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ENERGY SUPPORT IN THE RESIDENTIAL SECTOR USING BUILDING INTEGRATED PHOTOVOLTAIC (BIPV) - A REVIEW

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Over the past decade, there has been significant growth in power demand in Saudi Arabia. This has been due to various factors, including population increase, economic development, advancements in living standards, severe weather conditions, industrial growth, energy use policies, energy source diversification and low pricing energy regimes. It is necessary to use renewable energy sources as one of the solutions to cover and reduce that demand, which is particularly high in the residential sector. The use of solar power systems, such as building-integrated photovoltaic (BIPV) systems, in residential roofs is the fastest and simplest solution. Solar energy utilization could be one of the solutions to generate alternative energy in ways appropriate for the geographical location and other aspects of Saudi Arabia. This study will indicate the impact of this approach, which will have many advantages in supporting residential energy use. This study finds that Saudi Arabia is undoubtedly one of the countries in the world that needs to produce a combination of energy which balances oil production and sales and reduces domestic consumption. Such a balance must also provide sufficient energy to meet the targets of the Saudi economy, especially since most areas of Saudi Arabia are characterized by a very high-temperature tropical climate in the summer.

Keywords:, Solar power, Drivers, Barriers, Built environment, Saudi Arabia.

1 INTRODUCTION

Energy is key to the origin and survival of life on Earth. Civilization depends on it. Over history, various resources were exploited and different means employed to deliver energy. In the Industrial Revolution, humans and animals were replaced as a source of work by engines fueled primarily by coal, and later by oil and gas (Moe 2010). As industry grew at a rapid pace, the slowly developing and delayed environmental consequences that now threaten life on Earth were not fully appreciated (Smil 2019). Developing countries are well-placed to avoid some of the environmental problems that have plagued developed countries. This is because many developing countries have not only an abundance, but also a diversity, of energy resources. For example, rather than just coal and oil, many such countries are also blessed with natural gas or nuclear power generation plants, as well as emerging renewable energy projects.

This paper is a review of relevant literature about BIPV. It is a list of appropriate knowledge and information to better understand some of the main issues linked to the paper topic. Also, it will discuss three main sections, namely, energy demand, BIPV technology and their motivation to adopt it in the residential building. This paper used a scientific literature analysis of BIPV

topics related to residential buildings. The results provide a greater knowledge of the current state of BIPV technologies and analysis and describe the main subjects in the literature. Nearly 150 research publications have been reviewed.

2 ENERGY DEMAND

2.1 Energy Consumption in Saudi Arabia

There are different predictions offered by various institutions about energy and oil markets. The differences are due to multiple factors. Perhaps the most significant is the different assumptions and definitions of the economic variables and political factors that strongly influence the global oil supply. Some institutions use global economic growth rates published by international institutions, while others use global economic growth rates balanced by the consumption of oil by states. For example, a report from the Organization of Petroleum Exporting Countries (OPEC) predicts that global oil demand will rise in 2020 by about 1.2 million barrels per day, bringing the total to about 101 million barrels per day (OPEC 2019).

Oil consumption is expected to continue to grow until 2040, as economic growth rates are expected to increase over the next two decades (IEA 2019), especially in developing countries where manufacturing will expand. The Middle East will see a significant increase in its oil consumption in the coming years, as shown in Figure 1 (Stevens 2019). The prospects for continued use of oil in global economic activities and as a primary source of energy until 2040 support Saudi Arabia's aspirations for economic development.

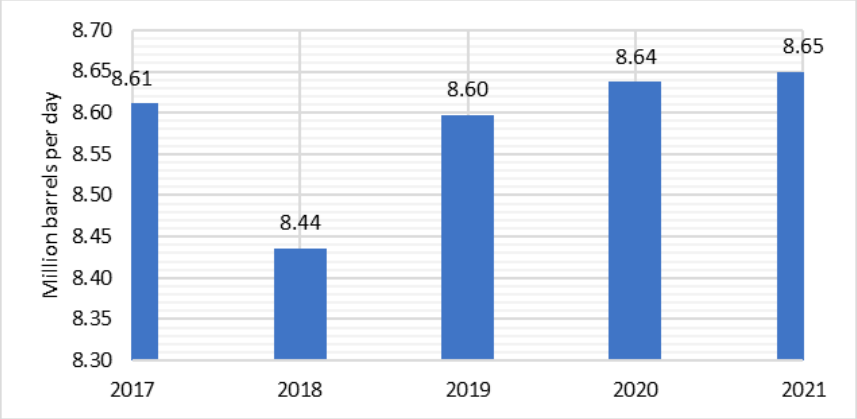

Figure 1. Annual change in Middle East oil consumption from 2018 to 2019 as a record and from 2020 to 2021 as forecast (OPEC 2019).

Figure 2 shows that the domestic consumption of oil and its products in Saudi Arabia has declined since 2016. This is due to the increased use of natural gas, cogeneration of electricity production with thermal seawater desalination, reduced direct consumption of crude oil in electricity generation, and energy efficiency measures (Shabaneh 2020). Growth is likely to return to Saudi Arabian oil demand for years to come, but at low rates due to the industrial and economic plans that the Saudi government will put forward in the future, such as Vision 2030 (Al-Darwish *et al*. 2015).

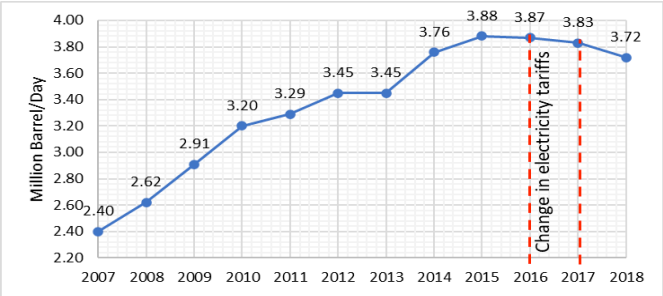

Figure 2. Saudi Arabia Oil Consumption from 2007 to 2018 (ECRA 2020a, GAS 2020).

Electricity sales in Saudi Arabia have grown rapidly over the past three decades. Sales in 2018 reached nearly 300,000 GWh—63% more than 10 years previously. Electricity consumption in Saudi Arabia rose significantly over the past 20 years. In 1990, the number of electricity customers was 2.33 million and the per capita energy index (consumption) was 4,000 kWh per person. In 2018, the customer numbers quadrupled to 9.4 million, and the average daily energy consumption was 8,900 kWh per person. The Saudi Arabian population doubled from 1990 to 2018 to 33.7 million, and the average annual population growth rate for 2019 was 2.4% (GAS 2020). In the summer of 2018, Saudi Arabia recorded a peak load of 61,743 MW. This coincided with a sharp rise in summer temperatures, which in some areas reached around 50°C. The weekly load in the Central Region of Saudi Arabia for 2018 is observed to increase dramatically as the temperature increases throughout the year. The residential sector in Saudi Arabia consumes about 44% of the electricity generated in the country. This sector recorded a 9% decline in electricity consumption in 2018—the most significant drop in 12 years. The residential sector consumption in 2018 was about 130 GWh compared to 143 GWh in 2017, which was the lowest since 2013 (when it was 126 GWh).

2.2 Energy Consumption in Saudi Arabian Residential Sector

The residential sector in Saudi Arabia is one of the more prosperous sectors of the construction industry. For decades, the general nature of urbanization has tended to be in the form of independent houses. There is no doubt that mast Saudi Arabian citizens aspire to own their own homes. However, with the launch of significant development projects in the residential sector, the concept of residential complexes has begun to be more widely accepted among citizens, primarily because these projects have provided relatively lower prices and are benefiting from government support. The residential complexes also often provide residents with services and facilities that are not available in scattered constructions. According to data from the Saudi Arabian Ministry of Housing, the number of housing units under construction during 2019 reached 321,000 units (The Housing Data and Observatory Center 2020). Makkah has the largest number of these units (69,000) followed by Riyadh (87,000). In addition, the construction of 330,000 units was completed in 2019, Makkah has more than 90,000 completed units, followed by Riyadh with 70,000 completed units, and the Eastern Region with 38,000 completed units.

3 BUILDING-INTEGRATED PHOTOVOLTAICS (BIPV)

PV technology which started as a basic and expensive approach for generating power has advanced in efficiency and declined in price to the point that it is now an attractive investment worldwide. Solar energy will be one of the ideal resources for renewable energy in the future. One approach to expanding the use of solar PV is to incorporate it into the façade of a building as

an element of the building. This is called building integrated PV (BIPV). This is an attractive solution because the appearance of the building can be enhanced in creative ways, thereby achieving high architectural quality. The harmonized overall appearance can be adapted depending on how BIPV is incorporated into the surfaces that are exposed to sun representing the channel between internal and external environments of buildings. BIPV can be defined as an alternate multifunctional element because it replaces other building elements and can be treated as a construction material or architectural component. It has a different integration level depending on its type and location in the building such as a hidden system on the roof and modest shading component. It can even help direct the original design for the appearance of the building. BIPV supply chain participants believe BIPV to be of benefit to society (Pagliaro *et al.* 2010). The main benefits are environmental and health related, stemming from the reduction in CO2 as well as the economic viability of power generation for communities. The social cost of carbon can be addressed through electricity generation from PV panels, which is recognized as environmentally sustainable. Since BIPV is located where most of the electricity is used, the transmission and distribution losses are less than those that occur between central plants and their customers. Also, infrastructure and maintenance costs are reduced (Yang and Zou 2016). The use of BIPV technologies has shown that the amount of electricity supplied by the grid will be reduced, while excess electricity can be exported to the grid causing reducing in the payback period (Sozer and Elnimeiri 2007).

3.1 BIPV Motivation in Saudi Arabia

The Board of the Electricity & Cogeneration Regulatory Authority (ECRA) of Saudi Arabia has adopted a regulatory framework for small solar PV systems (ECRA 2020b). This allows consumers to connect their home-installed solar energy systems to the public electricity distribution network under specific conditions and procedures. In order to this export surplus productive to the electricity grid. The exported electricity is recorded in the billing system of the distribution service provider. The regulatory framework covers the effectiveness and safety of installing, maintaining and operating small solar PV systems at independent home facilities in Saudi Arabia.

Saudi Arabia's most notable effort in the field of renewable energy was when it joined the International Solar Alliance—part of which involved signing a 200 GW agreement with SoftBank at the cost of $200 billion. In addition, The Saudi Arabian government announced a plan (Vision 2030) to build a sustainable solar energy sector with the establishment of integrated factories and research centers for technology localisation. Vision 2030 seeks to have a mix of energy sources and utilization in all areas, including renewable energy sources and especially solar energy. A timeline was set for the proposed projects, with the interim 2030 target raised from 9.5 GW to 27.3 GW.

There is a high amount of solar insolation throughout Saudi Arabia during the year, and the coming has one of the highest solar insulations in the world. The total area of Saudi Arabia is 2,200 million square kilometres, and most of this consists of deserts. The mean daily Global Horizontal Insolation (GHI) per year is between about 6 kWh/m2 to 6.5 kWh/m2, and the mean of daily Direct Normal Insolation (DNI) per year is between 4.5 kWh/m2 and 7 kWh/m2, (The World Bank 2019). The capacity of PV systems can be maximised in Saudi Arabia because the climate remains sunny throughout almost the whole year.

The implementation of solar power development significantly depends on the solar radiation resource data of a location. In order to ensure the optimum location and technology are carefully selected, accurate information about the temporal and spatial changes are in solar energy

required. In Saudi Arabia, such information is collected by a nation-wide, solar measurement network developed by the King Abdullah City for Atomic and Renewable Energy (KACARE). The comprehensive information from more than 50 monitoring stations is supplied by the Renewable Resource Monitoring and Mapping (RRMM).

One benefit of solar power generation is that coincides with peak electricity demand in mid to late afternoon, when there is a higher amount of electricity required for space cooling. Therefore, solar systems like BIPV can reduce the amount of electricity that must be generated through fossil fuel by conventional power plants. Such a coincidence among solar irradiance, air temperature and electricity demand has been established for the Saudi Arabian city of Riyadh (Almarshoud and Adam 2018).

Financing is a significant factor in the successful establishment of renewable energy projects. There are many banks and investors in Saudi Arabia that are willing to invest in such projects. Therefore, there is no requirement to depend on foreign financial support for finance. As for the technical expertise to implement these projects, there are many international engineering procurement and power generation companies that have operated in Saudi Arabia that are eager to participate in projects on renewable energy in the country due to the high economic feasibility of such projects there. Similar domestic companies would be able to learn and gain critical experience in the field of renewable energy if they work with their global peers. Banks and companies providing support services in this sector will also gain expertise while working with the main developers.

In order for renewable energy power generation projects to be successful, there must be a satisfactory regulatory framework for the sale of the generated electricity. In February of 2020, the Electricity & Cogeneration Regulatory Authority (ECRA) of Saudi Arabia amendment the regulation for small-scale solar PV. One amendment ensured that distribution service providers develop procedures for previously installed systems to ensure they meet government regulations. Another amendment set the tariff rate for excess PV electricity production in housing at 1.9 US cent/kWh. These regulations could be a catalyst for the prosperity of the BIPV technology market in Saudi Arabia.

3.2 BIPV Challenges in Saudi Arabia

Even though a sunny desert might be is assumed to be the most appropriate location for BIPV, dust accumulation over the PV module during sandstorms presents a major challenge. That is because dust can reduce the operational efficiency of PV systems. While the sunny desert environment in Saudi Arabia is good for electricity generation from solar PV, the accompanying heat is not. The efficiency of a solar PV module decreases with temperature (Dubey *et al*. 2013). The high temperatures in Saudi Arabia most therefore be factored into the expected power generation from BIPV.

The price of PV modules is expected to drop over time (Fu *et al.* 2018). However, the price could rise due to the growth of PV installations projects globally if there is a worldwide shortage in raw materials or production capacity by the PV industry. However, Saudi Arabia aims to create a domestic PV industry, which will be able to tap into the local availability of primary raw materials and capital. The environment is faced by recycling PV modules because of the deactivation of wasted PV cells. It consists of heavy metals and organic substances that can leach from modules and exceed acceptable limits of contaminators. Consequently, the risks to both human life and biota can increase if large quantities of PV modules are improperly discarded in an inadequate landfill (Srinivasan and Kottam 2018).

4 SUMMARY

From the review above, Saudi Arabia is undoubtedly one of the countries in the world that needs to produce a combination of energy which balances oil production and sales and reduces domestic consumption. Such a balance must also provide sufficient energy to meet the targets of the Saudi economy, especially since most areas of Saudi Arabia are characterized by a very high-temperature tropical climate in the summer. This requires the country to drain significant resources and energy to provide a suitable environment. Raising energy prices will not be an appropriate solution so much as it will drive the provision of sustainable energy sources such as solar, especially given that global trends point to lower costs and increased competitiveness in these areas. The adoption of BIPV in residential buildings represents an important role in the use of an alternative energy source in Saudi Arabia. This study finds that there are motivations related to adopting that technology in the country. Scientific research on these factors may help to produce a framework for adopting BIPV technology in the residential sector in Saudi Arabia.

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