Journal of Building Engineering 25 (2019) 100809

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Solar PV on mosque rooftops: Results from a pilot study in Saudi Arabia

Amro M. Elshurafa[a,*], Abdullah M. Alsubaie[b], Ayman A. Alabduljabbar[b], Shafi A. Al-Hsaien[c]

[a] King Abdullah Petroleum Studies and Research Center (KAPSARC) PO Box 88550, Riyadh, 11672 , Saudi Arabia
[b] King Abdulaziz City for Science and Technology (KACST), PO Box 6086, Riyadh, 11442 , Saudi Arabia
[c] Saudi Electricity Company (SEC), PO Box 22955, Riyadh, 11416, Saudi Arabia

ARTICLE INFO

Keywords:
Solar PV
Distributed generation
Net metering
Mosque
Technoeconomics
Highlights

ABSTRACT

Muslims congregate for prayers in mosques five times daily: at dawn, noon, afternoon, sunset, and evening. Because these times are governed by the sun, they change within the year but are perpetual. As such, mosque load profiles are highly predictable and witness little variation year over year. The relatively large size of mosque rooftops and their ubiquity in the Muslim world make them ideal candidates for solar photovoltaic (PV) installations. We perform a technoeconomic analysis on a 124 kW PV system commissioned in 2017 on a mosque rooftop in Riyadh, Saudi Arabia, under a net metering mechanism. At a capital cost of 1.18 US$/watt, it was found that net metering reduces the annual energy bill by more than 50%. If some prior planning were incorporated in the early stages of the mosque's construction, PV can bring down the electricity bill to zero. We compare our theoretical modeling results with an actual commissioned system, serving as a pilot-project, and the field results confirm our a priori theoretical expectations. The capacity factor obtained from the physical system was 18.2%. The results of this study can be extended to other houses of worship and community halls with appropriate modifications.

1. Introduction

The cost of solar photovoltaics (PV) technology has fallen significantly over the past four decades. From over 100 dollars per watt (US$/W) in the mid-1970s, the cost of solar modules is now around 0.30 US$/W. This remarkable cost decline coupled with international concerns to reduce fossil-fuel-based carbon emissions served as main drivers, for many countries, to maintain a steady PV installation rate [1–3]. From virtually no installations in 1990, the global cumulative installation capacity of PV by the end of 2017 worldwide was nearly 400 GW [4].

Solar PV systems, with respect to size, are broadly categorized into three segments [5]: residential systems (2 kW–10 kW), commercial/industrial systems (100 kW–500 kW), and utility scale systems (1 MW and above). Residential and commercial systems are also referred to as distributed generation (DG), where the term DG refers to power generation units that are located within the distribution network at or near the load [6].

In this paper, we focus on commercial-scale systems, and will do so through a techno-economic analysis of a solar PV system installed on a mosque rooftop. The financial analysis and technical performance will be buttressed with experimental data from an actual pilot project commissioned in Riyadh, Saudi Arabia. Similar DG performance assessment studies have been done previously and were reported in the literature [7–9]. These studies provide valuable lessons and are of interest to the renewable energy community as they inform policymakers, researchers and businesses about the technical and economic prospects of DG installations. In addition to the well-known usage of rooftop solar PV in the residential and commercial sectors, solar PV is proving to be an effective solution in a number of less-known applications including hostels [10] and airports [11,12]. Integrating the PV panels in the early phases of building construction is also becoming more common [13]. This paper will focus on solar PV systems installed on mosque rooftops, as this area has not received the same research attention as other types of installations have.

Islam is a religion with 1.6 billion followers worldwide, which represents a little less than a quarter of the world population; it is the majority religion in nearly 50 countries [14]. The mosque is where Muslims gather for their daily congregation, weekly sermons, annual festivities, and other religious and social activities. Mosques vary significantly in their sizes: from small that can accommodate 50–100 people to grand ones that accommodate tens of thousands of worshippers. An estimated 3.5 million mosques exist globally [15]. Given their ubiquity in the Muslim World, governments have realized that

* Corresponding author.
E-mail addresses: amro.elshurafa@kapsarc.org (A.M. Elshurafa), aalsubaie@kacst.edu.sa (A.M. Alsubaie), ajabbar@kacst.edu.sa (A.A. Alabduljabbar), SHAlhsaien@se.com.sa (S.A. Al-Hsaien).

https://doi.org/10.1016/j.jobe.2019.100809
Received 15 January 2019; Received in revised form 20 May 2019; Accepted 22 May 2019
Available online 26 May 2019

mosques deserve attention from an energy standpoint, and significant research has been dedicated to mosques from various angles – we summarize some of this effort in the following.

For example, life cycle analyses for mosques have been performed [16]. In fact, more aggressive steps have also been taken by introducing the 'Smart Mosque' concept as presented by Deloitte [15]. This concept essentially entails reducing the energy footprint of mosques through energy efficiency and renewable energy initiatives. From a solar PV perspective, mosques are considered suitable buildings for rooftop solar PV installations given the relatively large roof area available. From a financial perspective, once the solar PV system is installed, it can contribute to bringing down the energy bill considerably as the capital cost (or CAPEX) of solar PV systems is the only major hurdle [17].

Given these advantages, we note that there were few studies that considered the economics of solar PV on mosque rooftops. A study for PV deployment for all the 1,400 mosques within Kuwait performed back in 2014 showed that a payback period of 13 years is expected given the prevailing prices then [18]. The objective of the latter study was to assess peak-shaving opportunities through distributed generation deployment. Certainly, if the analysis were to be redone now with the new developments both in terms of electricity prices and solar technology costs, the payback period would be shorter. Another study designed a hybrid microgrid system for a Mosque in Libya [19]. The mosque was located in a rural area, and because maintaining a stable diesel supply was costly, the authors proposed incorporating a PV system to reduce the reliance on diesel. Clearly, the dynamics and constraints for a grid-connected mosque will be different than an off-grid one. In Malaysia, a study on a specific mosque showed installing a PV system would reduce the energy bill by 47% [20].

More recently, the financial attractiveness of solar PV systems on mosque rooftops has increased given the decreasing capital costs of the technology. The business case becomes even more compelling in countries where the energy prices are considered high. In a country like Jordan for example, where the price of electricity has been on the rise since 2012, an average sized mosque can be paying an annual power bill of approximately USD 17,000. Recently, Jordanian government officials announced that Jordan's 6,300 mosque will utilize solar PV for electricity generation [21]. Solar has particular appeal in Jordan as it is a country with good solar conditions and is also a country that is almost entirely reliant on imports for meeting its energy demand [22].

Similarly, Morocco initiated an ambitious plan to install PV on 600 mosques by 2019 and more thereafter. It is worth noting that there are nearly 50,000 mosques in Morocco [23]. Part of the funding for this Moroccan plan comes from the German Federal Ministry for Economic Cooperation and Development. The Moroccan Ministry of Religious Affairs, which is the body responsible for paying the energy bills of mosques, gladly received the news. Besides economic benefits, governments view 'green mosques' as a way that raises energy awareness across the population, and as an implicit campaign that can encourage wider acceptance and adoption of renewable technologies [24]. Akin to Jordan, Morocco relies on imports for nearly all of its energy needs [25].

Within the same realm, Saudi Arabia is considering wide deployment of solar PV systems on its mosques. Although there could be high-level similarities between these deployment programs launched across the Muslim world, there are a few characteristics that are specific to Saudi Arabia: the severe hot weather necessitating air conditioning, rather large mosques, and the fact that there are nearly 94,000 mosques present within the kingdom [26]. The latter particularly burdens the budget of the Ministry of Islamic Affairs, which pays the electricity bills of these mosques. Further, the electricity regulator in Saudi Arabia (www.ecra.gov.sa) has recently released provisional bylaws that would govern DG installation within the kingdom. On that front, Saudi Arabia will be implementing a net metering mechanism to promote solar DG deployment [27,28]. Such observations justify a dedicated and tailored assessment of the financial viability of installing solar PV system on mosque rooftops in the Saudi context.

To that end, we present for the first time a detailed technoeconomic analysis of installing a solar PV system on a mosque rooftop in Riyadh, the capital city of Saudi Arabia. The objective of this paper is to assess financial and other policy implications that would stem from deploying PV systems on mosque rooftops. Ultimately, this study would serve as one building block that aids in providing insight to policymakers as to whether a nationwide PV deployment program on mosques is justified in the kingdom and beyond. One of the key aspects of this study is that the theoretical modeling and technical assumptions have been cross-checked and verified with an actual physical system that has been erected and commissioned. The results from both analysis exhibit excellent agreement. Further, we model the effect of policy, by way of implementing a net-metering mechanism, on the financial viability of the project. We find that net metering has a more pronounced (positive) effect on the mosque's financial health compared net metering applied to the residential sector given the different load profiles between both sectors. The significance of the results stems from the fact that the study relies on a wealth of data spanning the period of two years.

Our result show that solar PV deployment is financially advantageous for mosques in Saudi Arabia: if net metering were implemented, the net present cost (NPC) would reduce by 22%. The study, given its high level of granularity, can serve as a basis to inform policymaking decisions related to solar PV deployment in Saudi Arabia.

2. Assumptions and methodology

2.1. Overview and scope

The project undertaken by this paper aims to design and install a solar PV system on a mosque rooftop in the city of Riyadh. Such a system would be classified as a 'commercial-size system' despite the fact that mosques are non-commercial buildings. As expected, when embarking on such an endeavor, i.e. installing a distributed generation PV system, numerous aspects could be analyzed and assessed both qualitatively and quantitatively as previously reported. We summarize some of the literature in the following.

On a 'micro' level, assessment of DG focus on aspects that pertain to the system itself including for example financial viability [29–31], engineering analysis [32,33], and the role of storage [34–36]. At the other side of the spectrum, and on a higher 'macro' level, the literature has also evaluated policy support options [37–39], environmental and carbon footprint implications [40,41], job creation [3,42,43], business models [44–46], and grid stability concerns and/or benefits due to the two-way flow of power when excess energy generated from the PV system is exported to the grid [47–49].

Clearly, this study will not cover all the above-mentioned aspects. Rather, the study herein will focus on the financial attractiveness of installing the solar PV on the mosque's rooftop. Macro aspects are beyond the scope of this paper. With respect to DG, the regulator has released the code that would govern DG adoption. Although the actual regulation has not been officially approved, the draft of the regulation is available. As noted earlier, net metering mechanism is the policy support choice that has been proposed [50]. Other sizing limitations, installer requisites, legal conditions, etc. were also articulated.

2.2. Assumptions and methods

2.2.1. Site information and load profile

The mosque is located in Riyadh, the capital city of Saudi Arabia; it is considered a relatively large mosque with an approximate area of 2,300 square meters.[1] For any PV sizing (optimization) exercise to be

[1] For confidentiality purposes, the name of the mosque and exact location will not be shared. For more information, please contact the authors.

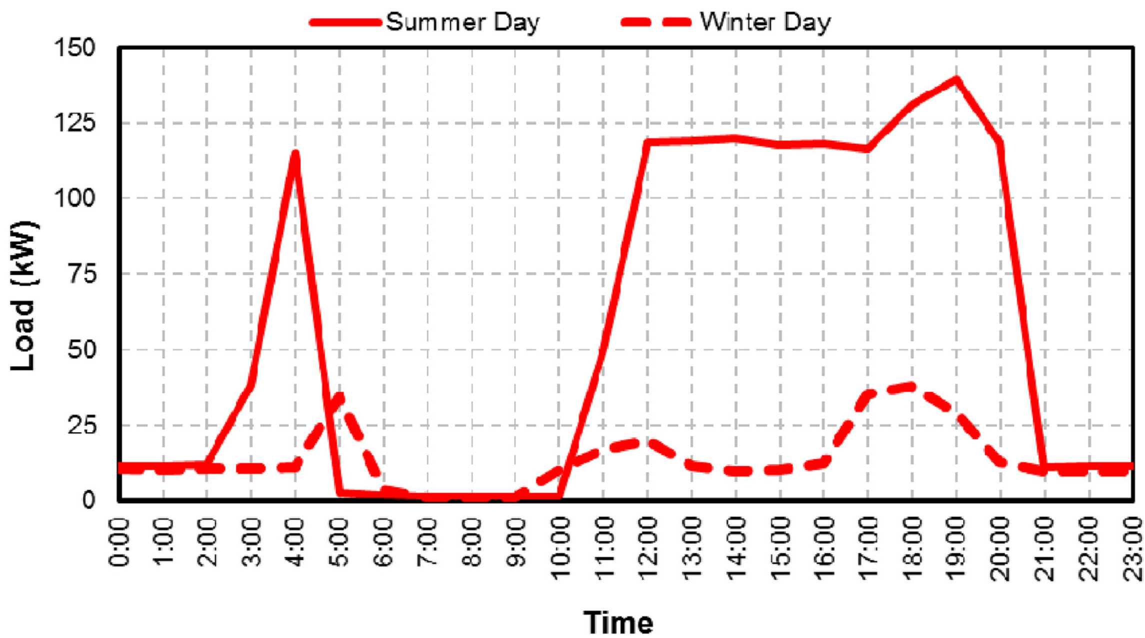

Fig. 1. Representative load profiles for the masjid: a sample summer day and a sample winter day. The profiles are from the actual measured data.

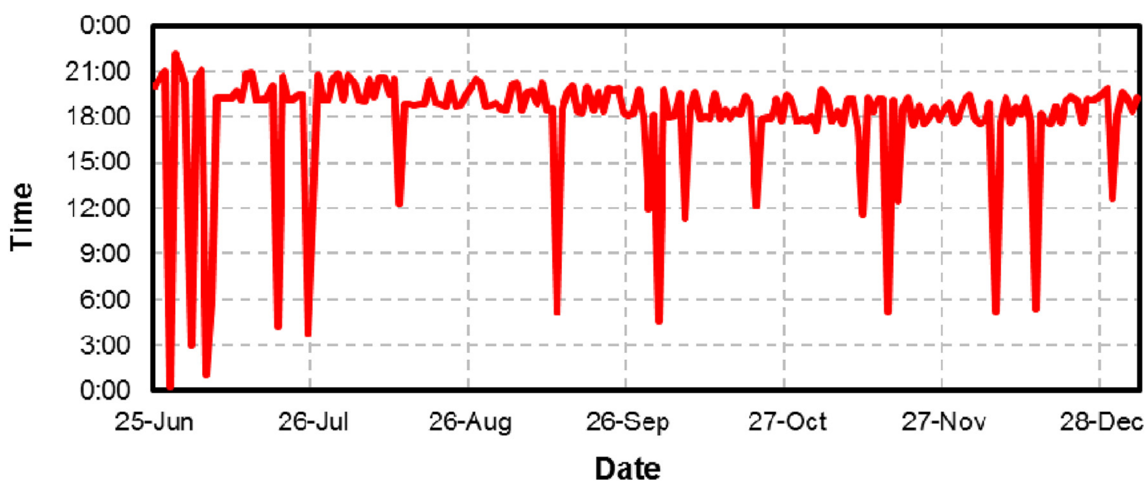

Fig. 2. The time of day at which the peak load occurs. Note that the peak load mostly occurs around 6:00pm, which coincides with sunset prayers.

meaningful, the load profile is to be known. Hence, a full year of load data has been collected with a 5-min resolution. However, we content with an hourly resolution (i.e. 8,760 data points for the full year) to strike a balance between accuracy and model tractability.

Muslims congregate for prayers in mosques five times a day: at dawn, noon, afternoon, sunset, and evening. This means that the exact timing of the prayers are governed by the movement of the sun and will hence change over seasons. Despite these time shifts, the timings are known precisely throughout the year and, because they are dependent on the sun, are perpetual. The latter fact makes the load profile of mosques highly predictable, with very little room for deviation. This also includes the weekly sermon which occurs every Friday during the time of noon prayers. If a particular mosque does not undergo any expansions, does not invest in efficiency measures, or change the air conditioners for example, little variation would be expected from one year to the next. As a sample, we provide, in Fig. 1, two load profiles for the mosque: one profile representing a summer day and another representing a winter day.

From Fig. 1, we can make a few comments:

- As expected, a significant difference in load exists between summer and winter due to the air conditioning load required during the summer. This difference is in excess of 100 kW during some hours.
- The peak that occurs at around 4:00am is due to the dawn prayer congregation. Note that the dawn peak during the summer months is significantly higher than the dawn peak during the winter months due to the use of air conditioning. We also note that dawn prayers are nearly an hour apart during summer and winter days given that the length of day changes considerably between seasons.
- Although no prayers are held between the afternoon and sunset prayers, other activities may take place during this time. Hence, the air conditioners would still be on.
- The highest load (as per the sample of Fig. 1) is approximately 140 kW. However, the peak load for the mosque was approximately 176 kW and occurs during the evening.
- The lowest load occurred in the period between dawn and noon: the load during this time drops to around 2 kW. The latter observation is an important one and will be examined further in the paper.

Another aspect that we look at is identifying when the daily maximum loads occur. This information contributes to the decision of what PV capacity is to be installed. As a sample, we provide in Fig. 2 below

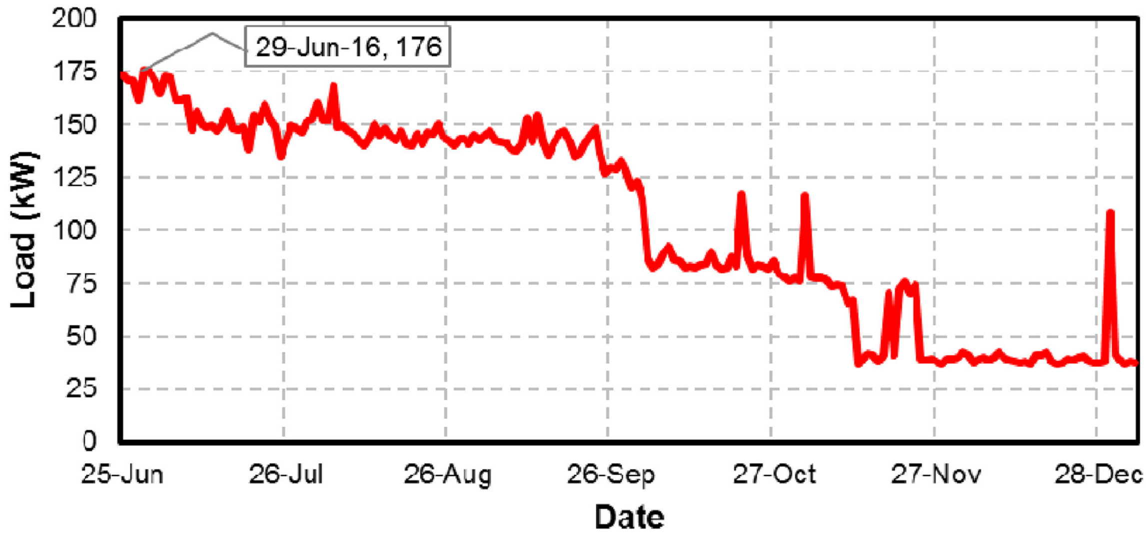

Fig. 3. The magnitude of the maximum load that occurs daily in kW. The peak load was found to be 176 kW and occurs towards the end of June.

the time at which the peak load occurs during the period of July to December. As can be seen, the daily peak occurs mostly during the early evening which coincides with sunset prayers. It is worth noting, however, that the difference between the noon peak and the evening peak is relatively small and is mainly due to the additional lighting needs that is only required during the evening.

For completeness, Fig. 3 depicts maximum loads witnessed on a daily basis for the same time period of Fig. 2. As expected, the maximum daily load starts to drop significantly during October due to reduced air conditioning use. The peak load, as shown in Fig. 3, was measured to be 176 kW, and occurred during the end of June.

2.2.2. Financial assumptions

Renewable technologies in general enjoy low operation and maintenance (O&M) costs, and solar PV is no exception. Explicitly, variable O&M costs, which are usually associated with fuel costs, are practically nonexistent. This leaves a small fixed O&M cost component to be catered for. For this reason, the marginal cost of generation for renewable technologies is nearly zero [51].

As such, the capital cost is the key cost element that influences the decision to install a PV system. In Table 1, we summarize the costs that are associated with erecting the solar system as provided from local vendors. Note that some cost elements were provided in dollar per watt terms (US$/W), whereas others were provided in US$ terms as they are sold on a per-unit a basis. Note that this section restricts the assumptions to CAPEX of the PV system itself. Other financial assumptions that affect the attractiveness of this installation but are not tied to the physical installation like the discount rate and the grid electricity price will be covered in the next section. We also note that the price of the module specifically was reflective of the prevailing conditions back in early 2017. If the project were to be commissioned now, the module costs are expected to be lower.

Table 1
Capital costs. Source: Authors' analysis based on quotes from local vendors with the exception of modules and some design activities. The modules and inverters were provided through King Abdulaziz City for Science and Technology at cost, whereas the design activities were conducted as part of the authors' research.

Item	Cost	Unit
Module (monocrystalline)	0.405	US$/W
Inverter	0.133	
Ground Mounts (Mechanical structure)	0.343	
DC cables	0.052	
AC cables	0.011	
Labor (Installation) Costs	0.080	
DC Junction Box	782	US$
Protection Relay	1,970	
Power Meter	230	
Controlled Switch	75	
Controller	135	

2.2.3. Technical and operational assumptions

The technical and operational assumptions, in addition to the capital cost assumptions, have a major effect on the financial viability of solar installations. These assumptions are summarized in Table 2 and encompass specifications related to the PV system itself, the solar resource, and 'external' financial assumptions (like the discount rate and inflation).

The parameters included in Table 2 are self-explanatory. However,

Table 2
Technical and Operational Assumption used for the analysis of the PV system.

Parameter		Value	Unit
Environmental	Solar Resource	Riyadh	W/m^2
	Temperature	Riyadh	°C
	Ground Reflectance	20	%
Technical	Module Efficiency at standard test conditions	16.6	%
	Nominal Operating Cell Temperature (NOCT)	47	°C
	Annual Degradation of Module Efficiency	0.5	%
	Temperature Dependent Power Loss	0.4	%/°C
	Zenith[a]	65	Degrees
	Azimuth (east of south)	20	Degrees
	Inverter Lifetime	10	Years
	Inverter Efficiency	96	%
	Inverter Replacement Cost	0.10	US$/W
	System Lifetime	25	Years
	Derating Factor	85	%
Financial	O&M Cost	15	US$/kW/Year
	Nominal Discount Rate	3	%
	Inflation (applies to all costs)	2	%
	Price of Grid Electricity	0.0853	US$/kWh

[a] The zenith angle is the angle between the zenith line and the module. The elevation angle, on the other hand, is the angle between the horizontal line and the module. In other words, the zenith and elevation angles are complementary. In our case, the zenith angle is 65°, translating to the modules creating a 25° angle with the horizon.

three of these parameters deserve some elaboration: namely the derating factor of 85%, the discount rate of 3%, and the electricity price. Regarding the derating factor, it is the parameter that describes the efficiency of the solar PV system. A derating factor of 85% is equivalent to losses of 15%. In our case, the derating factor entails all the losses of the solar system including the losses that occur due to shading, but excludes losses of the inverter; the losses of the inverter are taken into account separately.

With respect to discount rates, it is well-known in the literature that arriving at the 'correct' discount rate is not straightforward. Because the discount rate quantifies the time value of money, discount rates largely vary across individual investors, the private sector, and governments. For individuals, arriving at discount rates tends to materialize via surveys and generally yield high discount rates that can reach as high as 60% [52–55]. For the private sector, one way to view the discount rate is through the lens of the opportunity cost of the project relative to other investments (which is also applicable to individuals). Clearly, this will vary by sector.

For government investments, note that governments do not necessarily pursue projects for profit purposes, but rather for social welfare. Because this is a research and development project, we opt to use a discount rate of 3%, which is lower than that used in the private sector as previously articulated in the literature [56,57]. We understand that the discussion about discount rates and their choice is not a topic of consensus, and we do not intend to delve further into this matter as it is not a core objective of this paper. To conclude however, we note that even if higher discount rate is used (around 5%), the insights of the paper would still hold.

Of all sectors, the governmental sector in Saudi Arabia pays the highest rate: a flat 0.32 SAR/kWh (0.0853 US$/kWh) irrespective of consumption. The residential and commercial sectors, for example, pay 0.18 SAR/kWh and 0.20 SAR/kWh for the first 6,000 kWh of consumption respectively, and both pay 0.30 SAR for every additional kWh. To keep industries competitive, the industrial sector pays a flat tariff of 0.18 SAR/kWh (0.048 US$/kWh). These prices can be viewed as lower than global averages, but they are new reformed prices that came into effect in early 2018. Before 2018, electricity prices were much lower. For the purpose of this paper, the relatively high price that is paid by the governmental would favor PV installation.

3. Methodology

The purpose of this study is to assess the technoeconomics of installing a PV system on a mosque's rooftop. As motioned earlier, the focus will be directed towards the financial betterment of the mosque. Quantitatively, the latter objective would be achieved by minimizing the net present value of the costs, which we would refer to as net preset cost (NPC) hereafter. To aid in optimization and to link all the parameters presented in the previous section, we adopt HOMER, a commercially available software, to facilitate analyzing renewable power generation and its interaction with the grid.

Note that the regulatory and policy details are of importance as the type and magnitude of support, if any, would affect the sizing of the PV system [58,59]. In a setting where no net metering or no feed-in-tariffs would be implemented for example, the system size would be designed to meet the (peak) load. Conversely, if net metering were implemented then there would be value in increasing the size of the PV system. At any point in time, if the generated PV energy is higher than the load, then the excess energy would be instantaneously exported to the grid at the electricity price. If at the end of the billing cycle (monthly or annually), the customer were a net importer of energy, then the customer would pay the utility. Likewise, if the customer at the end of the billing cycle was a net exporter of energy, then the utility would pay the customer at a predetermined rate which is referred to as the Net Excess Export Price. Generally, this net export price is lower than the electricity price, and most net metering programs would require utilities to

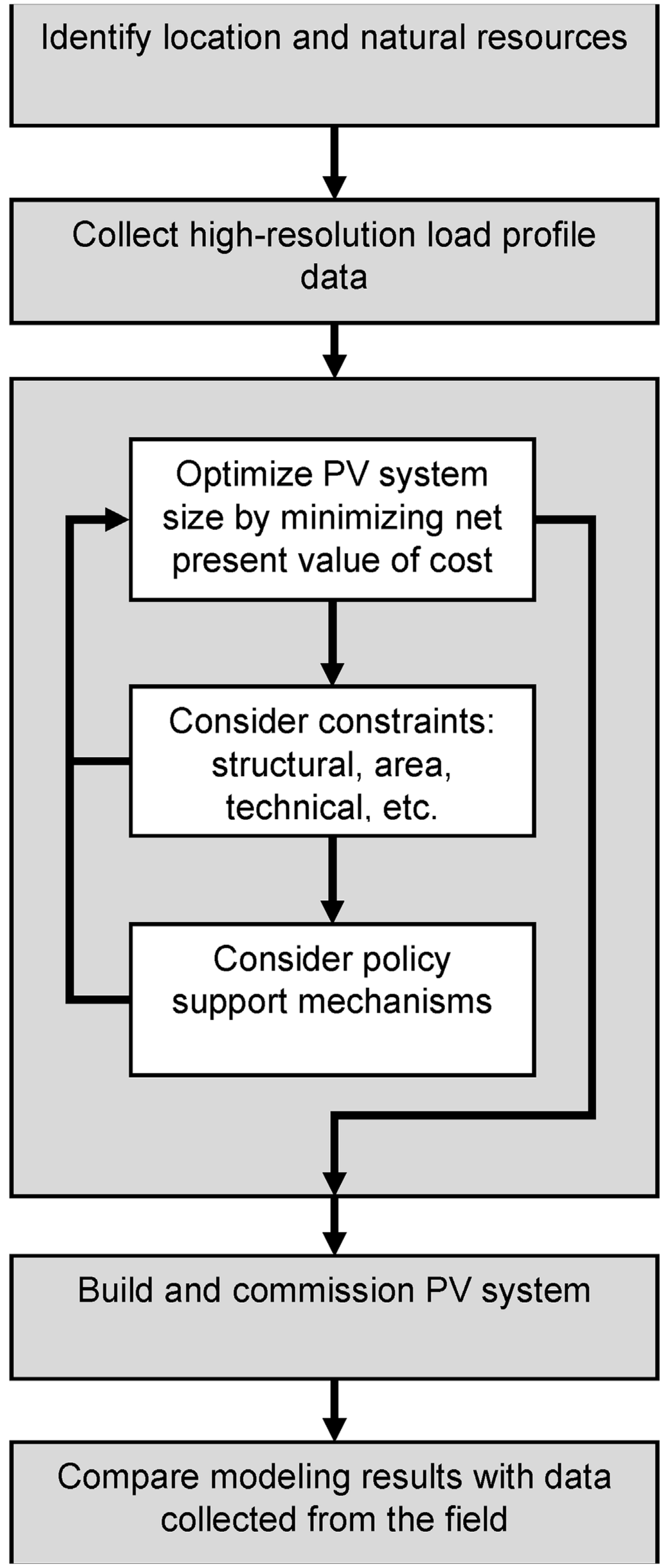

Fig. 4. A flow chart summarizing the technoeconomic methodology adopted in this paper.

buy back this excess generation from the homeowner at either the day-ahead wholesale electricity price [60] or at the avoided cost [61]. The latter refers usually to the fuel cost component, without incorporating capacity and transmission costs. The regulator in Saudi Arabia did not explicitly announce this net excess export price. For the purposes of this

Table 3
Modeling results of the scenarios.

Scenario	Installed PV Capacity (kW)	Net Present Cost US$	CAPEX (US$)	Renewable Share to Meet Load (%)	Annual Energy Exported (kWh)
A. PV without policy support	65	726,522	65,785	16	38,927
B. PV with net metering (annual)	124	581,606	134,030	25	94,184
C. Do nothing (grid only)	–	747,685	–	–	–

paper, we assume the net excess export price at 0.02 US$/kWh.

Our analysis considers two main scenarios: a no-policy support scenario and a net metering scenario. As with any other modeling exercise, the results, after being acquired, would have to be contextualized and interpreted within our project setting to account for factors like budget and space constraints. The methodology adopted in this paper is summarized in Fig. 4 below in the form of a flow chart.

4. Results

4.1. Summary of results

With all the assumptions and methodology laid out, we summarize the results of our analysis in Table 3 below. In addition to the two scenarios that were mentioned earlier (no policy support and net metering), we also include the 'do-nothing' scenario, i.e. a scenario where no PV would be installed. We name the scenarios of no policy support, net metering, and do-nothing as scenarios A, B, and C respectively.

The minimum NPC for scenario 'A' was found to be US$ 726,522 at a PV installed capacity of 65 kW. At this capacity, nearly 16% of the annual energy requirements would be met from the solar system. The exported energy, although found to be 38,927 kWh, is not compensated for in this scenario. On the other hand, when the annual net metering mechanism is implemented, the model finds that a PV capacity of ~250 kW achieves the minimum NPC assuming there are no area constraints and the net excess export price of 0.02 US$/kWh. Note that the model chooses to build a smaller size system in scenario 'A' as there is no benefit from a larger size system. However, for scenario 'B', because exported energy is compensated, the model arrives at a larger size model to benefit from exported energy.

However, the accessible area of the mosque rooftop only allows a maximum installation of 124 kW (more on this will follow in the next section). At 124 kW, the NPC was found to be US $581,606 while both the CAPEX and the renewable share increase to US$ 134,030 and 25%, respectively. The levelized cost of energy at this PV capacity would be 0.054 US$/kWh, which is lower than the electricity price of 0.0853 US $/kWh.

At a first glance, the CAPEX values provided may seem contradictory to the information provided in Table 1. Note that for scenario 'A', the model chooses to build an inverter of any size (45 kW in this case). However, for scenario B, an overall inverter capacity with multiples of 30 kW was dictated to the model. This is because the inverters of choice were the 30 kW inverters provided by KACST.[2] Because 124 kW was deemed as optimal, a total number of five inverters were required bringing the total inverter sizes to 150 kW.

The overall US$/W equivalent value for scenario 'B', which is the scenario that will be implemented, is 1.08 US$/W. Given the nature of this project, the modules and inverters were provided at cost (i.e. no profit). Further, many design aspects were also not charged for. We lump these non-captured costs as 0.10 US$/W and add them to the CAPEX, which results in an overall CAPEX of ~1.18 US$/W. We reiterate that these costs are reflective of prevailing conditions in early 2017 when the project was in the design phases. It is expected the overall CAPEX of this project would be less if it were to be erected now.

[2] Visit: https://www.kacstpvlab.com/.

4.2. Role of net metering

Despite the fact that the net metering scenario nearly doubles the CAPEX compared to the no-policy case, the NPC for the net metering scenario is significantly lower. To understand the reasons behind this observation, we take a discerning look at the load profile, PV generation, grid purchases, and grid sales. Recall from Fig. 1, virtually no load occurs after dawn prayers until shortly before noon prayers during both summer and winter seasons. During this period, any energy that is generated from the solar system can easily be exported to the grid.

This qualitative description is graphically depicted in Figs. 5 and 6, where the power generated from the PV system, the mosque's load, grid purchases (i.e. energy bought from the grid), and grid sales (i.e. energy sold back to the grid) are provided for two exemplary days (i.e. a summer day and a winter days). In Fig. 5, where a typical summer day is represented, the energy generated from PV exceeds the load from 6:00am till approximately 12:00pm. Nearly all the energy generated during this period is exported to the grid. Beyond noon, the load becomes larger than the generated capacity and the contribution of the grid starts to increase until the grid fully takes over at sunset.

On the other hand, and as shown in Fig. 6, the energy that is generated via the solar system during a winter day is always larger than the load except for a short time before sunset. Hence, a small percentage of the solar-generated energy is used to satisfy the load, and the rest is exported to the grid. As expected, and given this load and PV generation profile, the mosque would be a net exporter of energy during the winter months.

Translating the above information into monetary terms, we provide in Table 4 below the monthly energy consumption for the mosque and contrast the do-nothing case with the net metering scenario. In the do-nothing scenario, the total consumption of the mosque over the entire year is 397,043 kWh at a total cost of US$ 33,880. With PV installed and subject to net metering, the energy bill is reduced by more than 50% to reach US$16,546. The sources of the savings are twofold: the energy that is exported (i.e. 102,068 kWh), which amounts to approximately a quarter of the overall consumption, and the energy that is generated by PV and self-consumed amounting to 101,006 kWh (not shown in Table 4). As expected, the mosque is a net-exporter during the winter months of January, February, November, and December. The mosque, however, is a net importer overall.

4.3. Comparing model to physical measurements

For the physical installation, a total of 460 modules, each rated at 270 W, were used – bringing the total capacity of installation at standard test conditions to 124.2 kW. As mentioned, five inverters were used for the system, each with a rating of 30 kW. A photograph of the overall installed system is shown in Fig. 7. Further, and as mentioned earlier, it was not possible to utilize the complete rooftop area of the mosque for PV installation. As shown in Fig. 8, the presence of air conditioners, ducts, and other service units limited the maximum PV capacity that could be deployed.

The system was commissioned in August 2017, and this system has been monitored closely since its initialization. Two power quality measurement devices were installed: one at the sending end of the medium voltage feeder suppling the transformer feeding the mosque, and the other at the main breaker of the mosque. A communication

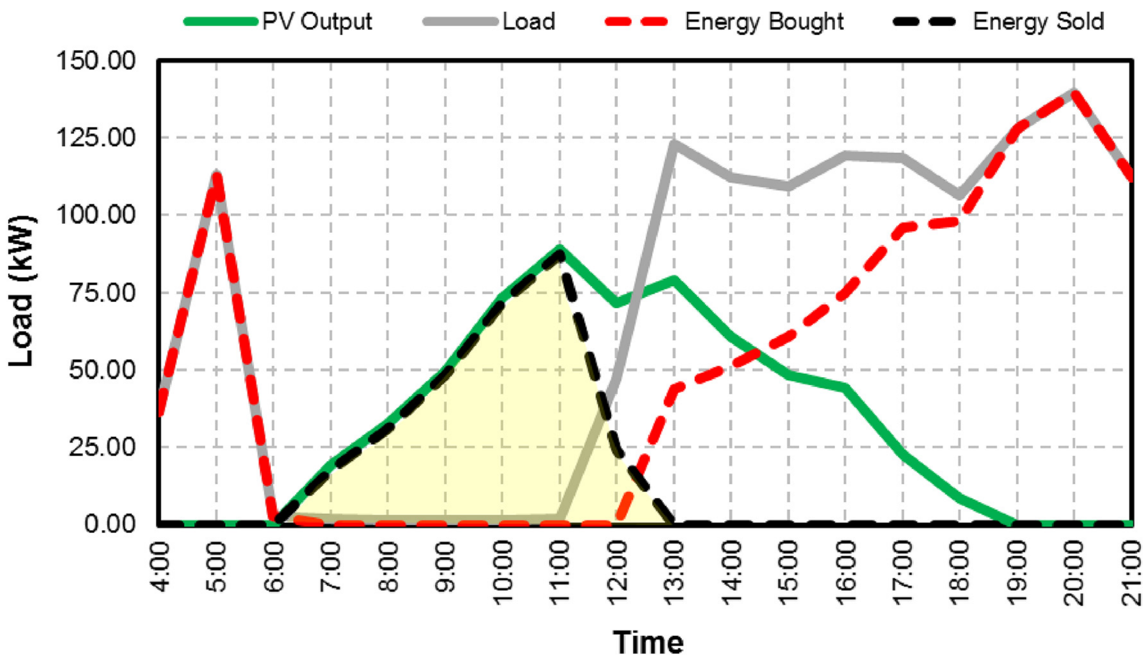

Fig. 5. The energy generated from the PV system, the load, the energy bought from the grid, and the energy sold (i.e. exported) to the grid during a sample summer day. The yellow region represents the energy sold back to the grid. This energy flow applies to all scenarios. However, the difference between scenarios would be in the compensation that the homeowner would receive for each exported kWh depending on the policy mechanism used. In Scenario A for example, no credit will be received. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

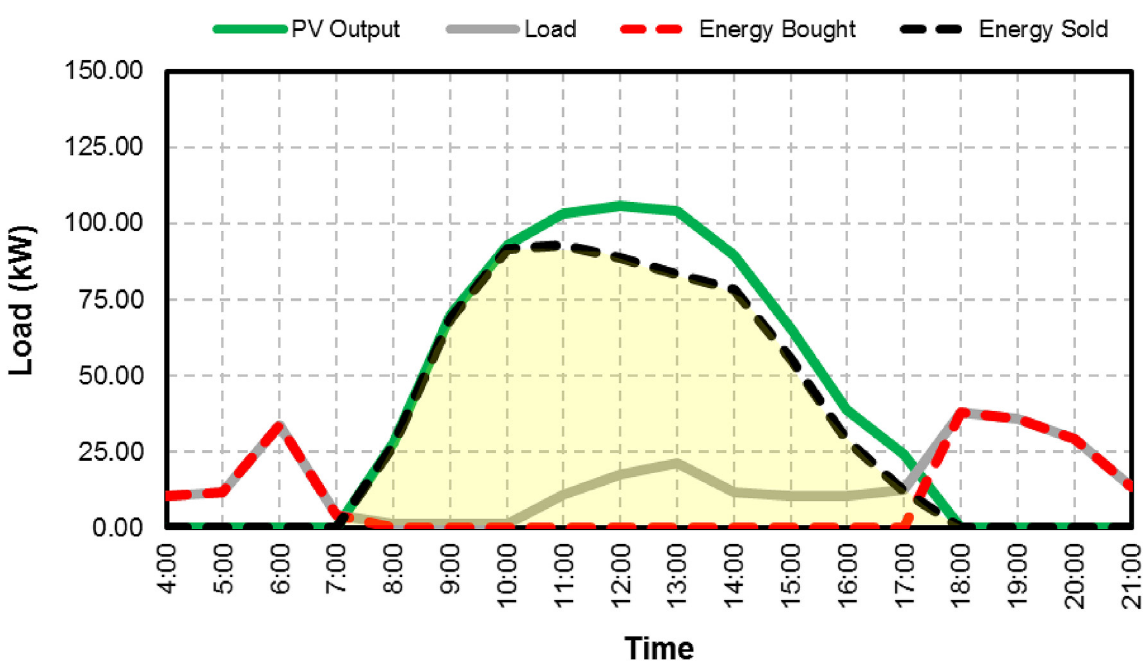

Fig. 6. The energy generated from the PV system, the load, the energy bought from the grid, and the energy sold (i.e. exported) to the grid during a sample winter day. The yellow region represents the energy sold back to the grid. This energy flow applies to all scenarios. However, the difference between scenarios would be in the compensation that the homeowner would receive for each exported kWh depending on the policy mechanism used. In Scenario A for example, no credit will be received. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

system was also installed and linked to a Human Machine Interface (HMI) to enable monitoring and controlling the performance of the solar system remotely. The monitoring and controlling activity takes place in real time.

Since the system has been operational for over a year, a significant amount of data exists. In interest of brevity, we only compare the results of generation: Table 5 compares the actual performance of the system compared to the predicted performance by the model for a period of one year (from September 2017 to August 2018). As can be seen, the results from the theoretical model and the actual commissioned system exhibit excellent agreement. Overall, the average discrepancy over the entire year was around 6%.

Based on the results obtained in Table 5, we can conclude that the capacity factor for the PV system as acquired from the model is 18.7%, whereas the capacity factor would be 18.2% if the measured data are used. This numerical value which is obtained from the field is an

Table 4
The monthly consumption of the mosque and subsequent energy bill for the grid-only and net metering scenarios. Any discrepancies are due to rounding. Source: Authors' modeling and analysis.

		Grid Only (Scenario C)		Grid + PV (124 kW) with net metering (Scenario B)			
Month	Load (kWh)	Energy Purchased from Grid (kWh)	Bill to be Paid (US$)	Energy Purchased from Grid (kWh)	Energy Sold to Grid (kWh)	Net Energy Purchased from Grid (kWh)	Bill to be Paid[a] (US$)
Jan	10,505	10,505	896	7,542	11,706	(4,164)	–
Feb	9,455	9,455	807	6,518	11,924	(5,405)	–
Mar	28,622	28,622	2,442	18,673	7,400	11,273	–
Apr	44,991	44,991	3,839	33,976	5,997	27,979	–
May	45,614	45,614	3,892	33,890	6,602	27,288	–
Jun	70,845	70,845	6,045	60,170	7,718	52,452	–
Jul	46,243	46,243	3,946	33,935	6,356	27,579	–
Aug	46,418	46,418	3,961	34,266	6,525	27,742	–
Sep	45,438	45,438	3,877	33,960	6,375	27,585	–
Oct	28,200	28,200	2,406	18,502	8,438	10,064	–
Nov	10,146	10,146	866	7,089	12,152	(5,064)	–
Dec	10,564	10,564	901	7,516	10,876	(3,360)	–
	Total	397,043	33,880	296,037	102,068	193,969	16,546

[a] Because the net metering is annual, there would be no monthly bills to be paid.

Fig. 7. The installed and commissioned solar PV system on the mosque's rooftop.

important and useful one that could be used for similar projects in the region. The capacity factor utilization (CUF) is a parameter that is often used to describe how well a solar PV system is performing. Both the capacity factor and the CUF represent essentially the same value, as both parameters represent the ratio of the energy generated to the maximum theoretical output of the system [8]. We also note that based on a rated capacity of 124 kW and an annual generation of 203,073 kWh, the annual yield is found to be 1,637 kWh/kW.

5. Discussion

5.1. Securing capital

The capital cost of a PV system is considered the only genuine financial hurdle that stands in the way of its installation. For public buildings, mosques included, two classic sources can secure the capital: governments can fund the project, or a third party ownership (TPO) model can be adopted [62,63]. In the TPO financing model, an energy services company (ESCO), for example, installs the solar system, usually bearing the brunt of the CAPEX, and is responsible for maintaining the system. The ESCO would recover its investments through a power purchase agreement [64] or a lease agreement [65]. TPOs are popular in many parts of the world [66], and especially in the United States [67]. Other variations and financing models also exist [68].

Another source of funding for mosques, and houses of worship more generally, is donations. Changes to economic, social and political environments globally are making resources allocated to charitable organizations increasingly scarce [69]. As for the motives of philanthropic acts, or donations, these can be: (a) political: to build political status or change public opinion; (b) financial: to receive financial benefits such as tax credits; or (c) religious: to attain spiritual benefits or eternal happiness [70]. Donations to houses of worship, whether coming from individuals or organizations, fall under the last category, and are considered an important financing mechanism that is relied upon throughout the world and across different faiths.

Globally, and in Saudi Arabia particularly, there is a growing interest in developing endowments and managing their returns [71]. To that end, The General Authority of Islamic Affairs and Endowments in Saudi Arabia launched a project under the name of Investment Funds Project. The aim of this project is to achieve financial stability and sustainability for non-profit bodies [72]. Although there would be no financial returns in terms of cash in-flow if solar PV systems are commissioned on mosque rooftops, there would be significant cost savings. The same applies to other initiatives within the same orbit like energy efficiency programs for example.

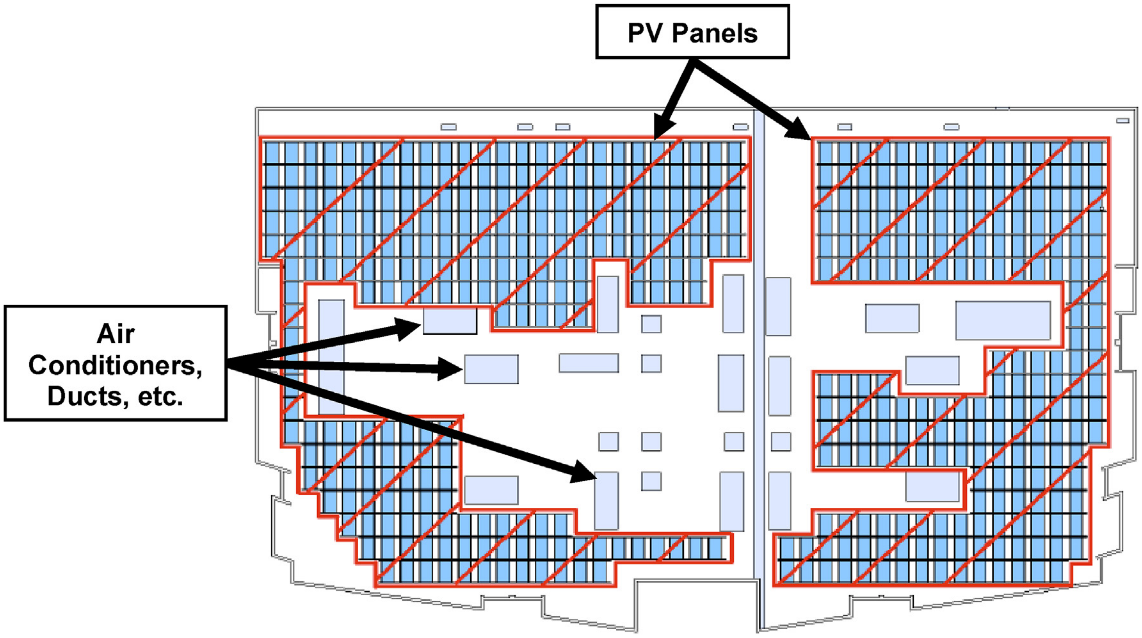

Fig. 8. A schematic showing the top view of the mosque. Note how the full rooftop area was not utilized from a PV perspective given the existence of the Air Conditioning Units, Ducts, etc.

Table 5
The monthly generation from the PV system as calculated via the model and as measured from the actual physical PV system.

Month	Total PV Generation in kWh (from Model)	Actual PV Generation in kWh (from field)	Discrepancy in %
Sept 2017	17,853	17,434	2.3
Oct 2017	18,136	17,671	2.6
Nov 2017	15,209	12,978	14.7
Dec 2017	13,924	13,371	4.0
Jan 2018	14,669	12,466	15.0
Feb 2018	14,861	12,861	13.5
Mar 2018	17,349	19,246	10.9
April 2018	17,012	16,850	1.0
May 2018	18,326	17,772	3.0
June 2018	18,393	18,250	0.8
July 2018	18,664	19,483	4.4
Aug 2018	18,677	19,451	4.1
Average Monthly Discrepancy			6.4

5.2. Impact on bill

It has been shown that installing a PV system on rooftops of large Mosques in Saudi Arabia is a financially viable endeavor, even without any financial policy support. Recall that when the net metering mechanism was studied, the initial results that yielded from the model indicated that ~250 kW is to be installed to minimize the NPC. Explicitly, the energy bill at such an installation capacity was found to be near-zero; i.e. the exported energy was almost equal to the imported energy.

However, it was not possible to install this capacity on the rooftop. Although the overall 'area' in absolute terms could accommodate such a capacity, the actual 'accessible area' of the rooftop could not. The main reason behind this limitation is that the mosque, when built, was not designed with the potential of installing a PV system in the future (refer to Fig. 8 above to see how the roof was not fully utilized because it was occupied with air conditioning units, ducts, etc.).

The installation of 124 kW with net metering was able to reduce the annual bill by nearly 50%. Note that the net export energy price, which we assumed to be 0.02 US$/kWh, did not come into play in our analysis because the mosque was a net importer of energy. Explicitly, at the end of the billing cycle (annually in our case), the mosque imported a net energy of 194,000 kWh from the grid as shown in Table 4.

Consider now that a monthly net metering mechanism is to be implemented. In this case, we see from Table 4 that the mosque is net exporter of energy in four months in the year. Assuming this scenario, the mosque would be credited, each month, a value totaling the product of the net monthly exported energy and the net energy exported price. This case would be less beneficial to the mosque compared to the annual net metering, because in the annual net metering scenario the monthly excess energy is being compensated for at the electricity price in the following months, and the electricity price is higher than the net export energy price.

The net export energy price, if adequately high, can invite oversizing of the PV system (provided the capital can be secured) allowing for an arbitrage-like situation. The main driver of installing a PV system on mosque rooftop is to reduce the energy bill as much as possible, and not necessarily make money. As such, it is worthwhile that a limit, whether on the energy exported or the capacity commissioned per mosque, be articulated in order to control installations.

5.3. Implications to grid/utility

As mentioned earlier, this installed PV system on the mosque rooftop is categorized under the umbrella of distributed generation. While we have established that it is beneficial for the mosque to install PV, it is also desirable that the utility benefits. Here, we affirm that DG, along with the challenges that it comes with, bestows a number of benefits to the grid. For example, DG can contribute to a reduction in peak loads [73], provide frequency control and correction [74], and defer capital investments that need to be made by the utility to meet growing demand [75].

On the other hand, DG poses some challenges including potential overloading of the distributed network [76] and protection malfunction [77] due to the two-way flow of energy. Further, when DG systems are deployed, the utility also suffers forgone revenues as customers no longer rely on the grid for all their energy needs. The reduction in revenues alongside the benefits and challenges mentioned above all need to be put in context and assessed to the extent possible when deciding on the proper deployment policy framework. Ultimately, the utility wants to reach a win-win situation by ensuring that the benefits outweigh the costs. Properly siting these DG systems can also aid in fulfilling strategic goals set by the utility [78]. Generally, we note that these benefits and costs surface only at relatively high penetration levels – the effects of a few DG systems on the grid is negligible.

The paper here focused on the mosque's financial viability of solar PV for the mosque. The financial implications on the grid is beyond the scope of this paper. As mentioned, there would be both benefits and costs to such a deployment. Given the specificity of each distribution network in different jurisdictions even within the same country, tailored studies would be necessary to assess the full impact on the utility and on society.

6. Conclusion

In this paper, we have assessed the economic implications of installing a PV system on a mosque rooftop in Riyadh Saudi Arabia. Our results indicate that, at the current electricity prices and prevailing PV CAPEX costs, it is financially viable for mosques to install PV systems even without policy support. Our analysis showed that the annual bill of the mosque can be reduced to nearly zero under a net metering mechanism. To complement the theoretical analysis, a physical PV system was installed and commissioned at a CAPEX of 1.18 US$/W (in 2017). Overall, results from the theoretical model and the physical installation exhibit good agreement. The measured capacity factor from the physical installed system was 18.2%.

Among the unique characteristics of mosques is their highly predictable load profiles. Congregation takes place at specific times that are governed by the movement of the sun, and most of the load occurs during these times. The time between dawn and noon prayers, in particular, is considered dormant and virtually all the energy that is generated from the PV system can be exported to the grid. If the rooftop area is large enough to allow an installation of a relatively large PV capacity, then the mosque can become a net exporter of energy. It is advisable to formulate an upper limit as to how much energy can be exported, or equivalently, how much capacity can be installed to disallow arbitrage.

It is worth noting that a compromise is to be exercised between the capital invested and the reduction in the electricity bill. Further, the funds may be available to install a system with a certain capacity, but the accessible area may not allow it. We realize that there is little that can be done to existing mosques. However, it is advisable that future mosques be built with the possibility that a PV system may be installed in the future. Although we focus on mosques, the same analysis can be extended to other houses of worship or community public halls with appropriate modifications.

Conflicts of interest

None.

Acknowledgement

The authors would like to acknowledge the support by the Joint Research and Development Center for the Distribution Sector between King Abdulaziz City for Science and Technology (KACST) and the Saudi Electricity Company (SEC).

References

[1] K. Chawla, Drivers, apparatus, and implications of India's renewable energy ambitions, The Geopolitics of Renewables, Springer, 2018, pp. 203–227.
[2] C. Isik, T. Dogru, E.S. Turk, A nexus of linear and non-linear relationships between tourism demand, renewable energy consumption, and economic growth: Theory and evidence, Int. J. Tour. Res. 20 (1) (2018) 38–49.
[3] A. Pegels, W. Lütkenhorst, Is Germany' s energy transition a case of successful green industrial policy? Contrasting wind and solar PV, Energy Policy 74 (2014) 522–534.
[4] REN21, Global Status Report, Renewable Energy Network for the 21st Century, Paris, 2018.
[5] B.K. Sahu, A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries, Renew. Sustain. Energy Rev. 43 (2015) 621–634.
[6] F. Zhang, et al., Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China, Energy Policy 81 (2015) 43–55.
[7] B. Huang, et al., Performance evaluation of solar photovoltaic/thermal systems, Sol. Energy 70 (5) (2001) 443–448.
[8] B.S. Kumar, K. Sudhakar, Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India, Energy Rep. 1 (2015) 184–192.
[9] L.M. Moore, H.N. Post, Five years of operating experience at a large, utility-scale photovoltaic generating plant, Prog. Photovoltaics Res. Appl. 16 (3) (2008) 249–259.
[10] A.K. Shukla, K. Sudhakar, P. Baredar, Design, simulation and economic analysis of standalone roof top solar PV system in India, Sol. Energy 136 (2016) 437–449.
[11] S. Sukumaran, K. Sudhakar, Performance analysis of solar powered airport based on energy and exergy analysis, Energy 149 (2018) 1000–1009.
[12] S. Sukumaran, K. Sudhakar, Fully solar powered airport: A case study of Cochin International airport, J. Air Transp. Manag. 62 (2017) 176–188.
[13] M. Debbarma, K. Sudhakar, P. Baredar, Thermal modeling, exergy analysis, performance of BIPV and BIPVT: A review, Renew. Sustain. Energy Rev. 73 (2017) 1276–1288.
[14] T. Elshennawy, L. Abdallah, An initiative towards transforming mosques in Egypt to be environment-freindly and energy saving, International Scientific Conference on Environment and Sustainable Development, 2017 (Cairo).
[15] Deloitte, The Digital Islamic Services Landscape, Deloitte, London, 2015.
[16] M. MAWED, A.A. ASSEM AL-HAJJ, THE IMPACTS OF SUSTAINABLE PRACTICES ON UAE MOSQUES" LIFE CYCLE COST, Smart Sustain. Healthy Cities (2014) 307.
[17] A. Elshurafa, et al., Estimating the learning curve of solar PV balance-of-system for over 20 countries: Implications and policy recommendations, J. Clean. Prod. 196 (2018) 122–134.
[18] Y.B. Almutairi, Peak shaving using grid-connected solar panels case study: Ministry of Islamic Affairs mosque, Int. J. Eng. Res. Afr. 4 (8) (2014) 158–166.
[19] A. Mustafa, et al., Techno-economic analysis of renewable power system for a remote mosque in Libya, Recent Advances in Energy, Environment and Development, Proceedings of the 9th International Conference on Energy & Environment (EE'14) Geneva, Switzerland December, 2014.
[20] E.E. Rashid, S.R.W. Alwi, Z.A. Manan, Evaluation of photovoltaic system installation for a mosque in Universiti Teknologi Malaysia, PERINTIS eJournal 1 (2011).
[21] A. Abdulhamid, All 6000 Mosques in Jordan Getting Rooftop Solar, (2015) [25 June 2018]; Available from: https://cleantechnica.com/2015/02/24/6000-mosques-jordan-getting-rooftop-solar.
[22] K. Alrabie, M.N. Saidan, A preliminary solar-hydrogen system for Jordan: Impacts assessment and scenarios analysis, Int. J. Hydrogen Energy 43 (19) (2018) 9211–9223.
[23] L. Osborne, Solar Panels Make Morocco's Mosques a Model for Green Energy, (2017) [28 June 2018]; Available from: http://www.dw.com/en/solar-panels-make-moroccos-mosques-a-model-for-green-energy/a-37583670.
[24] A. Neslen, Morocco to Give 600 Mosques a Green Makeover, (2016) [29 June 2018]; Available from: https://www.theguardian.com/environment/2016/sep/05/morocco-to-give-600-mosques-a-green-makeover.
[25] T. Kousksou, et al., Renewable energy potential and national policy directions for sustainable development in Morocco, Renew. Sustain. Energy Rev. 47 (2015) 46–57.
[26] S. Alkhotani, 60% of 94,000 Mosques Offer Iftar, (2016) [30 June 2018]; Available from: http://www.arabnews.com/node/942731/saudi-arabia.
[27] S. Comello, S. Reichelstein, Cost competitiveness of residential solar PV: The impact of net metering restrictions, Renew. Sustain. Energy Rev. 75 (2017) 46–57.
[28] S. Hagerman, P. Jaramillo, M.G. Morgan, Is rooftop solar PV at socket parity without subsidies? Energy Policy 89 (2016) 84–94.
[29] B. Numbi, S. Malinga, Optimal energy cost and economic analysis of a residential grid-interactive solar PV system-case of eThekwini municipality in South Africa, Appl. Energy 186 (2017) 28–45.
[30] E. Nyholm, M. Odenberger, F. Johnsson, An economic assessment of distributed solar PV generation in Sweden from a consumer perspective–The impact of demand response, Renew. Energy 108 (2017) 169–178.
[31] N. Sommerfeldt, H. Madani, Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part one–Review, Renew. Sustain. Energy Rev. 74 (2017) 1379–1393.
[32] C. Koo, et al., Improving the prediction performance of the finite element model for estimating the technical performance of the distributed generation of solar power system in a building façade, Appl. Energy 215 (2018) 41–53.
[33] C. Lupangu, R. Bansal, A review of technical issues on the development of solar photovoltaic systems, Renew. Sustain. Energy Rev. 73 (2017) 950–965.
[34] T. Lang, D. Ammann, B. Girod, Profitability in absence of subsidies: A techno-economic analysis of rooftop photovoltaic self-consumption in residential and commercial buildings, Renew. Energy 87 (2016) 77–87.
[35] G. Merei, et al., Optimization of self-consumption and techno-economic analysis of PV-battery systems in commercial applications, Appl. Energy 168 (2016) 171–178.
[36] Y. Wang, et al., Energy management for a commercial building microgrid with stationary and mobile battery storage, Energy Build. 116 (2016) 141–150.
[37] D. Atsu, E.O. Agyemang, S.A. Tsike, Solar electricity development and policy support in Ghana, Renew. Sustain. Energy Rev. 53 (2016) 792–800.

[38] L. Dusonchet, E. Telaretti, Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries, Energy Policy 38 (7) (2010) 3297–3308.
[39] X. Zhao, Y. Zeng, D. Zhao, Distributed solar photovoltaics in China: Policies and economic performance, Energy 88 (2015) 572–583.
[40] R. Kannan, et al., Life cycle assessment study of solar PV systems: An example of a 2.7 kWp distributed solar PV system in Singapore, Sol. Energy 80 (5) (2006) 555–563.
[41] K. Qian, et al., Analysis of the environmental benefits of distributed generation, Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, IEEE, 20082008 (IEEE).
[42] W. Fischer, et al., German energy policy and the way to sustainability: Five controversial issues in the debate on the “Energiewende”, Energy 115 (2016) 1580–1591.
[43] M. Wei, S. Patadia, D.M. Kammen, Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? Energy Policy 38 (2) (2010) 919–931.
[44] R. Hanna, et al., Evaluating business models for microgrids: Interactions of technology and policy, Energy Policy 103 (2017) 47–61.
[45] M. Richter, German utilities and distributed PV: How to overcome barriers to business model innovation, Renew. Energy 55 (2013) 456–466.
[46] S. Tongsopit, et al., Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand, Energy Policy 95 (2016) 447–457.
[47] N. Ansari, C.-H. Lo, Alleviating solar energy congestion in the distribution grid via smart metering communications, US Patent 9 (2016) 246–334.
[48] E.J. Coster, et al., Integration issues of distributed generation in distribution grids, Proc. IEEE 99 (1) (2011) 28–39.
[49] R. Passey, et al., The potential impacts of grid-connected distributed generation and how to address them: A review of technical and non-technical factors, Energy Policy 39 (10) (2011) 6280–6290.
[50] J. Parnell, Saudi Arabia Approved Net Metering Framework for Systems up to 2MW, (2017) [1 July 2018]; Available from: https://www.pv-tech.org/news/saudi-arabia-approves-net-metering-framework-for-systems-up-to-2mw.
[51] C.S. Lai, M.D. McCulloch, Levelized cost of electricity for solar photovoltaic and electrical energy storage, Appl. Energy 190 (2017) 191–203.
[52] U. Benzion, A. Rapoport, J. Yagil, Discount rates inferred from decisions: An experimental study, Manag. Sci. 35 (3) (1989) 270–284.
[53] H.B. Enzler, A. Diekmann, R. Meyer, Subjective discount rates in the general population and their predictive power for energy saving behavior, Energy Policy 65 (2014) 524–540.
[54] G.W. Harrison, M.I. Lau, M.B. Williams, Estimating individual discount rates in Denmark: A field experiment, Am. Econ. Rev. 92 (5) (2002) 1606–1617.
[55] A.K. Meier, J. Whittier, Consumer discount rates implied by purchases of energy-efficient refrigerators, Energy 8 (12) (1983) 957–962.
[56] P.A. Grout, Public and private sector discount rates in public–private partnerships, Econ. J. 113 (486) (2003) C62–C68.
[57] S. Park, Optimal discount rates for government projects, ISRN Economics (2012) 2012.
[58] D. Watts, et al., Potential residential PV development in Chile: The effect of net metering and net billing schemes for grid-connected PV systems, Renew. Sustain. Energy Rev. 41 (2015) 1037–1051.
[59] Y. Yamamoto, Pricing electricity from residential photovoltaic systems: A comparison of feed-in tariffs, net metering, and net purchase and sale, Sol. Energy 86 (9) (2012) 2678–2685.
[60] S. Borenstein, Private net benefits of residential solar PV: The role of electricity tariffs, tax incentives, and rebates, J. Assoc. Environ. Resour. Econ. 4 (S1) (2017) S85–S122.
[61] Y.-h. Wan, Net Metering Programs, National Renewable Energy Lab. (NREL), Golden, CO (United States), 1996.
[62] C. Davidson, D. Steinberg, R. Margolis, Exploring the market for third-party-owned residential photovoltaic systems: Insights from lease and power-purchase agreement contract structures and costs in California, Environ. Res. Lett. 10 (2) (2015) 024006.
[63] T. Hong, et al., A model for determining the optimal lease payment in the solar lease business for residences and third-party companies–With focus on the region and on multi-family housing complexes, Renew. Sustain. Energy Rev. 82 (2018) 824–836.
[64] P.T. Lam, J.S. Yu, Developing and managing photovoltaic facilities based on third-party ownership business models in buildings, Facilities 34 (13/14) (2016) 855–872.
[65] V. Rai, B. Sigrin, Diffusion of environmentally-friendly energy technologies: Buy versus lease differences in residential PV markets, Environ. Res. Lett. 8 (1) (2013) 014022.
[66] L. Strupeit, A. Palm, Overcoming barriers to renewable energy diffusion: Business models for customer-sited solar photovoltaics in Japan, Germany and the United States, J. Clean. Prod. 123 (2016) 124–136.
[67] R. Fu, et al., US Solar Photovoltaic System Cost Benchmark: Q1 2017, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.
[68] D. Horváth, R.Z. Szabó, Evolution of photovoltaic business models: Overcoming the main barriers of distributed energy deployment, Renew. Sustain. Energy Rev. 90 (2018) 623–635.
[69] D. Grace, D. Griffin, Exploring conspicuousness in the context of donation behaviour, Int. J. Nonprofit Voluntary Sect. Mark. 11 (2) (2006) 147–154.
[70] N.C. Degasperi, E.W. Mainardes, What motivates money donation? A study on external motivators, Rev. Adm. 52 (4) (2017) 363–373.
[71] M. Obaidullah, A framework for analysis of Islamic endowment (waqf) laws, Int'l J. Not-for-Profit L. 18 (2016) 54.
[72] Arab-News, Saudi Islamic Affairs Body Launches Endowment Investment Funds Project, (2018) [25 September 2018]; Available from: http://www.arabnews.com/node/1319296/saudi-arabia.
[73] Y. Yang, et al., Sizing strategy of distributed battery storage system with high penetration of photovoltaic for voltage regulation and peak load shaving, IEEE Trans Smart Grid 5 (2) (2014) 982–991.
[74] F. Guo, et al., Distributed secondary voltage and frequency restoration control of droop-controlled inverter-based microgrids, IEEE Trans. Ind. Electron. 62 (7) (2015) 4355–4364.
[75] R.E. Brown, et al., Siting distributed generation to defer T&D expansion, Transmission and Distribution Conference and Exposition, 2001 IEEE/PES. IEEE, 2001.
[76] T. Ackermann, V. Knyazkin, Interaction between distributed generation and the distribution network: Operation aspects, Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES. IEEE, 2002.
[77] P. Mahat, et al., A simple adaptive overcurrent protection of distribution systems with distributed generation, IEEE Trans. Smart Grid 2 (3) (2011) 428–437.
[78] P.S. Georgilakis, N.D. Hatziargyriou, Optimal distributed generation placement in power distribution networks: Models, methods, and future research, IEEE Trans. Power Syst. 28 (3) (2013) 3420–3428.