Estimating Rooftop Photovoltaic (PV) Potential in the Northern Region of Riyadh, Saudi Arabia

Completed Research

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Abstract

Renewable energy sources (RES) offer clean energy generation that mitigates negative environmental and economic issues compared to fossil fuels sources. Photovoltaic (PV) systems are a popular form of RES to integrate into an electricity grid. Optimal PV-grid integration requires the design of effective supply-demand optimization models for electricity distribution networks. Accurate rooftop PV potential estimation is a first step in building the PV-grid integration optimization model. This paper aims to accomplish two main tasks. First, it presents an innovative approach to estimate the rooftop PV installation capacity in the northern region of Riyadh, Saudi Arabia. Second, calculating the rooftop PV potential. The results show the rooftop PV potential for the northern region of Riyadh counts up to 8.18 TWh per year. This estimation would help Saudi Arabian government to understand the high potential of rooftop-PV systems, enabling the adoption in the residential aspect of RES based on the Saudi Vision 2030.

Keywords

Rooftop PV Potential, Saudi Arabia, RES, Sustainable Energy Management

Introduction

Electricity companies around the world mainly to adopt effective energy management strategies that ensure a robust balance between electricity supply and demand for current situations and future changes. Recently, there has been a noticeable growth in energy demand around the world. For example, in Saudi Arabia, the electricity demand is growing rapidly at a pace of 6.7% annually (SEC 2016). This growing demand creates sustainability challenges of traditional fossil fuels (e.g., coal, oil, natural gas) because these are non-renewable energy resources. These challenges include the reduction of fossil fuels reserves, the negative environmental impact towards the climate change and air pollution, geopolitical and military disagreements, and the increase in fuel price (Asif and Muneer 2007). Therefore, there is a need to find an alternative way to produce electricity.

Fossil fuel resources are the world's primary energy source. In 2015, almost 80% was the total global energy generation by fossil fuels resources and only 2.2% is the portion of geothermal, solar, wind, tide/wave/ocean, heat and other (IEA 2017). This is a huge amount of burning fossil fuel resources that negatively impact the globe with respect to sustainability, economy, and environment. After realizing all of these negatives related to generating electricity via fossil fuels resources, Renewable Energy Sources (RES) become a valuable choice to mitigate all the negative consequences.

RES exist in nature in many forms: sunlight, wind, waves, geothermal, hydroelectric, or biomass. RES are considered to be clean, free, and sustainable forms of energy. Thus, RES can be considered as a viable option to replace fossil fuels in producing electricity. Among RES forms, solar energy, which is radiant light and heat from the sun, is among the oldest and the newest forms of energy (Boyle 2012).
A photovoltaic (PV) system is a power system that generates energy by directly converting solar energy into electricity. A PV system consists of different components, such as solar panels and a solar inverter to change the electric current from direct current (DC) to alternating current (AC). PV systems are the most widely adopted renewable energy form and promising renewable technology around the world with 227 GW total global capacity in 2015 (IRENA 2016; Zell et al. 2015).

A rooftop/ small-scale PV system is where a household installs on a building’s rooftop to generate electricity to the utility grid through a contract. On average, a single home can produce 3–7 kW and rooftop PV systems can offer net surplus energy to sell it back to the utility firm (Pick 2017). The PV-grid integration offers reliable and consistent electricity generation, mitigating the intermittent issues of RES. Therefore, the result is a better, more efficient supply and demand energy management (Lund 2006). Logically, by employing this strategy, electricity companies can manage the short periods of high electrical (peak) loads without building new generation power plants.

To apply the PV-grid integration, there is a need to estimate rooftop PV potential (i.e. to build a model to accurately estimate rooftop PV potential). The purpose of the paper is to build a model to accurately estimate available rooftop for PV installation as an important step to estimate rooftop PV potential in the northern region of Riyadh, Saudi Arabia. This paper first measures rooftop area via parcels data as the building footprint data is not available. Second, this paper estimates rooftop PV potential in the area under study.

The area under study in this paper has 50 neighborhoods of the northern region of Riyadh. The total area is almost 660 km² with a total population of 1.5 million. Saudi Arabia has access to a high annual daily average of solar resources across the country according to Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), and other related meteorological parameters. For the 30 stations distributed in the country, daily annual average GHI is between 5700 Wh/m² and 6700 Wh/m². This suggests that PV systems would perform well at any location in the country (Zell et al. 2015). Therefore, small-scale PV system would be a valuable means to produce electricity from.

The Saudi Arabia’s Vision 2030 is a methodology for economic and developmental action in the Kingdom of Saudi Arabia intended to place the Kingdom in a leading position for several domains. One of the strategic objectives is to enhance the efficiency of government energy subsidy programs by decreasing the government subsidy value of water and electricity in 2020 by 200 SAR Billion (“National Transformation Program | Saudi Vision 2030” 2016). In Saudi Arabia, almost all electricity is generated using diesel except some generated from renewable energy (Sedraoui et al. 2017).

This study is a part of a PhD dissertation that investigates analyzing integrating energy demand and supply side management in Saudi Arabia by building an optimization model. This paper shows a study two tasks to estimate the rooftop PV potential in the northern region of Riyadh, Saudi Arabia. We first innovatively measure the suitable residential buildings’ rooftops to install PV systems. This task helps to estimate the suitable capacity of rooftop PV system in the northern region of Riyadh, Saudi Arabia. Second, we calculate the rooftop PV potential in the area under study. The results show the rooftop PV potential counts up to 8.18 TWh/year.

The rest of the paper is structured as follows: Section 2 the literature review and background. Section 3 explains the methodology of the study. Section 4 describes the proposed model. Section 5 shows the results of this paper. Section 6 discusses the obtained results. Section 7 covers how we evaluate the proposed model. Section 8 Finally, concludes.

**Literature Review and background**

For an effective small-scale systems deployment, there are three main elements to consider that are: physical, geographic, and technical elements. these elements used to build a model that estimates PV systems potential beforehand. First, the physical element is the amount of solar radiation received into the buildings’ rooftops surface where PV systems is designed to install on. Second, the geographic element is the available and suitable rooftop area needed for PV installation. Third, the technical element that concerns about the PV modules technology efficiency.
Regarding estimating the geographic element, a study (Melius et al. 2013) reviewed 35 studies and six patents then they showed that there are three major methods of how to estimate the suitability of PV rooftop area. They are: 1. Constant-Value Method, 2. Manual Selection Method, and 3. GIS-based Method.

First, Constant-Value Method estimates a multiplier to calculate a factor of a small region or a sample of the study area and then apply that multiplier to the entire region. They are popular among reviewed studies due to their ease of use. These methods provide a beneficial starting point for calculating rooftop solar energy potential in a studied area. Also, they are not time or resource intensive. An example of this method is available rooftop area calculation based on the population density of a neighborhood. A study uses building footprints and existing GIS data sets with census data from a sample of 10 areas in southeastern Ontario, Canada to calculate available rooftop areas (Wiginton et al. 2010). The combination of these data sets allows researchers to estimate suitable rooftop space per capita for the sampled areas, which is about a third of the total study area. After that, researchers apply the constant value of 30% to the entire study area. The estimation results show that the supply can cover about 30% of Ontario's annual electricity demand. Similar studies have been done by (Izquierdo et al. 2008; Khan and Arsalan 2016; Lehmann and Peter 2003; Naroll 1962; Taubenböck et al. 2007, 2007).

Second, the Manual Selection Method uses sources like aerial photography to identify buildings' rooftops. Therefore, this type pf method is more accurate and time-consuming of estimating suitable rooftop areas. Examples for this type of method are Kingston studies (Nguyen and Pearce 2012). The study selects specific rooftops then applies these rooftops constant values depending on the roof shapes (50-62 % for pitched roofs and 100% for flat roofs). The factoring process considers any object that may make shadowing effects in the selected rooftops. The rooftop estimation result shows that 33% of the selected rooftops is available for PV deployment.

Third, the GIS-based Method depends on a computer model that processes input values of rooftop characteristics, then the GIS software visualizes the suitability areas. Several previous studies use these methodologies to estimate the suitable area for installing rooftop PV. Example for the GIS-based method is a study in Lisbon, Portugal (Santos et al. 2011). The ArcGIS tool requires an input of a Digital Surface Models (DSM), which is generated from LiDAR data. They show that 49% of buildings have rooftops suitable for PV in about 6-square-kilometer study area. Similar studies are (Colmenar-Santos et al. 2016; Lukač et al. 2016).

Regarding the physical, geographic, and technical elements, there are a number of tools and software that facilitate estimating the rooftop PV potential for the area under study. One of these valuable tools is PVWATTS that could study the feasibility of a solar PV system projects anywhere by estimating the power output. It is developed by the National Renewable Energy Laboratory (NREL). This tool is used in several previous studies.

One of the studies is in Detroit, Michigan for a residential sector. The study goes further into how to make improvements to an installed system and its cost effectiveness (White and Ali 2016). Another study to assess the environmental impact of grid-connected PV systems for 214 PV systems located across the US (Spiegel et al. 2005). A study of PV solar systems at Nevada’s Desert Research Institute (DRI) about the lifecycle climate impacts besides the economic performance of commercial-scale solar PV systems. The study uses the PVWatts model to measure the electricity generating for each PV system. Also, the PVWatts model is used to calculate average monthly solar insolation for a 30-year period at major cities globally. For the year 2013, the PVWatts estimation of power production was within 1% of the measured actual value (Liu et al. 2015).

There are some studies have been done for Saudi Arabia in regarding estimating the PV potential. (Khan et al. 2017) show a prediction study for the rooftop PV power generation potential for residential sector for 13 major cities in the KSA. They consider several aspects in the prediction process such as PV design considerations and local buildings' construction. (Ramli et al. 2015) investigate the optimal sizing of grid-connected PV system in Makkah, KSA. To obtain the optimal sizing, they examine a number of factors: unmet load, excess electricity, fraction of renewable electricity, and other economic and environmental aspects.

Khan and Arsalan (2016) estimate the rooftop PV potential in a neighborhood of Karachi - Pakistan. First, they calculate the solar radiation potentials. Second, rooftop areas estimation, they combined GIS and
object-based image recognition to measure small regions, then extrapolating the total available roof area using the areas-population density correlation. Third, they estimate PV efficiency by taking into account four types of PV modules that are Mono-crystalline Si (c-Si), Poly-crystalline Si (p-Si), Amorphous Si (a-Si), and Cadmium-Telluride Cells (CdTe). They validate the estimated energy output by comparing to an actual electrical output of a specific building.

The previous studies do not show a rooftop PV system potential in the city of Riyadh. Also, no study found has estimated buildings’ rooftops using parcel data as we introduce here. These types of research mainly depend on the data availability as a main deriver and how to accomplish the proposed goals. In this study, the data we have is a shapefile that contains the parcels data, population distribution, number of units, and the administrative boundaries for 50 neighborhoods in the northern region of Riyadh, Saudi Arabia. We find the correlation between parcel area and the area rooftops by measuring a sample of for 15 buildings.

Methodology

Design Science Research (DSR) is a practicum research approach to develop artifacts. DSR can be defined:

“A research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artifacts, thereby contributing new knowledge to the body of scientific evidence. The designed artifacts are both useful and fundamental in understanding the problem” (Hevner and Chatterjee 2010).

The DSR result, which is an artifact, can be a construct, a model, a method, or an instantiation. However, produced artifacts must be evaluated. In this paper, I will follow the Seven DSR guidelines proposed by (Von Alan et al. 2004). The DSR as is considered as a main umbrella for this paper because information systems usually are implemented to improve improving the effectiveness and efficiency of organizations.

To solve these types of the proposed problem, we build a model to estimate rooftop PV potential using the hierarchical methodology as previous studies have used (Assouline et al. 2017; Izquierdo et al. 2008; Khan and Arsalan 2016; Wiginton et al. 2010). Using this methodology, researchers focus mainly on the three main elements: the physical potential, the geographic potential, and the technical potential. First, the physical potential reflects the amount of received solar energy from the sun. Second, the geographic potential concentrates on determining the suitable rooftops to install PV systems. Third, the technical potential examines PV systems components and process to convert the solar radiation into electricity.

Proposed Model

The proposed model estimates the rooftop PV potential in 50 neighborhoods in the northern region of Riyadh. The main three elements considered in the estimation process are: the physical, geographic, and technical potentials. The process is divided into two main phases.

Phase One: Estimating the Capacity of the Rooftop PV System

In order to assess the geographic potential, the first step is to calculate the available and suitable buildings’ rooftop area needed to install PV systems on. This phase requires first to obtain a shapefile with parcels data for the area of estimation. Then, a correlation between parcels and rooftop areas needs to be calculated before assessing the suitable buildings’ rooftop area for PV system deployment.

We collected the required data to build the proposed model from the High Commission for the Development of Riyadh (HCDR). The data is a shapefile that includes the parcels data, population distribution, number of units, and the administrative boundaries for 50 neighborhoods. The data spans the northern region of Riyadh, Saudi Arabia. We imported this shapefile ArcMap 10.5 software for future analysis.

First, we utilize ArcMap 10.5 and add the Imagery Basemap where rooftops are clear and easy to measure manually. Then, by using the measurement tool, we calculated the area of a sample of 15 buildings’ rooftops in the northern region of Riyadh in square meters. Then we compared the manual measured results with actual measurements, which are buildings’ footprints, to ensure the accuracy of our calculation. After that, the correlation of the parcel-rooftop area is calculated as 56%. We obtained this outcome by dividing the...
areas of measured rooftop by the parcel then multiplying it by 100. In the end, we compute the average of the division process.

According to SEC, suitable rooftop areas for PV installation in Riyadh is between 50% and 70% of whole rooftop areas. Therefore, in this paper, we assumed the most conservative percentage (50%) to determine the total suitable rooftop area to install rooftop PV systems on. Ultimately, we estimated the whole available rooftop area for 42 km² using the parcel-rooftop area correlation (see Figure 1 below).

![Figure 1 Phase one: The flowchart of the calculation process](image)

**Phase Two: Estimating Residential Buildings PV Potential**

In phase two, the result from phase one is used to estimate the buildings’ rooftop PV potential. An online tool, NREL’s PVWatts® Calculator, is utilized to facilitate this estimation. The tool uses solar resource data from the latest NREL National Solar Radiation Database that allows to estimate the energy production of PV energy systems globally.

Utilizing PVWatts online tool, we first calculated the rooftop PV potential for 100 m² in one of the rooftops in the northern region of Riyadh. By careful consultations with the experts and previous study (Khan et al. 2017), eight criteria are considered as inputs in the PV potential estimation (Table 1). The result showed that the PV potential of the target area as 19.471 kWh/year. We further consulted Saudi Electricity Company (SEC) experts about the accuracy of the result, and then applied it for the whole area under study. Ultimately, the PV potential for an area of 42 km² area (the whole area under study) was estimated to be 8.18 TWh/year.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC System Size</td>
<td>15.0 kW</td>
</tr>
<tr>
<td>Module Type</td>
<td>Standard</td>
</tr>
<tr>
<td>Array Type</td>
<td>Fixed (roof mount)</td>
</tr>
<tr>
<td>Array Tilt</td>
<td>23°</td>
</tr>
<tr>
<td>Array Azimuth</td>
<td>180°</td>
</tr>
<tr>
<td>System Losses</td>
<td>35%</td>
</tr>
<tr>
<td>Inverter Efficiency</td>
<td>96%</td>
</tr>
<tr>
<td>DC to AC Size Ratio</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Table 1 NREL’s PVWatts® Calculator Criteria**

**Results and Discussion**

The phase one estimated available rooftop area for PV installation in the northern region of Riyadh as 42 km² (table 2). The result indicated a Parcel-Rooftop area correlation of 56%. Based on the phase one result,
the estimated rooftop PV potential in the northern region of Riyadh is 8.18 TWh/year. This result is considered a very high rooftop-PV potential according to electricity experts.

<table>
<thead>
<tr>
<th>Buildings’ rooftop area data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Parcel area (km²)</td>
<td>150</td>
</tr>
<tr>
<td>Parcel-Rooftop area correlation (%)</td>
<td>56%</td>
</tr>
<tr>
<td>Rooftop area (km²)</td>
<td>84</td>
</tr>
<tr>
<td>Suitable area to install PV systems (%)</td>
<td>50%</td>
</tr>
<tr>
<td>Suitable rooftop area to install PV systems (km²)</td>
<td>42</td>
</tr>
</tbody>
</table>

| Table 2 Estimated Suitable Rooftop Area |

The results of this study may inform the Saudi Arabian government about the high potential of rooftop-PV systems and consequently, creating incentive programs to encourage homeowners to install rooftop-PV systems. By doing so, it would support the “Saudi Arabia’s Vision 2030” that acts as a methodology for economic and developmental action in Saudi Arabia. In order to achieve the ambitious goals of the Saudi Arabia’s Vision 2030, the National Transformation Program 2020 is designed across 24 government organizations with strategic objectives for the year 2020. The results provide insights on designing RES programs that can maximize the efficiency of fuel utilization in the electricity sector, minimize fuel consumption emissions, enable renewable energy to contribute in the national energy mix, and other strategic objective for the year 2020.

**Evaluation**

Evaluating proposed artifact is a critical step of the DSR. In phase one, a sample of 15 rooftops in different neighborhoods was measured. Then the estimation accuracy is evaluated by comparing with the actual rooftops measurements by contacting the sample units’ owners. The evaluation showed that the area measurements were very close to the actual areas. 

In phase two, both the physical and technical potentials were used to obtain the total buildings’ rooftop PV potential using NREL’s PVWatts® Calculator. The PVWatts tool is widely accepted tool among researchers. The estimated total rooftop PV potential was evaluated using experts from SEC, and it was confirmed as a realistic estimation.

**Conclusion and Future Work**

One of the main challenges of this kind of studies is data availability. Without available rooftop area measurements, the novelty of this research is to design an approach that processes parcel area data on the way to estimate suitable rooftops for PV installation. After much research, this approach has not previously done by any other study.

The recommended future work is to estimate the economic potential by introducing the required costs and benefits for several stakeholders. In addition, the evaluation should be expanded to cover more rooftops to ensure the parcel-rooftop area correlation. Similarly, because rooftop PV systems are new means in Saudi Arabia to produce electricity, there is no actual rooftop PV systems’ potential data to compare with. Therefore, in future work, we will collect some actual data for the comparison task with the proposed model's estimated outcomes.

**References**

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