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A STRATEGIC IMPLEMENTATION OF VISION 2030: INTEGRATING SUSTAINABLE ENERGY PRINCIPLES WITHIN RIYADH'S URBAN DESIGN

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ABSTRACT

Riyadh is the fastest-growing city in Saudi Arabia. Rapid technological urban expansion in Riyadh does not depend on conventional urban building concepts predefined and solar panels applied to city planning processes. International construction standards resulted in new urban constructions and pedestrian layouts., Riyadh's modern urban form is primarily built around transportation and commercial considerations when ignoring environmental concerns. This study examines how building codes impact the solar power for electricity consumption of residential construction in Riyadh to provide design rules that consider the city's external factors. Following are the two steps of the approach used to accomplish the objectives of this research. Initially, a review of research on the evolution of solar energy in building codes in Riyadh as of 2018 was conducted. The solar energy performance of typical residential building frames in Riyadh was then studied using simulation models of the facilities followed by different changes in building standards to see how they affect the radiation performance of the structures. To analyze household electricity usage, electricity rate structure, cost, solar conditions, and home types to determine how quickly domestic solar energy is used. In addition, using energy panels in Saudi Arabia will benefit the country's socioeconomic situation.

KEYWORDS: Urban Design, Building Codes, Solar Energy Integration, Residential Buildings, Energy Performance, Solar Radiation Analysis, Sustainability, Riyadh, Saudi Arabia.

1. INTRODUCTION

Blazquez et al. (2017) stated that as an initial step to expand its energy production mix, which now consists almost entirely of crude oil and refined petroleum products, including oil and gas, Saudi Arabia is building utility-scale solar power facilities. With a target of 3.45 gigawatts (GW) of additional green electricity by 2020 and 9.5 GW by 2023. The Saudi National Renewable Energy Plan broadly seeks to significantly increase the proportion of renewable energy in the Kingdom's electricity balance. This study examines the potential cost-effectiveness and acceleration of emissions reductions in Saudi Arabia's renewable energy mix, specifically residential-scale rooftop solar deployments in Riyadh. Systems relying on a specific household example based on its cost-benefit analysis in various households were the norm in studying the feasibility of photovoltaic deployments in Riyadh. The research divides families into categories based on how much energy they consume. This strategy coincided with domestic electricity prices, determined by usage and predicted in decreasing order. The objective of this study is to evaluate the feasibility of implementing solar energy at home in Riyadh. They developed a new algorithm based on night-time satellite photographs combined with the population's geographic stratification and the level of the Riyadh metropolitan area. In February 2018, Saudi Arabia selected ACWA Power to receive its first renewable energy farm concession. The 300 MW project will become commercially operational in 2019.

Mather et al. (2017) provided the initial phase of diversification of the Kingdom's power generation mix from its current exclusive reliance on crude oil, refined petroleum products, and natural gas. With 3.45 GW of installed renewable power generation in the country by 2020 and a target of 9.5 GW by 2023, the Saudi National Renewable Energy Policy aims to expand the percentage of modern electricity significantly. This study examines the potential cost-effectiveness and acceleration of carbon reduction in the balance of renewable energy generation in Saudi Arabia, specifically rooftop solar deployments in the household sector in Riyadh. This study examines the feasibility of rooftop solar PV in Riyadh using traditional cost-benefit analysis. However, it draws its findings on several households rather than a typical population. The research divides families into categories based on how much energy they consume. This strategy is consistent with domestic electricity prices, determined by usage and established on a relative scale. This study identified 58 homogeneous

clusters of the National Oceanic and Atmospheric Administration (NOAA) Visible Infrared Imaging Radiometer Array (VIIRS) day and night band (DNB), global population estimate, night-time light intensity, and population density across Riyadh. And the Global Human Migration Layer (GHSL) developed by the European Commission's Joint Research Center (JRC).

Henderson et al. (2012) used NOAA's nocturnal illumination photographs as a stand-in for the first commercial or social activities published. This approach was used in previous investigations by Elvidge et al. (2012), Townsend et al. (2010), and Chen et al. (2011). To assess productivity expansion, geographic income inequality, and power consumption. However, according to the researchers, this work is the first to use this paradigm in change research.

Shi et al. (2014) explained that about 50% of the fuel system used by Saudi Arabia for electricity generation is made up of refined petroleum liquid fuels. Also, the cost of oil used by the Kingdom's energy plants was lower than anywhere else in the world. Any reduced household electricity from the grid would reduce domestic oil consumption, increasing oil export profits by providing employment opportunities to use petroleum more efficiently. The costs and benefits of promoting the rapid adoption of domestic solar energy may interest Saudi authorities. The remainder of this article is structured as follows: The first part examines the published literature on residential renewable radiation, emphasizing the Middle East and Gulf Cooperation Council (GCC) countries. The second section explains the approach and collection of various groups in the Riyadh metropolitan area. The third section provides more information on the study's findings and explains their policy implications.

1.1. Aim

The study aim of the values of sustainable development relates to (the vision of KSA 2030) and is applied in the urban design of Riyadh- KSA.

1.2. Objective

- (i) To determine the value of sustainable development in solar power in the residential building in Riyadh.
- (ii) To analyze the cost estimation of the solar system to reduce electricity consumption.
- (iii) To find the benefits of using technology in the residential building in Riyadh city.

1.3. Research Questions

What is the potential value of implementing sustainable solar energy systems in residential buildings in Riyadh?

How can the cost of rooftop solar installations be accurately estimated to assess their effectiveness in reducing household electricity consumption?

What are the key technological, economic, and environmental benefits associated with adopting solar-energy technologies in Riyadh's residential sector?

2. LITERATURE REVIEW

2.1. Development of Solar Energy In GCC

Nemadollahi et al. (2016) stated that government implementation of solar energy, particularly in Saudi Arabia and Egypt, is primarily driven by that country's rapid growth in electricity consumption with favourable sunshine conditions. The Middle East's manufacturing potential for photovoltaics has been explored in such scholarly articles. Abdmouleh et al. (2015) showed that the significant increase in energy consumption in the GCC countries presents an opportunity to deploy renewable technology. A significant problem for developing solar energy in the GCC countries is the current low costs among most such electricity users. Griffiths (2013) noted that low electricity prices deter the adoption of solar technology without government incentive packages. Martin-Pomares et al. (2017) explained that Saudi Arabia's Energy Solar Photovoltaic (PV) Production Is Low Cost Because of the Low Regulatory Pricing of Natural Gas. Additional laws and higher benefits are needed to compensate for the lack of economic sustainability of PV technology in Qatar, which is partially responsible for the country's cheap electricity prices.

2.2. Electricity Generation in Saudi Arabia Using Solar Energy

Ramli et al. (2017) provided that an assessment of the feasibility of photovoltaic and renewable energy systems in Saudi Arabia and a sustainable procurement standard strategy may be the best way to implement those innovations. Almasoud and Hatim (2015) conclude that solar energy can be a significant challenge for fossil fuel producers such as Saudi Arabia whenever additional costs are considered. Shahid and El-Amim (2009) investigate the potential of hybrid PV for electricity generation in Saudi Arabia. The most significant possible residential solar implementation in 13 Saudi Arabian localities was estimated by Khan et al. (2017) found that their total electricity generation from those cities was 51 terawatt hours (TWh) or 30% of the

Kingdom's domestic energy needs. Griffiths et al. (2016) focus on the United Arab Emirates (UAE), stressing that solar energy technology thrives when strong government protection exists; however, at this time. Mainly in the UAE, electricity can be compared to photovoltaic systems.

Byrne et al. (2015) examined the reliability of photovoltaic systems in Seoul, South Korea. They calculated how many rooftops would be suitable for installing PV panels and found that the city could accommodate about 11 GW.

Peng and Lu did similar research (2013) and determined that the city's rooftops are suitable for installing 6 gigawatts of solar panels in Hong Kong. They also found that there must be widespread public support from a centralized controller perspective for PV technology to compete with grid power. Cole et al. (2016) investigated PV Solar Rooftop Technologies and the Adaptation of Major Manufacturing Units in the United States (US).

Elshurafa et al. (2017) found an almost perfect alternative to decentralized PV. They found a close match between utility-scale and diffuse PV; other studies have looked at the utility-scale implementation of solar energy in the Middle East from a broader perspective. The socioeconomic impact of PV solar technologies on the overall well-being of Saudi Arabia is positive. Investigate how much solar energy costs the Saudi electricity grid. They emphasize that utility-scale PV solar deployments should reduce operating costs. Liberalization of carbon resources with a framework supporting managed pricing can promote the energy installation of PV systems in the Kingdom Matar and Anwer (2017).

2.3. Renewable Energy in Saudi Arabia of Vision 2030

EIA (2022) considered a significant portion of global petroleum and natural gas production, Saudi Arabia (KSA), one of the top oil-producing countries. It means that its electricity needs, especially electricity generation, are met by natural fuels. IEA (2022) reported that gas provided 56.4% of the world's energy in 2019, oil accounted for 43.5%, and renewable energy sources accounted for 0.1%. Hafez et al. (2020) addressed environmental issues and improved financial returns from its fossil fuel reserves; Saudi Arabia has embarked on a path of resource diversification for power generation. However, the country has sizeable solar radiation and rich wind energy, allowing it to switch its electricity consumption based on renewable energy sources. Various federal agencies have considered

the use of alternative energy sources. The Ministry of Energy (ME) plans to build 60 GW of renewable energy capacity by 2030, comprising 40 GW of solar

photovoltaics (PV), 16 GW of turbines, and 2.7 GW of concentrated solar power (CSP) perfect ideas from Bahajet al., (2020).

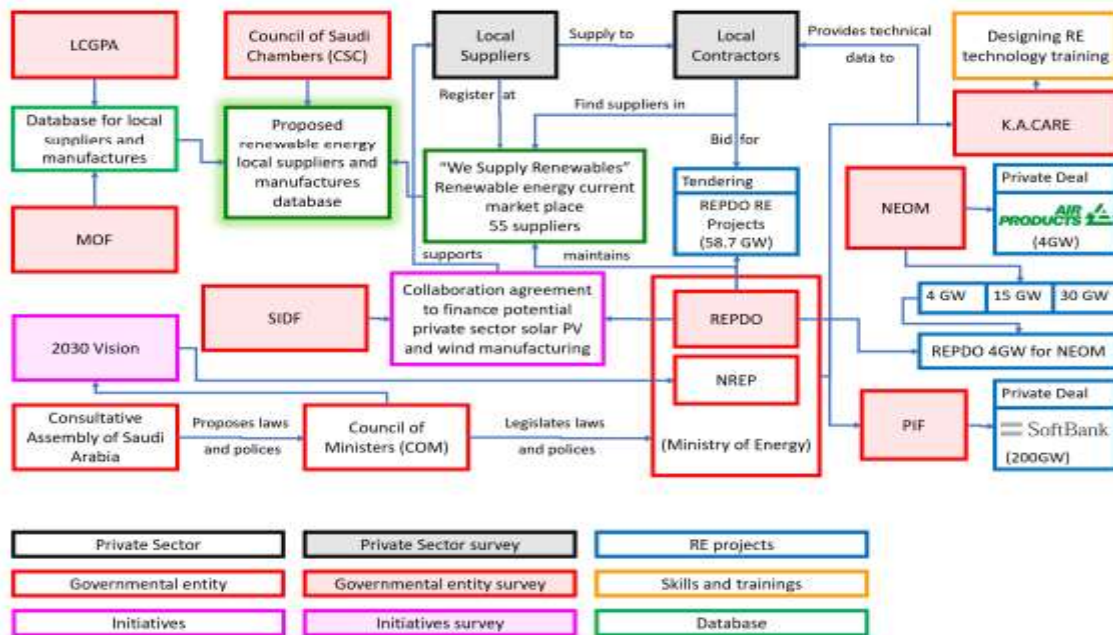


Fig 1: Saudi Arabia Renewable Energy Vision 2030.

Figure 1 illustrates the strategic framework of Saudi Arabia's Renewable Energy Vision 2030, highlighting the national targets for clean-energy capacity expansion and the transition toward a more diversified energy mix. The figure provides essential context for this study, as it underscores the policy drivers and institutional priorities that shape the feasibility and long-term relevance of residential solar adoption in Riyadh. By linking the research to Vision 2030 objectives, the figure reinforces the importance of decentralized renewable systems in achieving national sustainability and urban-design goals.

IEF (2017) studied that the Renewable Energy Projects Development Office (REPDO), created by the ME to achieve capacity targets, made these proposals in Riyadh. Value of initiatives to be exported and the area provided by domestic service companies and vendors are defined by REPDO. Fixed and variable costs related to the development and operation of the project are included in the project value. Local content refers to the forward (L.C.) limit. REPDO has three LC goals for solar and wind projects in KSA. LC required that represent 17-19% project's cost, increasing to 33-5% by 2024-2025 and 40-45% starting in 2028 and after that with a long-term objective. Those LC objectives are consistent with the newly published strategy to achieve net zero emissions of greenhouse gases by REUTERS (2021).

IRENA (2021) studied that with just 0.36 GW of solar PV capacity in 2020, KSA needs to increase its

photovoltaic solar production more than 110 times to reach 40 GW by 2030. The Sakaka project, a 300 MW solar PV plant, is now under construction. The construction covers an area of about 6 km². Achieving the desired 40 GW output at a similar regional concentration of 800 km², half the size of Greater London, would require. To complete the aggressive 40 GW target, it is evident that such growth requires a solid and efficient distribution network and awareness of domestic generation. They fulfil the objective required by unique supply network requirements, and this study provides relevant data to support the desired growth in photovoltaic processing in Vision 2030 (2021).

2.4. Sustainable Development of Solar System in Riyadh

SANUPGS (2021) showed that the Consultative Assembly of Saudi Arabia (CASA) should influence the decisions of the Council of Ministers (COM), which may take into account the demands and targets for renewable energy in Riyadh. The details are then determined by the REPDO and the National Renewable Energy Program (NREP), all of which are under the control of the Ministry of Energy (ME), and a Royal Proclamation containing the decisions taken is sent to the ME by Moenergy (2022).

NREPP (2022) created an RFQ accessible to domestic and foreign contractors and designers using REPDO. The development of an auction-based

process and the time frame required to deploy Saudi Arabia's renewable electricity initiatives come next. At the same time, the minimum LC requirement for domestic and foreign suppliers was determined by REPDO and the Local Content Government Procurement Authority (LCGPA 2020). Additionally, REPDO forms a "community," a network of regional RE producers and suppliers. Both local and foreign builders can raise the project's LC to a pre-determined limit by using such trades in Riyadh's sustainability by Katar (2022).

K.A. CARE (2020) identified that necessary information, including research related to timing, sustainable energy outputs, and locations for domestic or foreign providers, is provided by the King Abdullah Center for Atomic and Renewable Energy (K.A. CARE). It has partnered with Public Investment Funds (PIF), a more significant task to focus on future expansions in renewable energy development. Beyond what is targeted by ME, another source of funding that ME collaborates with to support regional companies that want to participate in Saudi Arabia's renewable energy market is the Saudi Industrial Development Funds (SIDF). NEOM, a large profitable future green metropolis to be developed in the north of Saudi Arabia, has stated vague objectives of deploying 4 GW to 30 GW of renewable energy capacity by 2030. It is contrary to the ambitions of REPDO and PIF to increase the potential for green energy in Saudi Arabia. According to NEOM's current announcement, they intend to deploy 16 GW to 20 GW of solar PV power capacity and 8 GW to 10 GW of renewable electricity. It is actively developing educational programs to support workforce development covering many areas of renewable energy-related fields in addition to processing and

databases from Jamal et al. (2022).

We Supply Renewables (2020) assessed how the nation's capacity has grown in each sector. REPDO has set up a system of enterprise registration. Although they are the most PV providers and producers affiliated with REPDO, it is essential to know whether this commercial system should allow the 2030 LC targets to be met. However, it seems unlikely that KSA will start producing solar cells before the deadline. China now controls 80% of world production in that industry, so there will be no LC linked to photovoltaic production in KSA Ghoudelbourk et al., (2020).

AlOtaibi et al. (2020) studied that the Local Content (LC) proportional cost of components was 34% in 2018, whereas a similar survey predicted it to be 45% in 2023 (Table 1). According to the last column of Table 1, the component price estimate in 2023 should be 15.3. %, or 34.5% or 45.0% of the project's total cost. The other LC ratios in the table are estimated using the same method. The whole LC of the 10 MW plant in 2018 was 47%; It is expected to increase to 74% by 2023.

Rao et al. (2022) estimated the cost of photovoltaic modules to be 56% of the overall cost of the modules (or 34% of the system's total cost). As a result, Saudi Arabia would achieve a 15% LC improvement if it chose to manufacture all photovoltaic panels domestically instead of importing them from elsewhere. However, a scheme like Sakaka can have up to 19% markup, where the block element is 44% of the actual cost. The Riyadh feature expands the local production of transformer elements and is the most practical way to improve LC in Saudi Arabia's renewable energy projects to be implemented by 2030.

Table 1: Local Content Cost Estimate.

| Component | 2018—10 MW | | | 2023—10 MW | |
|-------------|---|-------------------------------------|---|---------------------------------|--|
| | (a) Project Component Cost (%) | (b) Local Content of (a), (%) | ((c) [(a × b)] Overall Local Content Cost (%) | (b2023) Local Content (%) | (c2023) [(a × b2023)] Overall Local Content Cost (%) |
| Module | 34 | 20 | 6.8 | 45 | 15.3 |
| Inverter | 6 | 10 | 0.6 | 50 | 3.0 |
| Structure | 14 | 50 | 7.0 | 100 | 14.0 |
| Electrical | 11 | 80 | 8.8 | 100 | 11.0 |
| Civil Works | 14 | 100 | 14.0 | 100 | 14.0 |
| Admin | 14 | 45 | 6.3 | 80 | 11.2 |
| Others | 7 | 50 | 3.5 | 80 | 5.6 |
| LC (%) | | | 47.0 | | 74.1 |

Table 1 Summarizes the Local Content Cost Estimate for The Solar System, Highlighting Capital, Installation, And Operational Expenses. It Emphasizes the Role of Domestic Resources in Reducing Costs and Supporting Vision 2030 Objectives.

ACWA Power (2022) Sakaka Solar Energy Company (SSEC), the developer of the project, states

on its web page that its improvement has achieved a local data level of >30%. Nevertheless, SSEC admitted in our discussion that local generation for such a 300 MW plant exceeds 35%. SAKAKA project's IPP funding from ACWA Electricity totalled US\$302 million [26]. To determine the portion of the Sakaka project related to PV systems, we estimated the cost of single crystal PV modules based on a Bloomberg/IEA report [27]. The efficiency system price for 2017 (USD (2015) 0.4 \$/Wp) and 2018 (USD (2015) 0.3 \$/Wp) has been adjusted to USD 2021 (+25%) to give a modular price of 0.44 \$/Wp. As a

result, according to IEA module cost figures, the total modules cost of 300 MW farms is USD 131 million or 44% of the total development cost (Table 2). Digital data is estimated to account for 35% of the total cost. The cost of the non-module parts of the program, i.e. 56%, is multiplied by the local resource percentage of non-module particles of 63% to get the total local content ratio. The local production for the Sakaka project is the localized sourcing rate of non-block components, as the local content percentage for such a block area is zero to IEA (2022).

Table 2: Local Component Module.

| Component | Project Component Cost (%) | Local Content % | Overall Local Content cost (%) |
|-----------|----------------------------|-----------------|--------------------------------|
| Module | 44 (see text) | 0 | 0 |
| Other * | 56 | 63 | 35 |
| LC (%) | | | 35 |

* where other represents all items in column 1 of Table 1 without the modules.

Using the module production cost percentages of the 10 MW and 300 MW initiatives from Tables 1 and 2, KSA's LC targets of 33–35% by 2024 can be achieved without locally manufactured modules. Cell cost percentage from blocks budget. However, domestic production of modules should be necessary to meet LC's objectives. It raises the issue of whether or not the expected trend in Saudi Arabian modules' production capacity is consistent with the expected PV implementation rate from Sathik et al. (2020).

3. METHODOLOGY

The methodology study was conducted with a Quantitative research method using a questionnaire survey. This article initially analyzes a metropolitan area in Riyadh State to identify residential clusters and regions with high night-time light levels in urban areas with a constant human presence. After that, it converts the amount of power used by the night lights by estimating the typical amount used by each household in each cluster. It calculates the cost of energy produced using solar PV rooftop technology based on the technologies' costs and Riyadh's radiation conditions. Finally, it discusses the financial costs and benefits of using this technology.

The potential benefits of reducing carbon pollution are not taken into account. This article takes a practical look at PV technology. Residents often contrast the cost of electricity from a home PV system with the cost from the grid. If the overall price of solar rooftop systems is lower than the cost of buying electricity from the grid, they will build one. It means that each household chooses its installation in the same way to pay the same energy rate. Therefore, a substantial cost is monetary.

3.1. Dividing Riyadh into Homogenous Clusters for Nightlight Intensity and Population

Vittorio (2016) identified that a geographically compressed multimodal segmentation was used to divide the Riyadh metro area into 100 zones. Such a method detects communities of fluorescent devices in a group and pre-determined size meshes (clusters) across the image with low-intensity variations while ensuring that the clustering results are as distinct. The 2013 Survey of Household Expenditures and Income and the Esri World Population Estimates Geographical Layer 2015 are used in this study to analyze population makeup. Using a statistical

regression approach, in the footsteps of the final distribution of the population across groups was

produced, and typical evening light data is provided by NOAA's VIIRS data in the given below figure 1.



Fig 2: NOAA's VIIRS Data.

Figure 2 presents night-time satellite imagery from NOAA's VIIRS sensor, illustrating spatial electricity consumption patterns in Riyadh. This data supports the clustering analysis and identifies areas with high potential for rooftop solar deployment.

Lopez-Ruiz et al. (2020) explained that annual averages and monthly composites provided by NOAA for 2015 were used in this analysis. The images used in this research were taken during daily activity occasions in Riyadh. As a result, they depict Riyadh's average monthly brightness while omitting anomalies and gas bursts. Figure 1 shows a March 2015 VIIRS image of the region from NOAA. This study uses the Global Human Settlement Layer (GHSL) developed by the European Commission's JRC, which determines the degree of urbanization in 100 uniform groups of population size and night light in Riyadh. JRC's extensive study of Sentinel satellite photographs were the foundation for GHSL. GHSL shows the visual distribution of built-up and urban areas.

3.2. Estimation of The Energy Consumption by Households in The City of Riyadh

This research combines the current average temperature and fluorescent bulb strength using a basic economic model (independent variable) with a

typical tenant's electricity usage (dependent variable) in three Saudi Arabian locations. Annual data from the Saudi Arabian Ministry of Finance for 2015 served as the basis for the monthly electricity consumption figures. Accordingly, the previous assessment calculated how much electricity each house in each location consumes. The World Bank's Global Warming Information Network is a reference for temperature increase. Descriptive variables of lamp strength were constructed using satellite VIIRS DNB information provided by NOAA. There are 36 observations, corresponding to 12 months of 2015 and three regions. Basic Least Square Estimation (LSE) is used in regression analysis to estimate the parameters.

Table 3 shows the results that considering the characteristics obtained during the calculation, the overall typical household consumption can be calculated in each of the clustering areas of Riyadh. This strategy has potential drawbacks as each of the midnight lights in this article's algorithm is associated with domestic activity. However, commercial or industrial action may also occur in a populated area. They mainly consider commercial and industrial areas. This analysis excludes groups with huge consumers per household and less than 100 households to

reduce the possibility of errors.

Table 3: Estimation Of Electricity Charge.

| | Coefficients | Standard Error |
|-------------------|--------------|----------------|
| Intercept | -1.24 | 0.56 |
| Nightlight | 1.41 | 0.13 |
| Temperature | 1.01 | 0.13 |
| R Square | 0.82 | |
| Adjusted R Square | 0.81 | |
| Standard Error | 0.22 | |

Table 3 presents the estimated electricity charges for residential buildings, highlighting potential cost savings achievable through solar PV adoption. This assessment provides a quantitative basis for evaluating the economic feasibility of the proposed renewable energy systems.

The research excludes groups whose monthly

power usage is five times the national average. Critical data on Riyadh's electricity consumption are presented in Table 4. They include an overview of the clustered population structure and Riyadh's average power consumption per cluster.

Table 4: Statistics Of Population.

| Number of clusters | 58 |
|---|---------|
| Total households in 2015 ^a | 798,090 |
| Mean of monthly consumption per household (kWh) in 2015 | 2,327 |
| Median of monthly consumption per household (kWh) in 2015 | 1,923 |
| Standard deviation | 1,757 |
| Adjusted R Square | 0.81 |
| Standard Error | 0.22 |

Table 4 summarizes the population statistics of Riyadh, providing context for household energy demand and supporting the analysis of solar energy deployment at the residential scale.

3.3. Estimation of The Equalized Cost of Electricity for Residential Solar Rooftops

Shakiret al. (2018) studied the limited adoption of domestic PV solar technology in Saudi Arabia, and no standardized commercial data on upfront costs are available. For this purpose, data on the cost of rooftop PV solar technologies from other countries is used in this research. Based on the KAPSARC Electricity Toolbox, the cost of solar panel investments at the household level ranged from \$2.15 per watt (W) to \$5.25/W in 2015. Italy, Japan, and USA 2015 are available in KAPSARC's central registry of Australia, France, Germany, Italy, Japan, and the US. In other countries, the overall estimated cost of residential renewable PV installations is declining at a rate of 10.7% per year.

Zell (2015) expected capital costs in 2018 are \$2.36/W, compared to the average capital used in 2015 (\$3.32/W), and a 10.7% annual drop in the price of home solar installations in both 2016 and 2017. The typical capacity spectrum of a domestic PV rooftop service was still 1 kW to 5 kW. They should use 2.2 kW as the standard for that investigation. A PV solar

panel has an average life cycle of 25 years. According to the city's solar solid intensity, which is about 2.130 kilowatt-hours (kWh) per cubic meter per year, Riyadh's efficiency factor is about 21%. However, extreme heat and pollution can reduce the efficiency of PV cells (Baras 2012).

Those parameters were not taken into account in that investigation. The whole strength reduction rate is 85%, and the technical decline of the solar cell is 0.9% annually. When determining the net energy cost of energy, the cost of ownership (LCOE) is necessary. The weighted average cost of capital is a standard valuation method businesses use when valuing a venture (WACC). For example, the International Renewable Energy Agency (IRENA) (2017) uses the current value of 7.5% in OECD countries. It calculates the LCOE of various renewable technologies at a transfer level of 10% for such a balance worldwide. Because this yield curve is a product of an individual's perceived temporal desires and varies from person to person, households have no clear valuation pattern. Their investigation of the Danish government found that the average per capita interest rate was approximately 28% Harrison et al. (2002).

Bruderer et al. (2014) covered that the extreme were taken into account; the average attrition rate of the Swiss population is about 27%. A typical discount

percentage for buying air conditioners is 26%. Camillo et al. (2017) used an interest rate of 4%, comparable to the present social value used in monetary aggregates. The income ratio can range from 156% to almost zero, depending on each individual's age and income. Samwick (1998) explored the information on economic holdings, including personal worth, from the US Survey of Consumer Finances since 1992, with an average of 7.4%, to provide the variation in present value. This analysis assumes that the leverage ratio has a normal distribution with a mean of 27% and carries a

sampling variance of 15% of the typical for the Riyadh population in figure 2. The first percentile of the population is 0.6 times higher than the national average, such a characteristic that this research proposal applies to the standard deviation. This method produces a separate LCOE based on each household's discount rate Figure 3. Research refers to this measure as "perceived LCOE" to reflect it and prevent misunderstanding. It should be emphasized that a simple model for the rate of return does not provide an assumption of normality for the observed LCOE.

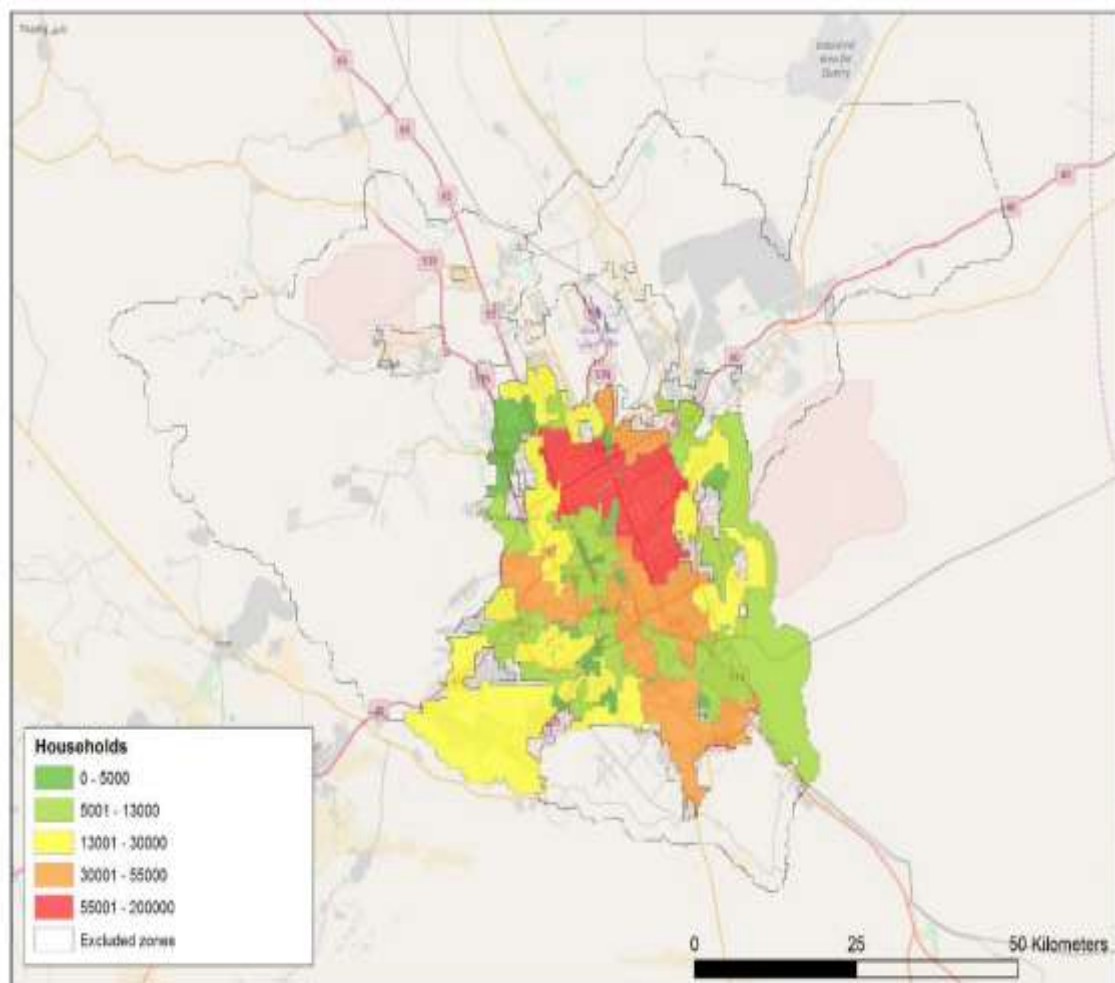


Figure 3: Population In Riyadh City.

Figure 3 illustrates the population distribution across Riyadh, highlighting areas of higher residential density. This information guides the assessment of potential solar PV adoption and energy demand patterns.

Because of this, research uses $N(0.27, 0.15)$ to generate 5,000 arbitrary discount rates before calculating the observed LCOE for each level. Figure 3 shows the realized LCOE developed over two years using this technique. The 2023 curve shows the reported LCOE assuming a constant decrease in the

cost of investment of 10.7% annually through 2023.

The 2023 curve shows the reported LCOE's continuous reduction in the acquisition price of 10.7% yearly through 2023. In contrast, the 2018 line depicts the reported LCOE for the expected expenditure cost in 2018 (\$2.36/W). The minimum realized LCOE in 2018 was 6.8 (US) cents/kW for households with a 0% discount rate, and the highest was 61.9 cents/kW for families with an 82.7% discount rate. Estimated LCOE figures generated

with negative borrowing costs were removed figure 3.

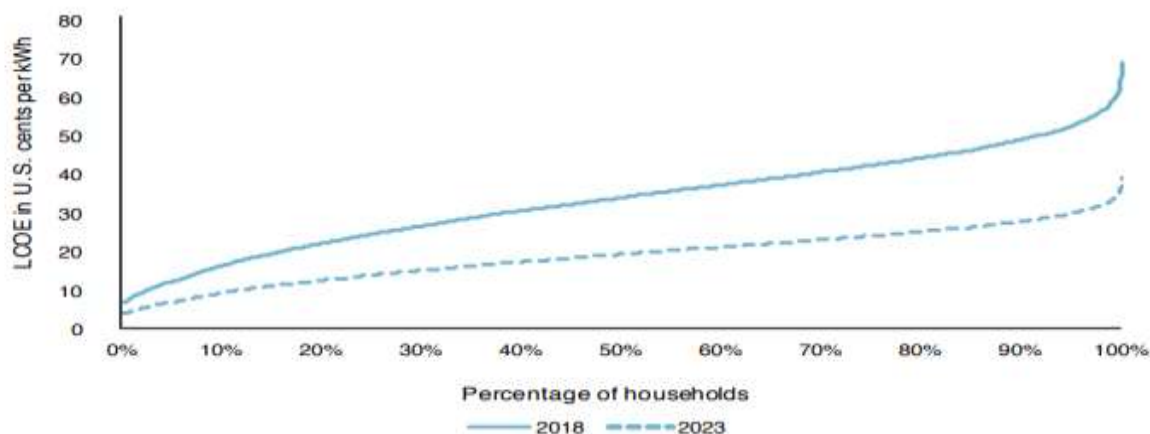


Fig 4: Percentage Of Electricity Consumption.

Figure 3 shows the percentage distribution of electricity consumption across different sectors in Riyadh. This data identifies high-demand areas, informing the prioritization of residential solar PV deployment.

4. ANALYSIS

4.1. Estimation of the 'Reasonable' Maximum Solar PV Deployment at The Residential Scale

Khan et al. (2017) estimated that the city's relatively tiny solar energy deployments are often assessed by determining how many square meters (m2) are suitable for implementing rooftop photovoltaic panels. This research, in contrast, takes a different tack, measuring the proportion of households suitable for rooftop PV solar panel installation. The method helps assess the potential effectiveness of regulations promoting solar energy on a household basis. According to the Saudi Housing Census, there are five main categories of Saudi housing: apartments, floors in traditional

houses, villa floors, traditional houses, and villas. All types of dwellings in the land area of Riyadh are estimated that typical houses typically have an area of 116 m2, whereas villas typically have 268 m2 of living space. For this investigation, a domestic solar PV system requires a minimum rooftop installation size of 16 m2 and consists of 10 PV modules with a total production capacity of 2.2 kW. The typical house type and the villa provide enough roof space to accommodate solar panels. This study assumes insufficient residential solar panel installation space for those living in apartments, house floors, or estates. Typical houses and villas account for 66.2% of all residential units. Given the extended maturity period of these renewable investments, it is logical to expect that only people who own their residences will use PV rooftop solar. The Dwelling Survey shows that 56% of Saudi Arabian family-owned places are family-owned power consumption in figure 5.

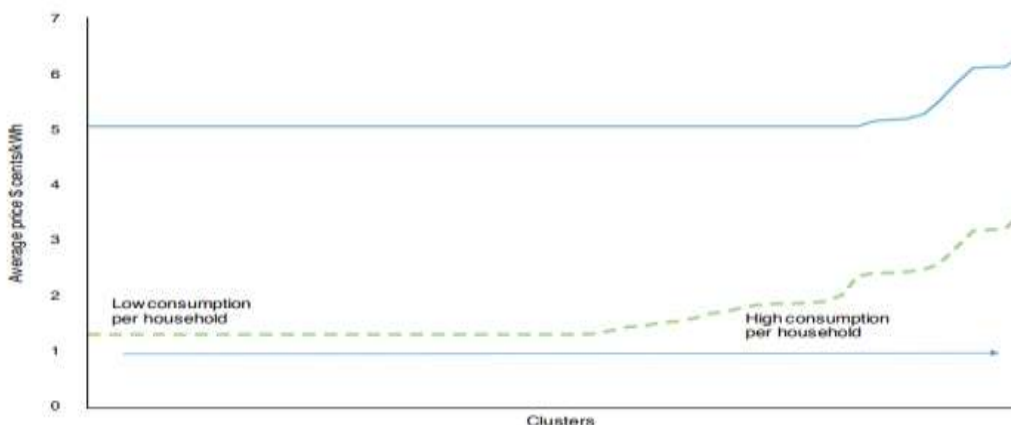


Fig 5: Power Consumption of Household.

Figure 5 illustrates the hourly and daily power consumption profile of a typical household in Riyadh. This

information is used to model energy demand and optimize the sizing of solar PV and hybrid systems.

Sultan et al. (2021) reported that the survey included 798,090 households in Riyadh's inland districts, both Saudi and non-Saudi households. Apartments rented by non-Saudi families are not included in the data from the residential survey. With 37.4% of the total population, the non-Saudi community is enough to think. The survey included 798,090 households in Riyadh's inland districts, both Saudi and non-Saudi households. Apartments rented by non-Saudi families are not included in the data from the residential survey. With 37.4% of the total population, the non-Saudi community is enough to think. Any calculation that electricity users in Saudi Arabia consider imprecise leaves out a significant portion of the city's electricity use. But since they can't afford private homes, most non-homeowners won't spend money on renewable radiation. This analysis calculates that Riyadh has 185,213 Saudi-owned palaces or regular houses based on the above data. When a home photovoltaic facility is profitable, those households are more likely to acquire one. Their maximum integrated domestic solar power capacity in Riyadh is 407 MW. If all 185,213 homes have rooftop PV solar facilities with an output of 2.2 kW, the project's total cost will be close to \$1 billion. The annual production of this deployment will be around 0.7 TWh.

4.2. Assessing the Residential Solar Deployment in Riyadh for Economic Reasons

Atalla (2016) determined that on a progressive scale, energy costs were based on monthly usage in Riyadh, Saudi Arabia. The rates were hiked in 2016 and again in 2018. According to the decision of the Council of Ministers published on 12/12/201711, the 2018 tariff plan has two rates: 0.18 Saudi Riyals (SAR)/kWh (4.8 US cents/kWh) for the initial 6,000 kWh consumed and 0.3 SAR/kWh (8 US cents/kWh) remaining kWh purchased. In January this year, a 5% value-added tax was implemented, raising electricity tariffs in the Kingdom. This research re-estimates household electricity consumption for 2018 while considering new electricity pricing and economic growth in Saudi Arabia from 2015 and 2018, which is helpful for regulators. The long-term earnings of 0.48 and a relative price of -0.16 estimate energy use in 2018. For the 58 regions studied, the total electricity consumption predicted in 2018 is 15.7% lower than in 2015. Once a household's 2018 consumption is estimated in each cluster, the overall cost per kWh used can be calculated. They compared electricity rates for different groups between 2015 and 2018, from the cheapest per household to the most prominent use.

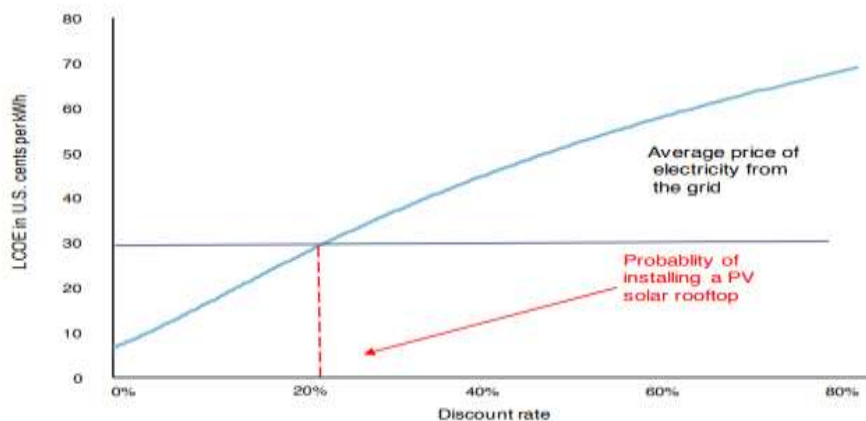


Fig 6: Probability Of Installation Of PV.

Figure 5: Presents the Probability of Rooftop PV Installation Across Different Residential Areas in Riyadh, Highlighting Zones with Higher Adoption Potential. This Analysis Supports Strategic Planning for Solar Energy Deployment.

Fraj and Martinez (2006) researched that examined the cost of power in the network for all regions with an estimated LCOE to evaluate the prospective installation of rooftop photovoltaic systems for financial purposes. A stochastic process, as stated earlier, assigns the discounted factor to households to produce the true LCOE. The feasibility

of installing a solar roof on the house depends on the typical electricity rate, as illustrated in Figure 5. The most considerable consumption rates and estimated cost per kWh used were 6.34 US Cents/kWh found in households in cluster 59. There is no financial reason to deploy rooftop solar panel modules at this price, below the minimum observed LCOE for 2018. A critical policy finding from this data is that current household electricity costs in Saudi Arabia are too low to incentivize the installation of rooftop solar economically. Therefore, this does not mean rooftop

PV installations should be avoided altogether figure 6.

Sommerfeld et al. (2017) argued that lifestyle judgments made by individuals are personally optimal actions taken for personal reasons. The accumulation of such fine-grained results should ultimately determine the adoption of solar PV systems installed at the household scale. Chen (2014) mentioned houses need to acquire rooftop photovoltaic power for various reasons, such as environmental issues, eco-friendly lifestyles, or the Adaptation of Innovation. The implementation of solar energy on rooftops was not considered in this study's analysis of potential peer effects or social factors. Residential solar energy implementation was not considered in this study's possible cultural presence or social factors analysis. Bollinger and Gillingham (2012) found solid supportive indications of a peer effect in photovoltaic power deployment across California.

5. RESULT

Elsurafa et al. (2017) declined that LCOE, due to lower capital expenditure, may encourage competitive installation in clusters with higher consumption per household in 2019. Across Riyadh, photovoltaic panels are expected to be installed in only a few homes in 2019. This number is deficient. When the research was repeated for 2020, it was found that 25 households in Riyadh were interested in setting up a solar panel system for financial reasons. Whenever the research is reflected for 2021, 2022, and 2023, the number of households involved in solar PV systems for investment purposes increases to 55, 97, and 145, respectively. The key finding is that despite a significant drop in the cost of photovoltaic equipment, the Kingdom's cheap domestic electricity rates do not encourage the installation of residential renewable energy systems. Like other GCC countries, Saudi Arabia has initiated power infrastructure reforms to increase the sector's efficiency, attract capital expenditures, and end energy subsidies.

Matar et al. (2017) defined that the costs and pricing policies were deregulated; the cost of electricity would be 7.1 US should be close to cents/kW. This scenario has some photovoltaic power deployment, with 2.5 MW in 2018 and 26.5 MW in 2023. Los Angeles, a city of 3.3 million homes, has 342 MW of existing photovoltaic solar capacity, based on California Distributed Generation Reports (2018). US According to the Energy Information Administration, the city's average household electricity cost in December 2018 was 18.8 cents/kWh

(EIA 2018). Using the same average output rate used in this research and modelling, residential solar installations in Riyadh would have reached 56.1 MW in 2018.

Blazquez et al. (2017) studied that Saudi Arabia's business benefits from using renewable panels from gasoline as an electricity source. They found that PV became costly when crude oil prices approached \$30 per barrel. Because of this, governments may consider implementing incentives to encourage domestic PV installation. If the net present value of the property is equal or neutral, households will install rooftop solar PV systems regardless of the type of strategic device used. Financially, a photovoltaic PV system should be desirable, whereas the difference between the LCOE and the typical cost per kWh produced is financed. It doesn't matter if the house is solar-powered or off-grid. In other words, the solar rooftop system will be commercially viable if the government pays the discrepancy between the electricity bill and the estimated LCOE. Initially, it was unclear how much the project would cost and how successful it would be in actual megawatts due to the uncertainty surrounding financing costs for households. Also, utility-scale PV solar is much less expensive.

IRENA (2018) stated that the global utility-scale LCOE in 2017 was around 10 cents/kW. Due to lower ratings recorded in Abu Dhabi, Chile, Dubai, Mexico, Peru, Saudi Arabia, Chile, and other countries mentioned above in 2016 and 2017, the LCOE of PV systems will decrease in the US starting in 2018 and can be reduced below 3 cents/kWh. The Saudi Arabian government may focus on energy photovoltaics to accelerate its carbon reduction program for two primary factors.

6. CONCLUSION

This study evaluated the economic feasibility of installing rooftop solar PV systems in residential buildings across Riyadh, integrating household energy demand analysis with high-resolution spatial and demographic data. Using night-time light intensity data, the Global Human Settlement Layer (GHSL), the World Population Estimates Geographical Layer 2015, and NOAA's VIIRS-DNB, household electricity consumption patterns were estimated with high spatial precision. Riyadh comprises 58 distinct zones, with a total population of 798,090, providing a comprehensive context for assessing residential solar potential.

The findings indicate that while individual rooftop PV systems are not yet commercially viable for most homeowners at current electricity tariffs,

community- or industrial-scale photovoltaic installations offer cost-effective alternatives. A controlled professional intermediary company model – which aggregates multiple households – can achieve economies of scale, reduce per-unit construction and maintenance costs, and improve operational efficiency. This approach presents a promising strategy for implementing residential-scale solar systems in Riyadh and other urban areas with similar energy demand profiles.

Urban-Design Implications

- The adoption of residential PV clusters can inform urban energy planning, guiding planners in identifying suitable neighborhoods for solar integration.
- Integrating solar systems into new residential developments can enhance sustainability, reduce urban energy dependency, and align with Saudi Vision 2030 goals.
- Urban designers and policymakers can use

population and consumption data to prioritize high-demand areas, optimizing both economic and energy outcomes.

Future Research Directions

- Investigating the integration of hybrid renewable systems (e.g., PV-wind) at the neighborhood scale to improve energy reliability.
- Exploring dynamic pricing and policy incentives to increase the financial viability of residential PV adoption.
- Applying spatial-temporal modeling to assess the long-term impact of residential PV deployment on urban energy networks.

This conclusion emphasizes both the practical urban-design applications of the findings and the next steps for research, providing a clear bridge between data-driven energy assessment and sustainable urban planning.

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REFERENCES

- Abdmouleh, Zeineb, Rashid AM Alammari, and Adel Gastli. 2015. "Recommendations on renewable energy policies for the GCC countries." *Renewable and Sustainable Energy Reviews* 50: 1181-1191.
- ACWA Power. Sakaka PV IPP. 2022. Available online: <https://acwapower.com/en/projects/sakaka-pv-ipp> (accessed on 31 August 2022).
- Almasoud, A. H., and Hatim M. Gandayh. 2015. "Future of solar energy in Saudi Arabia." *Journal of King Saud University-Engineering Sciences* 27, (2): 153-157.
- AlOtaibi, Z.S.; Khonkar, H.I.; AlAmoudi, A.O.; Alqahtani, S.H. Current status and future perspectives for localizing the solar photovoltaic industry in the Kingdom of Saudi Arabia. *Energy Transit.* 2020, 4, 1-9. [CrossRef]
- Atalla, Tarek N., and Lester C. Hunt. 2016. "Modelling residential electricity demand in the GCC countries." *Energy Economics* 59: 149-158.
- Bahaj, AS; Mahdy, M.; Alghamdi, AS; Richards, D.J. New approach to determine the Importance Index for developing offshore wind energy potential sites: Supported by UK and Arabian Peninsula case studies. *Renew. Energy* 2020, 152, 441-457. [CrossRef]
- Baras, Abdulaziz, Wail Bamhair, YahyaAlKhoshi, Maher Alodan, and Jill Engel-Cox. 2012. "Opportunities and challenges of solar energy in Saudi Arabia." In *World Renewable Energy Forum*, Denver, vol. 1, p. 4721.
- Blazquez, Jorge, Lester Hunt, and BaltasarManzano. 2017. "Oil subsidies and renewable energy in Saudi Arabia: A general equilibrium approach." *The Energy Journal* 38, (S11): 29-45.
- Blazquez, Jorge, Lester Hunt, and BaltasarManzano. 2017. "Oil subsidies and renewable energy in Saudi Arabia: A general equilibrium approach." *The Energy Journal* 38, (S11): 29-45.
- Bollinger, Bryan, and Kenneth Gillingham. 2012. "Peer effects in the diffusion of solar photovoltaic panels." *Marketing Science* 31, (6): 900-912.
- Byrne, John, Job Taminiau, LadoKurdgelashvili, and Kyung Nam Kim. 2015. "A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul." *Renewable and Sustainable Energy Reviews* 41: 830-844.
- Camilo, Fernando M., Rui Castro, M. E. Almeida, and V. FernãoPires. 2017. "Economic assessment of residential PV systems with self-consumption and storage in Portugal." *Solar Energy* 150 (2017): 353-362.

- Chen, KeeKuo. 2014. "Assessing the effects of customer innovativeness, environmental value and ecological lifestyles on residential solar power systems install intention." *Energy Policy* 67: 951-961.
- Chen, Xi, and William D. Nordhaus. 2011. "Using luminosity data as a proxy for economic statistics." *Proceedings of the National Academy of Sciences* 108, (21): 8589-8594.
- Cole, Wesley, Haley Lewis, Ben Sigrin, and Robert Margolis. 2016. "Interactions of rooftop PV deployment with the capacity expansion of the bulk power system." *Applied Energy* 168: 473-481.
- EIA. International—US Energy Information Administration (EIA). 2022. Available online: <https://www.eia.gov/international/rankings/country/USA?pid=4415&aid=1&f=A&y=01%2F01%2F2019&u=2&v=mapbubble&pa=288&ev=false> (accessed on 28 July 2022).
- Elshurafa, Amro M., and WalidMatar. 2017. "Adding solar PV to the Saudi power system: what is the cost of intermittency?" *Energy Transitions* 1, (1): 2.
- Elshurafa, Amro, NouraMansouri, WalidMatar, Axel Pierru, Shreekar Pradhan, David Wogan. 2017. *Transitioning to Liberalized Energy Markets, Workshop Brief, KAPSARC, Riyadh*.
- Elvidge, Christopher D., Kimberly E. Baugh, Sharolyn J. Anderson, Paul C. Sutton, and Tilottama Ghosh. 2012. "The Night Light Development Index (NLDI): a spatially explicit measure of human development from satellite data." *Social Geography* 7, (1): 23-35.
- Fraj, Elena, and Eva Martinez. 2006. "Environmental values and lifestyles as determining factors of ecological consumer behaviour: an empirical analysis." *Journal of Consumer Marketing* 23 (3): 133-144.
- Ghoudelbourk, S., Azar, A.T., Dib, D. and Omeiri, A., 2020. Selective harmonic elimination strategy in the multilevel inverters for grid-connected photovoltaic system. *International Journal of Advanced Intelligence Paradigms*, 15(3), pp.317-339.
- Griffiths, Steven, and Robin Mills. 2016. "Potential of rooftop solar photovoltaics in the energy system evolution of the United Arab Emirates." *Energy Strategy Reviews* (9): 1-7.
- Griffiths, Steven. 2013. "Strategic considerations for deployment of solar photovoltaics in the Middle East and North Africa." *Energy Strategy Reviews* 2, no. 1: 125-131.
- Hafez, A.A.; Nassar, Y.F.; Hammdan, M.I.; Alsadi, S.Y. Technical and Economic Feasibility of Utility-Scale Solar Energy Conversion Systems in Saudi Arabia. *Iran. J. Sci. Technol. Trans. Electr. Eng.* 2020, 44, 213–225. [CrossRef]
- Harrison, Glenn W., Morten I. Lau, and Melonie B. Williams. 2002. "Estimating individual discount rates in Denmark: A field experiment." *American Economic Review* 92, (5): 1606-1617.
- Henderson, J. Vernon, Adam Storeygard, and David N. Weil. 2012. "Measuring economic growth from outer space." *American Economic Review* 102, (2): 994-1028.
- IEA. Data & Statistics. 2022. Available online: <https://www.iea.org/data-and-statistics/data-browser?country=SAUDIARABI&fuel=Energy%20supply&indicator=ElecGenByFuel> (accessed on 28 July 2022).
- IEA. Evolution of Solar PV Module Cost by Data Source, 1970–2020–Charts–Data & Statistics. 2022. Available online: <https://www.iea.org/data-and-statistics/charts/evolution-of-solar-pv-module-cost-by-data-source-1970-2020> (accessed on 31 August 2022).
- IEF. Saudi Arabia National Renewable Energy Program. 2017. Available online: https://www.ief.org/_resources/files/events/third-ief-eu-energy-day/turki-al-shehri-24.02-repdoc-ief-riyadh_v2-2.pdf (accessed on 29 July 2022).
- IRENA. 2017. "IRENA Cost and Competitiveness Indicators: Rooftop Solar PV", International Renewable Energy Agency, Abu Dhabi.
- IRENA. 2018. "Renewable Power Generation Costs in 2017". International Renewable Energy Agency, Abu Dhabi.
- IRENA. Renewable Capacity Statistics 2021. 2021. Available online: <https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021> (accessed on 29 July 2022).
- Jamal, I., Elmorshedy, M.F., Dabour, S.M., Rashad, E.M., Xu, W. and Almakhles, D.J., 2022. A comprehensive review of grid-connected PV systems based on impedance source inverter. *IEEE Access*, 10, pp.89101-89123.
- Katar, I., 2022. Promoting pedestrian ecomobility in Riyadh City for sustainable urban development. *Scientific reports*, 12(1), p.14808.
- Khan, Mohammed, Muhammad Asif, and Edgar Stach. 2017. "Rooftop PV potential in the residential sector of

- the Kingdom of Saudi Arabia." *Buildings* 7, (2): 46.
- Khan, Mohammed, Muhammad Asif, and Edgar Stach. 2017. "Rooftop PV potential in the residential sector of the Kingdom of Saudi Arabia." *Buildings* 7, (2): 46.
- King Abdullah City for Atomic and Renewable Energy. Frequently Asked Questions. 2020. Available online: <https://www.energy.gov.sa/en/Pages/fq.aspx> (accessed on 5 August 2021).
- LCGPA. Local Content & Government Procurement Authority LCGPA. 2020. Available online: <https://lcpa.gov.sa/en/AboutUs/Pages/default.aspx> (accessed on 14 December 2021).
- Lopez-Ruiz, H.G., Blazquez, J. and Vittorio, M., 2020. Assessing residential solar rooftop potential in Saudi Arabia using night-time satellite images: A study for the city of Riyadh. *Energy Policy*, 140, p.111399.
- Martín-Pomares, Luis, Diego Martínez, Jesús Polo, Daniel Perez-Astudillo, DuniaBachour, and Antonio Sanfilippo. 2017. "Analysis of the long-term solar potential for electricity generation in Qatar." *Renewable and Sustainable Energy Reviews* 73: 1231-1246.
- Matar, Walid, and Murad Anwer. 2017. "Jointly reforming the prices of industrial fuels and residential electricity in Saudi Arabia." *Energy Policy* 109: 747-756.
- Matar, Walid, and Murad Anwer. 2017. "Jointly reforming the prices of industrial fuels and residential electricity in Saudi Arabia." *Energy Policy* 109: 747-756.
- Matar, Walid, Frederic Murphy, Axel Pierru, Bertrand Rioux, and David Wogan. 2017. "Efficient industrial energy use: The first step in transitioning Saudi Arabia's energy mix." *Energy Policy* 105: 80-92.
- Moenergy. Ministry of Energy-Saudi Arabia. Available online: <https://www.moenergy.gov.sa/en/Pages/default.aspx> (accessed on 2 August 2022).
- Nematollahi, Omid, HadiHoghooghi, Mehdi Rasti, and Ahmad Sedaghat. 2016."Energy demands and renewable energy resources in the Middle East." *Renewable and Sustainable Energy Reviews* 54: 1172-1181.
- Peng, Jinqing, and Lin Lu. 2013. "Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits." *Renewable and Sustainable Energy Reviews* 27: 149-162.
- Power Saudi Arabia. National Renewable Energy Program eProcurement Portal. 2022. Available online: [https:// powersaudi Arabia.com.sa/web/index.html](https://powersaudi Arabia.com.sa/web/index.html) (accessed on 28 July 2022).
- Ramli, Makbul AM, SennogaTwaha, and Zakariya Al-Hamouz. 2017. "Analyzing the potential and progress of distributed generation applications in Saudi Arabia: The case of solar and wind resources." *Renewable and Sustainable Energy Reviews* 70: 287-297.
- Rao, T.E., Sundaram, E., Chenniappan, S., Almakhles, D., Subramaniam, U. and Bhaskar, M.S., 2022. Performance Improvement of Grid Interfaced Hybrid System Using Distributed Power Flow Controller Optimization Techniques. *IEEE Access*, 10, pp.12742-12752.
- REUTERS. Top Oil Exporter Saudi Arabia Targets Net Zero Emissions by 2060. 2021. Available online: <https://www.reuters.com/business/cop/saudi-arabia-worlds-biggest-oil-exporter-unveil-green-goals-2021-10-23/> (accessed on 29 July 2022).
- Samwick, Andrew A. 1998. "Discount rate heterogeneity and social security reform." *Journal of Development Economics* 57, (1): 117-146.
- Sathik, M.J., Sandeep, N., Almakhles, D.J. and Yaragatti, U.R., 2020. A five-level boosting inverter for PV application. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 9(4), pp.5016-5025.
- Saudi Arabia's National Unified Portal for Government Services. Council of Ministers. 2021. Available online: https://www.my.gov.sa/wps/portal/snp/agencies/agencyDetails/AC103!/ut/p/z1/jZBBasMwEEXP0oWX8YyiOFWYUx0oCFynmCSOnsUJimywJSOrNb19RbsyaZPObob34P8BCSVIU300uvKNNVUb9qNcvoktWxCOJGeELPE1XbHNCxEUEEwBxKaPAUge8x5sSeICcj_-PjHcLznF8qAuAeFFnOXpZkG2VenjXmYqHkKUEaAsipnj-LRdDJbp6IPWKRXAHXHb-BGyVCQt3a089DuTIRFqI4dVFOufjdhXPtft-sI4xwHMDyW6tbFZ9tF-FvSm0HD-WUHl7bleMnxWbbHdjAH74AsfCikQ!!/ (accessed on 30 July 2022).
- Shaahid, S. M., and Ibrahim El-Amin. 2009. "Technoeconomic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia – a way forward for sustainable development." *Renewable and Sustainable Energy Reviews* 13, (3): 625-633.
- Shakir Khan, M., Suhail, M. and Alharbi, T., 2018. Evaluation of urban growth and land use transformation in Riyadh using Landsat satellite data. *Arabian Journal of Geosciences*, 11(18), p.540.
- Shi, Kaifang, Bailang Yu, Yixiu Huang, Yingjie Hu, Bing Yin, Zuoqi Chen, Liujia Chen, and Jianping Wu. 2014. "Evaluating the ability of NPP-VIIRS night-time light data to estimate the gross domestic product and

- the electric power consumption of China at multiple scales: A comparison with DMSP-OLS data." *Remote Sensing* 6, (2): 1705-1724.
- Sommerfeld, Jeff, Laurie Buys, and Desley Vine. 2017. "Residential consumers' experiences in the adoption and use of solar PV." *Energy Policy* 105: 10-16.
- Sultan, B., Katar, I.M. and Al-Atroush, M.E., 2021. Towards sustainable pedestrian mobility in Riyadh city, Saudi Arabia: A case study. *Sustainable Cities and Society*, 69, p.102831.
- Townsend, Alexander C., and David A. Bruce. 2010. "The use of night-time lights satellite imagery as a measure of Australia's regional electricity consumption and population distribution." *International Journal of Remote Sensing* 31, (16): 4459-4480.
- Vision 2030. Sakaka Solar Power Plant Project. 2021. Available online: <https://www.vision2030.gov.sa/v2030/v2030-projects/sakaka-solar-power-plant/> (accessed on 29 July 2022).
- Vittorio, Michele. 2016. "A GIS tool to create human population distribution layers", in: Esri User Conf., Esri, San Diego, California, USA.
- We Supply Renewables. We Supply Renewables Saudi Arabia. 2020. Available online: <https://www.wesupplyrenewables.com.sa/web/find-supplier.html> (accessed on 30 July 2022).
- Zell, Erica, Sami Gasim, Stephen Wilcox, Suzan Katamoura, Thomas Stoffel, Husain Shibli, Jill EngelCox, and Madi Al Subie. 2015. "Assessment of solar radiation resources in Saudi Arabia." *Solar Energy* 119: 422-438.