra electric power from these countries after 2015. Libya's electricity imports reached nearly 0.5 TWh in 2019 [7].58 Egypt plans to expand its interconnection capacity to Libya from 240 MW to at least 500 MW [8].

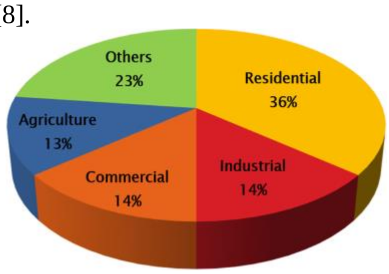

Fig.3. % of Electricity Consumption by Sector [5]

Libya is part of North Africa's interior and has an area of 1.75 square kilometers, with huge resources of renewable energy which is considered one of the highest solar radiation rates in the world. Most of this area can be considered a hot sunny desert which helps generate solar energy as a renewable source. The average annual solar radiation is 2,470 kWh/m^2/year, while the potential of the solar energy source is estimated at 140 × 10^6 GWh/year per hour/year [8]. Given that Libya lies on the Tropic of Cancer in North Africa's interior, it is exposed to sunlight throughout the year with long hours exceeding 7.2 from the global horizontal irradiance (GHI) in the south. With its distinctive geographical location and immense potential resources, Libya is capable of producing enough renewable energy for local use and can be exported abroad.

Solar power makes up an insignificant amount of power production in Libya, as it has no utility-sized plants. All solar energy in Libya comes from small-scale projects such as mini-grids at hospitals and public lighting projects. The Libyan government pursues to spread its energy supply and aims to produce 22% of its electricity from renewable sources by 2030 [10]. Although this goal is ambitious, Libya's huge solar potential has attracted many foreign investors. Furthermore, to its recent investment in Libya's oil and natural gas sectors, Total Energies intends to develop 500 MW of solar power projects in the country [11]. Libya has also discussed solar power projects with ENI and Shell.

The cost of photovoltaic systems has dropped dramatically over the past years from around $100/watt. In the mid-1970s, rooftop PV modules cost is now about $0.40/watt. This lower cost, combined with a growing desire on the part of customers and governments to lower significant fossil fuel-based carbon emissions, have aided as major drivers for several countries to increase or maintain a stable rate of PV installation [12].

Over the years several studies have previously looked into the effectiveness of photovoltaics as a load management tool [13-18]. In [13], demand-side management approaches in Qatar were presented to allow load reduction and PV integration. The results showed that the government efforts in improving energy efficiency might be reinforced by pricing-based tariffs to further improve the energy savings. In addition, we presented a case study in which the local utility able to control the AC units of the people who leave the state throughout summer months. Moreover, the result showed that because of local weather conditions, PV deployments of large scale might need integrating DSM techniques for a more responsive consumer load. In [14] a simulation model to study decentralized household DSM in a residential distribution network which consists of multiple smart homes with schedulable electrical appliances and some rooftop photovoltaic generation units was developed. Numerical experiments are achieved to inspect the adoption of dynamic pricing signal, through load shifting of lithe appliances in a household. It is found that the demand side management without high penalty for load shifting inconvenience will most efficiently flat the load profile. In [15], the potential for achieving high level of building self-sufficiency using hybrid PV-ESS-DSM solutions was investigated. Based on real measurements of electrical power, the Self-Sufficiency Ratio (SSR) and Self-Consumption Ratio (SCR) indices of various buildings equipped with PV and Battery Energy Storage Systems (BESS) that are located in Cyprus, Greece, and Italy are examined. The analysis exposed that using of DSM rises both indices, whereas it also influences the degree of battery utilization. In [16], demand response programs (DRPs), along with home energy management system (HEMS) strategies, were studied. The study showed that the economic gain and the reduction of peak-average-ratio resulted by load shifting within pre-defined thresholds that are set by the consumer. [17] proposed a real-time demand response strategy for optimum scheduling of smart home devices taking into account the uncertainty of consumer's behavior and real time electricity price in order to reduce electricity bills. In [18], a totally free CO_2 emission renewables micro-grid project using DSM in Japan was presented. For this purpose, storage units and a load shift algorithm are efficiently applied to exploit the excess renewable energy. The study illustrated that the use of surplus PV energy through the demand side management decreases the required capacity of the battery and rises the SSR of the microgrid.

The electrical system in Libya suffers from a severe shortage in electricity production, where there is a large gap between demand and production. This is addressed through the electricity rationing program for subscribers (load shedding process), making it difficult to maintain continuity of electricity supply for domestic use. Given the availability of vast solar energy sources in all parts of Libya, efforts are being made to increase investment in alternative and renewable energy sources to meet the increasing energy needs and exploit other available resources to provide more energy. Therefore, exploring the available options for the energy sector in Libya, especially regarding the potential use of renewable energy as one of the country's main sources, is of great importance for study and research. Therefore, researching the available options for the energy sector in Libya, particularly in regards to the potential of using renewable energy as one of the country's main sources, is of great importance for study and research. Additionally, advances in photovoltaic energy conversion systems make this use viable from both an economic and technical perspective.

In this paper, the possibility of using a rooftop PV system as a demand side management tool at residential community level has been investigated to see if it would be possible to shave some of the load from peak hours.

II. METHODOLOGY

In order to design a photovoltaic conversion system (PV) and evaluate its potential contribution to energy consumption, it is necessary to know the amount of solar radiation available at the site. Since the outputs of photovoltaic energy conversion systems depend mostly on the density of solar radiation during the day, the data inputs to be used are: average direct solar irradiation falling on the horizontal plane per unit area at hourly basis for the selected site, furthermore, The summer load profile at five minutes basis representing a real measured data samples of the residential sector provided by the Navigant Consulting (Navigant), and Global Energy and Technology Consulting (GETCON) who were contracted by the General Electricity Company of Libya (GECOL) to provide an assessment of the demand side management (DSM) potential in Libya is assumed to be used as the load of hypothetical building[19]. The roofs of proposed residential buildings will be used to install a solar energy system. The methodology followed in this study can be summarized as follows:

1- Getting the data of solar irradiance, which is the amount of solar energy falling on a unit area per unit time and measured in (Watt/m^2), for each month and daily hour.

2- 2- Calculating of the energy produced by photovoltaic systems.

3- 3- Study of loads in terms of their nature, quantity, pattern and relationship with time.

4- 4- Calculation of energy consumed from traditional energy sources (public grid) and the potential surplus that could be exported to the public grid if a photovoltaic system is connected to the public grid to supply a residential area.

5- Estimation the amount of carbon dioxide (CO_2) avoided in the presence of a photovoltaic system power generation.

Installed photovoltaic systems on buildings can supply the appliances inside the building with electricity directly, or export electricity to the main power grid (Figure 4). Electricity is only exported when the generated energy is greater than the loads consumed by the building. This can happen often when photovoltaic energy generation is high, as in mid-day, and electricity consumption is low as people are at work. The direct provision of photovoltaic electricity to the building load reduces the need to import energy from the grid and thus reduces electricity bills for residents.

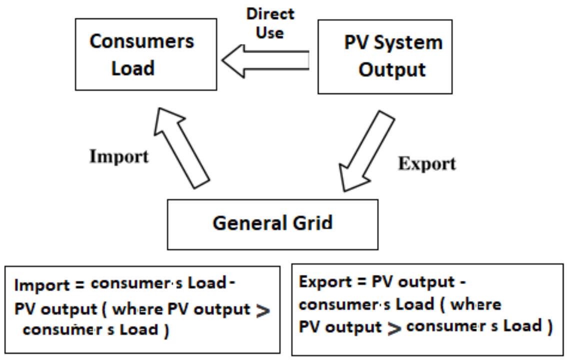

Fig. 4. Electricity flows in a grid connected building integrated PV system

A. Sources of Data

In this study, two types of data were used to understand the feasibility of using solar energy conversion systems for local consumption. These data consist of daily load data for the hypothetical building used in this study, located in the Karimiya area. The daily load profile has been obtained from [19], and solar radiation intensity data for the study area obtained from NASA's website, where NASA has produced a world map with available information according to latitude and longitude.

III. RESULTS AND DISCUSSION

Solar radiation data is crucial in order to conduct performance analyses of photovoltaic systems. Hourly radiation data, at Al Krimiya area , has been considered as the taken into account for the calculations. This region reflects Libya's climatically distinct coastal regions with a high population density. Al Krimiya is located at 32.748°, North latitude, 13.100000° East longitude, (32°44'53", 013°06'00"). The average solar irradiation for the selected site was obtained from the NASA website [18]. NASA has produced a grid map of the world with information available for any given latitude and longitude. The Solar irradiation (in KWh/m^2) for each month and daily hour for the selected location is shown in Figure 5 .

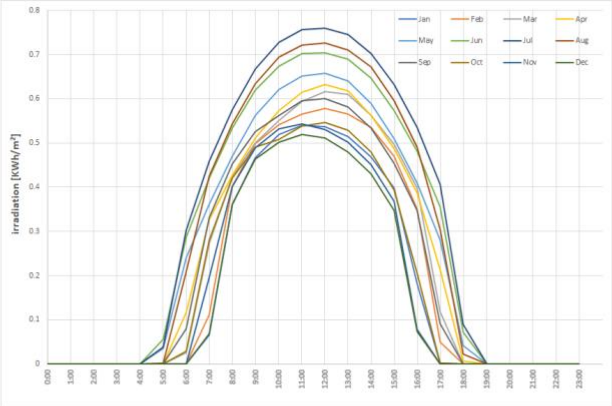

Fig. 5. Solar Irradiation (in KWh/m^2) for each month and daily hour

The measured load profile data which is assumed to be used to hypothetical building was obtained at 5 min intervals, as shown in Figure 6.

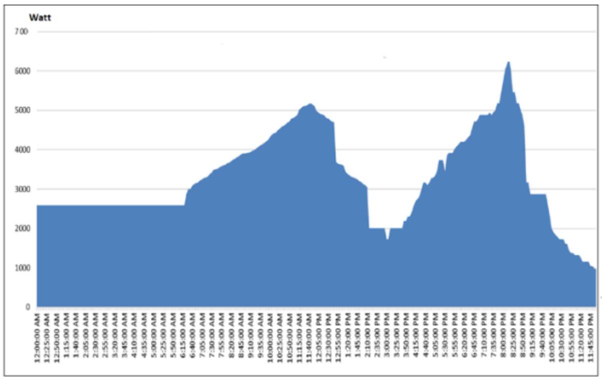

Fig. 6. Summer profile at five minutes basis

By observing the load profile shown in Figure 6, it is noticeable that the total load consumption has two peaks, one in the late morning at about 11:45 am with a maximum load value of 5180W, and the highest peak in the evening. the load is stable with low values from mid night to about 6:30 am (a bedtime).

A. Electricity demand and PV generation pattern

The total amount of electricity generated in output of a photovoltaic system could be estimated using the following formula.

$$E = (A)\times(r)\times(H)\times(PR) \quad (1)$$

Where, E is the PV energy output (kWh); r is the solar panel yield or efficiency (%) (about 0.14), annual average solar radiation on tilted panels (kWh/m2/day) which includes the direct and diffused solar radiation incident on a horizontal PV panel. A is the Total solar panel Area (m^2), PR is the performance ratio, coefficient for losses (range between 0.5 and 0.9). Monthly distribution of solar PV generation

As mentioned earlier, it is evident that PV output is significantly affected by the variability of solar power and load data. Determining the electrical load data gives the first idea of the necessary power required. For photovoltaic systems, the best option is roofing mounted installations. The roofs should be high enough not to be obstructed. Two main scenarios for the calculations and analysis were proposed: first scenario is that the installed capacity is 5 kWp, the second scenario is that the installed capacity is 8 kWp. Area of roofs that are planned to be covered for both scenarios are 60m^2 and 96m^2 respectively.

Given the insolation data previously mentioned and the electricity production per unit area, the total electricity generated by a PV system in hourly intervals for each month within a given site can be calculated and compared to the electricity load consumed.

The PV power is not always generated at the exact time needed by the households. The PV output (in KWh) for each month and daily hour for different months at the proposed location for first scenario is shown in Figure 7.

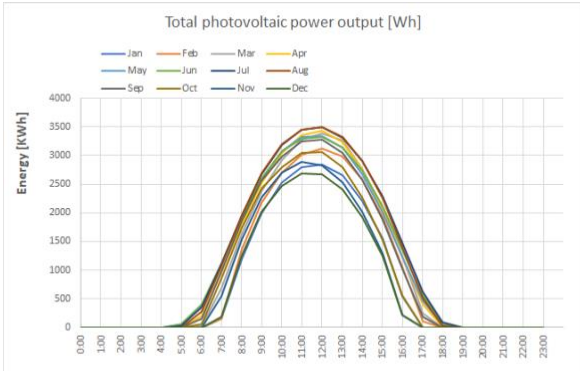

Fig.7. PV output (in KWh) for each month and daily hour

As shown in Figure 8, variations in the output power throughout the year are related to solar radiation fluctuations. Seasonally generated power from photovoltaic panels varies significantly. Thus, in July and August PV energy may is about 1.5 times higher than in January and December.

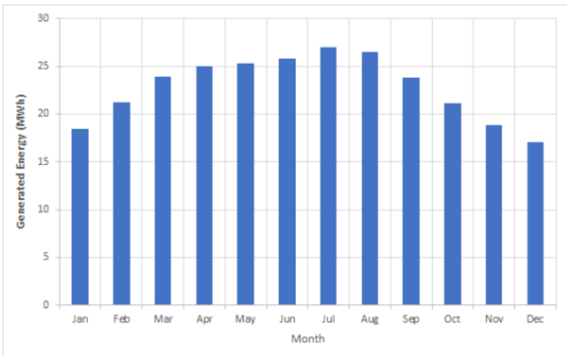

Fig.8. Monthly distribution of solar PV generation

The electricity chart for different months at the proposed location for first scenario is shown in Figure 9. The Figure shows that all produced energy would be consumed on site because the base load is higher than the maximum power output from the PV panels. However, the system could prove economically feasible if the roof area covered with the PV panels was increased. The variance in energy output among months could be explained by dissimilar weather conditions, such as cloud cover and the number of sun-shine hours during the year.

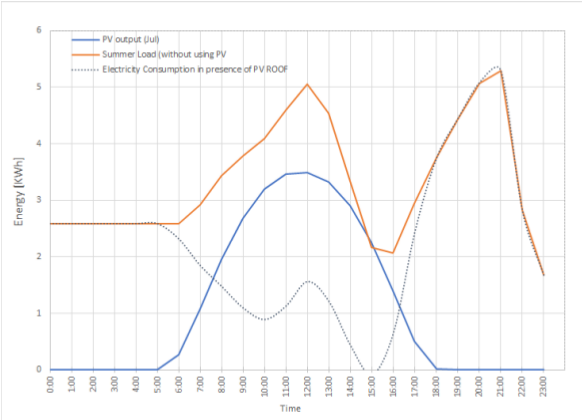

Fig.9. Electricity chart for Jul. (Scenario 1)

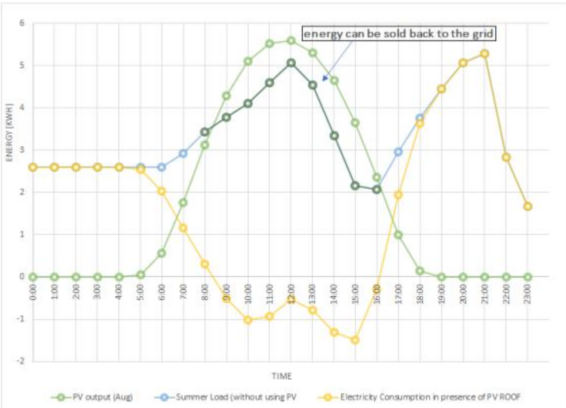

Fig.9. Electricity chart for Jul. (Scenario 2).

The energy generated from the rooftop PV exceeds the load from about 9 a.m. until approximately 16:00 pm (the negative values in the figure). It can be seen that a percentage of the daily load can be shaved to the mentioned hours (load shaving). Nearly the surplus of the energy generated during this period could be exported to the grid (sell back to grid). After 16:00 pm, the load becomes greater than the power generated on site, and the need to use (bought from national grid) power from the national grid starts to rise till all power to be supplied from the national grid to around 18:00 pm. The total electricity used on site can be calculated using the following formula.

$$E_s = E_{imp} + E - E_{exp} \quad (2)$$

Where, E_s= Total electricity used on site, E_{imp} = Imported, E= on-site generated, and $Eexp_{=}$ exported.

The annual average of total photovoltaic power output reached about 8.337MWh and 13.340MWh per year for scenario 1, and scenario 2 respectively. and the annual energy demand of the community was about 29 MWh. As a result the PV panels would produce annually approximately 28.7% and 64% of the energy demand of the whole residential building for the both scenarios respectively. The results showed that the energy that could be exported (6.8 kWh), which amounts to approximately 8.5% of the day's overall consumption, and the building would be an energy exporter for five months of the year.

B. Emission Savings of the PV System

The most significant environmental benefit is reducing of greenhouse gas emissions, especially carbon dioxide. Total emissions in the network come from conventional plants. Only CO2 emissions are considered in this paper. Solar power as a clean source of power has no output emissions. Daily electricity demand level varies at different hours of the day and is being supplied by different generation technologies, resulting in different levels of emissions during the day. Therefore, the amount of emission reduced by solar power depends on levels of solar power and demand. The long-term effect of solar power in the network is considered by giving priority dispatch to solar power. This means that for every MWh of solar generation produced at a certain hour during the day, it is assumed that there will be another MWh of power production that will not need to be produced at a conventional plant, at that particular hour or demand level

For the Libyan grid electricity use, the carbon dioxide emissions factor (2011) is 0.983 kg CO_2/kWh [20]. The annual energy output (AC electricity) of the PV system installed at the proposed site was 8.33 MWh and 13.34 MWh for both scenarios. By generating renewable energy, the PV system will reduce carbon emissions by 204.7 and 327.8 tons of CO2 over 25 years for scenarios 1&2 respectively.

In general, by increasing the photovoltaic system penetration it is expected that there will be a reduction in emission levels, as a result of the energy produced by conventional plants being displaced by solar power. This reduction level varies at different locations where the PV system is installed because of the network's impact. As we mentioned previously in this paper, the proposed electrical system installation on the building rooftop is considered a distributed generator (DG). While the installation of the electrical system is beneficial to consumers, DG offers many benefits to the network. For example, it can contribute to reducing peak loads, provide control over frequency and correction, and delay capital investments that may be required by facilities to meet increasing demand**.**

IV. Conclusion

In this paper, the possibility of using rooftop solar system as a demand side management tool at residential community level has been investigated to see if it would be possible to shave some of loads from peak hours. The study shed light on the ways of benefiting from solar energy as an alternative and renewable energy source and attempted to reach a study of mechanisms that allow its use as one of the energy sources used for domestic use in terms of their economic and technical feasibility. The energy that could be exported (6.8 kWh), which amounts to approximately 8.5% of the day's overall consumption, and the building would be an energy exporter for five months of the year. The amount of carbon dioxide emissions avoided when using photovoltaic conversion systems was estimated. The amount of carbon dioxide emissions avoided can be used to estimate the final cost of the system after taking into account the amounts saved by reducing carbon dioxide emissions, where carbon dioxide has a monetary value deducted from the cost of producing kilowatts for the solar system. The study showed the importance of government support for renewable energy projects so that these projects can offer prices suitable for consumers.

The results of this study lead us to formulate the following suggestions and recommendations:

- The necessity of conducting technical and economic studies for solar cell systems and designing these systems optimally without over-designing to avoid increasing costs.
- Emphasizing the importance of removing obstacles and providing means to encourage wide public participation such as providing easy green loans, qualifying executing companies, and raising awareness of the participants about the financial returns for connecting to the grid.
- Establishing a bank for periodic information necessary for using solar energy.
- Carrying out leading and large-scale projects that benefit the country as another source of energy and training personnel on them.
- Contributing to building national experiences, raising public awareness in energy conservation and renewable energy fields through holding courses, seminars, and other media.
- Setting laws and regulations to reward those who produce clean energy such as solar energy by reducing taxes on producers and giving them privileges over other companies.
- Seek assistance from international partners and enact supportive legislation to raise Libya's renewable energy capacity to a level comparable to neighboring and global countries in order to facilitate the acquisition of technology and a supportive economy.

Finally, this study includes some constraints that can be addressed in future research, such as its exclusive focus on one type of building; thus, this study will be expanded in the future to include additional types of buildings. The economic implications of installing a solar PV system on different types of buildings rooftop can be assessed. In addition, detailed studies could be used to investigate how renewable energy intervention could be used to help improve the load shape. This would help in observing the interaction of renewables with the dynamic behavior of the households. Furthermore, the use of other measures for DSM, such as storage elements, and time of use tariffs were found to be necessary to investigate.

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