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Research paper

Application of solar PV in the building sector: Prospects and barriers in the GCC region

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ABSTRACT

Solar Photovoltaic (PV) can make a significant contribution towards reducing the energy and environmental footprint of buildings. Helped by features like scalability, ease of use, and declining price, PV has become the predominant renewable technology for application in buildings. Estimates suggest that rooftop PV can help meet 25% to 49% of national electricity requirements in countries around the world. The Gulf Cooperation Council (GCC) countries, having traditionally relied on abundantly available fossil fuel resources to meet their energy requirements, are also planning to diversify their energy mix through the exploitation of solar energy. While several utility-scale PV projects have been initiated in these countries, their building sector remains largely untapped. This study aims to investigate the factors hindering the progress of PV in buildings. It investigates the barriers to the application of PV in buildings under four major categories: sociotechnical, economic, policy, and management. It employs both qualitative and quantitative approaches to determine the perspective of building industry professionals around these barriers. Data is gathered through a questionnaire-based survey and in-depth interviews. Results are then analyzed to determine the most significant barriers and their impact on the use of PV in buildings. The questionnaire reveals that lack of public awareness is the most significant factor that hampers the application of PV while the interviews indicate that the root cause for weak poor public awareness is subsidized tariffs. Policy recommendations are made to overcome the identified barriers and to promote the application of PV in the building sector of the country.

1. Introduction

Renewable energy is playing a key role in the national and international energy scenarios across the world. Owing to its comparative advantages over the traditional forms of energy – replenishing resource base, wider geographic distribution, reducing price trends, and environmental friendliness – renewable energy has become the cornerstone of the energy frameworks around the globe (Asif, 2016a; Asif and Dehwah, 2019). Renewable technologies, especially, solar energy and wind power, are already making a significant contribution to energy supplies both in developed and developing countries. The maturity of renewable technologies and their successful penetration can be depicted by the fact that countries like Germany and Portugal have recorded spells when renewable supplies were meeting the total demand on their national grids (Asif et al., 2019; Amelang, 2018).

When it comes to the application of solar energy in buildings, photovoltaic (PV) has been by far the most versatile and successful technology. Small and building-related applications have played a key role in the progress of solar PV throughout the world. Most of the leading countries with regard to the installed capacity of PV have extensively used the technology in the building sector (Khan et al., 2017). Conducive policies like feed-in-tariff and net-metering have been successfully implemented around the world — PV markets in countries like Germany, Japan, the UK, Italy, Spain, and the USA have recorded growth (Ismail et al., 2015) . The Gulf Cooperation Council (GCC) is a block of six oil and gas-rich Middle Eastern states: Kingdom of Saudi Arabia (KSA), United Arab Emirates, Kuwait, Qatar, Bahrain, and Oman. GCC countries have significant climatic, political, and socioeconomic similarities. KSA is the largest country in the GCC region in terms of population, land area, and economy. It also accounts for almost 45% of the investment in construction projects in the region (Asif, 2016a).

The building sector in the Kingdom of Saudi Arabia (KSA) is growing fast and is characterized as extensive in terms of energy

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consumption and associated carbon emissions (Alrashed and Asif, 2014; Asif, 2016b; Alrashed and Asif, 2017). Owing to factors like modernization, rising in the population and construction boom the country is experiencing, the electricity demand has been experiencing growth at an annual rate of over 8% (Asif and Alrashed, 2015b; Fardan et al., 2017). The building sector plays a key role in this rapid energy demand knowing that it consumes around 80% of the total energy consumption. Harsh climate conditions in the country are the main driver for the high share of the building sector. KSA has traditionally relied on fossil fuel to meet its energy requirements, thanks to the country's abundant oil and gas reserves, however, recently, there is a realization to diversify the national energy mix, reduce consumption of fossil fuels and curtail greenhouse gas emissions associated with the energy sector to improve the sustainability standard in buildings by reducing energy consumption as well as incorporating renewable energy solutions (Asif, 2016b; Alrashed and Asif, 2017). Also to match the global drive towards sustainability, renewable energy has attracted a great deal of interest in Saudi Arabia and GCC countries. There have been targets set to have renewable energy contribute significant proportions of their total energy supplies in the future. The Kingdom of Saudi Arabia, the largest country in the region, for example, has targeted to boost its renewable base from virtually none in 2018 to 58 GW by the year 2030 (OBG, 2019). Given the fact KSA is one of the richest countries in the world in terms of solar energy potential with an average annual solar radiation of more than 6 kWh/m^2/day (Alnaser and Alnaser, 2011), solar energy is set to lead the renewable developments in these countries. The emphasis however has been on large-scale projects and the building sector has yet to see a meaningful application of solar technologies (Asif, 2016a,b).

The building sector offers one of the most promising application areas for solar PV. Rooftop PV is estimated to represent over 40% of the world's total PV installed capacity. Rooftop PV, due to factors like quick deployment and low levelized cost of electricity, is also regarded to be important in achieving the Sustainable Development Goal (SDG) 7 (Josji et al., 2021). PV systems used in buildings are typically termed as building applied PV (BAPV) or building-integrated PV (BIPV) systems. Given its immense prospects, the application of PV in buildings is an active topic for researchers across the world (Josji et al., 2021; Hao et al., 2007; Ban-Weiss et al., 2013). In the GCC region in general and KSA in particular, the focus has been on large and utility-scale PV projects instead of building-applied PV (BAPV) systems. While it is primarily a policy matter, there are other factors too that actively play a role in the ongoing trends and practices. There is a lack of research studies on the application of PV in the region's building sector. While the slow progress of PV in the region's building sector has also been pointed out by some studies, only a few have briefly touched upon the concerned challenges (Asif et al., 2019; Khan et al., 2017; Alrashed and Asif, 2014, 2017; Asif and Alrashed, 2015b).

The present study aims to bridge the gap in the literature by providing a detailed and comprehensive analysis of the underlying barriers that have hindered the progress of PV in GCC's building sector, considering KSA as a case study. Also, to promote the application of PV in buildings, it is vital to first understand the wide range of barriers so that appropriate policy measures and techno-economic mechanisms could be worked out. In terms of structure, after the Introduction, the second section describes the methodology adopted in this study. Section 3 identifies and classifies the barriers to the application of PV in the GCC region's building sector. Section 4 describes the validation and ranking of barriers through engagement with the local stakeholders. Section 5 presents results and discussion while the last section makes conclusions and recommendations.

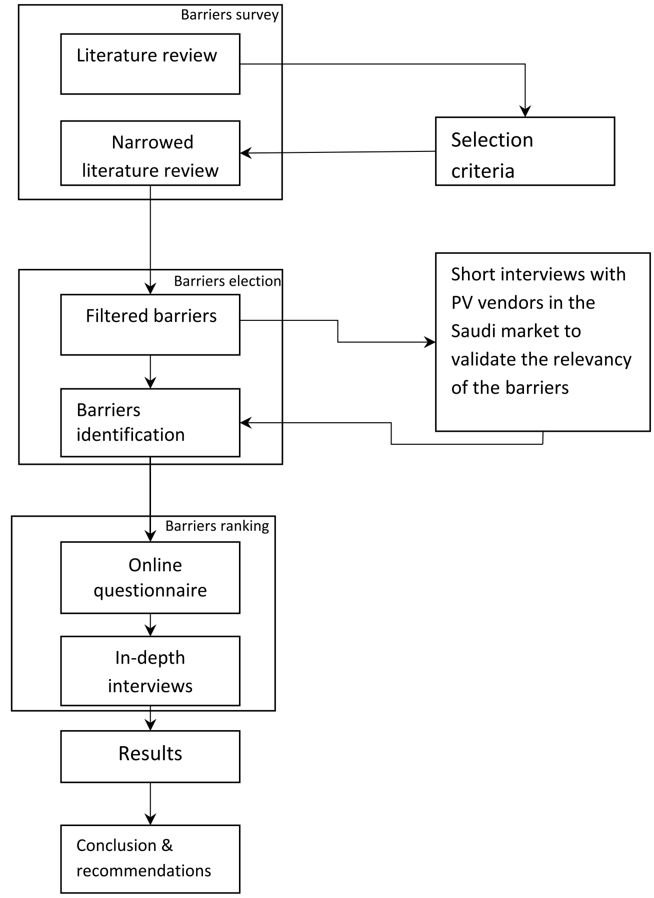

Fig. 1. Study methodology.

2. Methodology

Globally, the barriers to the application of solar PV buildings have been investigated by several researchers (Zhang et al., 2017; Asif and Alrashed, 2015a; Cleland et al., 2018; Kannan and Vakeesan, 2016; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Mondal et al., 2010; Zuboy and Margolis, 2006). The researcher started the study by conducting a literature review of the previous studies. This step concluded by listing all the potential barriers. To ensure the applicability of the found barriers, the researcher then conducted 31 interviews with a wide range of professionals involved in the building sector to assess each barrier with regard to their applicability to the local Saudi context. An online questionnaire was then developed and sent to a wide range of builders, designers, and building developers involved in the building industry. The researcher conducted a communication regime with the respondent soliciting their answers for the questionnaire. After receiving all respondents' responses, the researchers selected the keen respondents and invited them for a short in-depth interview in which the final output of the questionnaire was extensively discussed. The approach adopted in the present study has been presented in Fig. 1 and the below sections.

3. Identification and classification of barriers

It is widely reported in the literature that the use of solar PV, whether to substitute the demand on conventional fuel or to electrify rural areas, faces a wide range of challenges in low as well as high-income economies (Khan et al., 2017). To determine the barriers facing the use of PV, a detailed literature review is carried out. The literature search process took into consideration studies published in journals, conference papers, reports, and books focusing on the application of solar PV applications in buildings. The search considered the studies published between 2010 and 2021. The followings are the main categories of barriers as identified through the literature review.

3.1. Socio-technical barriers

Though solar PV is experiencing significant success in the building sector around the world, there are still issues posing hurdles to their wider adoption. It is reported by several researchers that the vast majority of the public has a wrong perception of the improvement in the PV industry (Cleland et al., 2018; Kannan and Vakeesan, 2016; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Mondal et al., 2010; Zuboy and Margolis, 2006; Timilsina and Shah, 2016; Pollmann et al., 2014). The absence of suitable planning at the early design stage, for example, results in a random allocation of the building equipment and systems on the roof leading to poor utilization of roof for PV modules (Kinab and Elkhoury, 2012; Akinwale et al., 2014; Zhang et al., 2012). Sometimes the observed hurdles entail new hurdles which worsen the buildings' acceptability towards the PV modules. Similarly, a lack of public awareness leads to lower demand for PV which in turn may result in a shortage of technical human resource needed for the installation and maintenance of the PV systems (Kannan and Vakeesan, 2016; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Mondal et al., 2010; Zuboy and Margolis, 2006; Akinwale et al., 2014; Zhang et al., 2012; Niles and Lloyd, 2013; Philibert, 2006).

3.2. Economic barriers

Economic factors play a key role in the stakeholders' decision to invest in PV technology. Like other renewables, PV is also a capital-cost-intensive technology. Subsidized electricity tariff significantly contributes to public reluctance to install PV systems in their buildings. The high initial cost is also one of the main reasons that some building owners are not inclined to install PV, especially in grid-connected settings (Cleland et al., 2018; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Mondal et al., 2010; Akinwale et al., 2014; Philibert, 2006). In climates like the GCC region, PV panels require a permanent regime for cleaning, which increases the maintenance cost (Gabriel et al., 2016; Luthra et al., 2015). The payback period, influenced by tariff and maintenance cost, is, therefore, an important factor in adoption of PV (Pasqualetti, 2011; Reddy and Painuly, 2004; Ruggiero et al., 2015; Engelken et al., 2016).

3.3. Policy barriers

The absence of policies or lack of public awareness about the existing policies leads to preclusion for wider adoption of PV in the building sector (Eleftheriadis and Anagnostopoulou, 2015; Emodi and Boo, 2015; Shaaban and Petinrin, 2014). Lack of infrastructure in terms of grid connectivity (Eleftheriadis and Anagnostopoulou, 2015; Emodi and Boo, 2015; Shaaban and Petinrin, 2014), for example, also poses challenges towards the application of PV where consumers want to benefit from policies like net-metering and feed-in-tariff (Cleland et al., 2018; Secretariat and Commonwealth, 2016; Charles, 2014; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Zuboy and Margolis, 2006; Akinwale et al., 2014; Zhang et al., 2012).

3.4. Management barriers

Different types of management barriers can directly as well as indirectly influence the application of PV in buildings. Poor coordination between various stakeholders, for example, the PV and building industry, can have a significant impact on the buildings' acceptability for PV (Aliyu et al., 2015; M and Shah, 2016). Table 1 highlights the range of barriers identified under various categories.

4. Barriers' validation

After identifying the potential barriers through the literature review, local PV and building industry stakeholders were interviewed to validate these barriers in the context of KSA's typical energy, economic, cultural and business environment. The interviewees were selected based on their exposure to the PV and building industries. Table 2 shows the details of the interviewees. Given the COVID restrictions, some of the interviews were conducted online. Interviewees were asked about each of the identified barriers to its validity in KSA.

Any barrier which was not considered relevant by at least 16 (over 50%) interviewees was deemed insignificant in the KSA context and was dropped. Subsequently, four barriers were excluded from the list as indicated in Table 3 highlighting the responses of interviewees. Barriers 20–23, as noted from the literature, were not validated by experts and hence eliminated. Barrier 24, added by one of the local experts, was also dropped for not meeting the validation criteria.

4.1. Barriers' ranking

After validating the potential barriers, the study ranked these barriers in terms of their importance in the context of KSA. For this purpose local building and PV industry stakeholders' opinion was acquired through the following two phases.

- Phase I: Online questionnaire
- Phase II: In-depth interviews with the shortlisted respondents from phase I.

4.2. Online questionnaire

The first method used to collect data for barriers' ranking was an online questionnaire survey. The survey targeted building owners as well as a variety of building industry professionals such as architects, engineers, consultants, and developers. An online survey was adopted for the reasons listed below:

- It provides the flexibility to the respondents to respond to the questionnaire at their convenience.
- Respondents have a better opportunity to reflect on their answers.
- It helps the researcher to target a larger sample of the targeted population despite their dispersed geographical locations.
- It helps avoid expenses in terms of papers and postage.
- It can also be regarded as an environment-friendly option.

The questionnaire was developed to determine the relevance of these barriers and their significance in the Saudi context. The survey targeted to find answers to the below set of questions:

- To what extent the building industry professionals in Saudi Arabia are aware of PV technology and its benefits in buildings?
- To what extent owners are willing to install PV systems in their buildings?

Table 1
Identified barriers (Cleland et al., 2018; Kannan and Vakeesan, 2016; Kinab and Elkhoury, 2012; Karakaya and Sriwannawit, 2015; Mondal et al., 2010; Zuboy and Margolis, 2006; Timilsina and Shah, 2016; Pollmann et al., 2014; Akinwale et al., 2014; Zhang et al., 2012; Niles and Lloyd, 2013; Philibert, 2006; Secretariat and Commonwealth, 2016; Gabriel et al., 2016; Luthra et al., 2015; Pasqualetti, 2011; Reddy and Painuly, 2004; Ruggiero et al., 2015; Engelken et al., 2016; Eleftheriadis and Anagnostopoulou, 2015; Emodi and Boo, 2015; Shaaban and Petinrin, 2014; Charles, 2014; Aliyu et al., 2015; M and Shah, 2016; Bazilian et al., 2012; Ohunakin et al., 2014; Asif and Khan, 2017).

Category	Barrier Description	References
Economic Barriers	High cost of PV Systems	[19, 30, 23, 27, 21, 22]
	Long payback period	[31, 22, 27, 34]
	Maintenance cost	[32, 33]
	Turbulent economic growth	[21]
	Subsidized tariffs	[35, 36, 37]
Sociotechnical Barriers	Lack of awareness	[19, 20, 21, 22, 23, 24, 25, 26]
	Architectural restrictions	[21, 27, 28, 44]
	Lack of technical & human resources	[28, 27, 29, 30, 23, 24, 22, 21, 20, 31]
	Lack of access to diversified technology	[21]
	Local weather condition	[32, 33]
	Low efficiency of PV systems	[33]
Policy Barriers	Lack of support policies	[38, 39, 40]
	Lack of regulation	[38, 39, 40, 45]
	Lack of standards	[46]
	Lack of subsidies	[19, 31, 41, 21, 22, 24, 27, 28]
Management Barriers	Poor after-sale service	[33]
	Inappropriate marketing strategies	[42, 43]
	Inactive education campaigns	[25]
	Poor collaboration between the building industry and the PV industry	[42, 43]
	Inadequate knowledge of the costing system	[21]
	Lack of PV infrastructure and policy support	[38, 39, 40]

Table 2
Interviewees' background.

Stakeholder category	Stakeholders	Number of interviewees	Experience (Years)
Building industry professionals	Developers	3	15–25
	Design engineers	5	5–20
	Contractors	8	4–12
	Facility manager	1	11
PV professionals	PV designers	3	5–8
	PV installers	6	3–8
Policy makers	Regulators	2	20–25
	Inspectors	3	4-5
Total		31	

- What are the main barriers and challenges encountering the application of PV in the Saudi building sector?

The rationale for conducting this questionnaire survey is:

- Saudi Arabia has one of the highest per capita energy consumption in the world.
- Building sector is the largest stakeholder when it comes to energy consumption, accounting for around 80% of the total national electricity (Ahmed et al., 2019; Ghaleb and Asif, 2022).

The questionnaire survey targeted a subgroup of the study population. The targeted subgroups represent the following:

- Client/building owners: A client or building owner is the most important player among all stakeholders. Client's awareness and interest are fundamental and decisive factors in transpiring the application of PV in buildings.
- Architect and building engineers: Architects in particular and building industry engineers, in general, are also important players with a great deal of influence on the decision-making process. Their ability to satisfy clients' desires and plans can have significant leverage in terms of convincing their clients to use PV in buildings.
- Contractors and builders: Translating the architects' designs into real products is also a job that cannot be overlooked. Effective application of PV systems in buildings is critical towards not only satisfying the building owners but also contributing to public awareness and motivation. Additionally, the ability of contractors to provide after-sale service and support helps a long way towards reliability of the PV systems.

To avoid the constraints associated with web-based surveys such as low response rate, technical difficulties in completing the survey, poor quality or presentation of survey, a pilot study was conducted to ensure the survey was free of errors, questions

Table 3
Validation of barriers by interviewees.

#	Barrier description	Developers	Design engineers	Contractor	Facility manager	PV designers	PV installers	Regulators	Inspectors	Total responses
	Ratified barriers									
B1	High price for the PV Systems	3	5	6	1	2	5	2	2	26
B2	Payback time	3	4	7	0	1	2	0	0	17
B3	Maintenance of the Modules' Costs	2	3	6	1	0	0	2	3	17
B4	Subsidized Tariffs	3	5	8	1	3	6	2	3	31
B5	Lack of awareness	3	5	2	1	3	6	2	3	25
B6	Public level of education	0	5	8	0	0	6	2	3	24
B7	Architectural dimension, no enough space for the PV	3	5	7	1	3	6	1	3	29
B8	Lack of technical & human resources	3	3	8	1	2	5	0	0	22
B9	Lack of after-sale services and support	2	5	5	1	3	4	1	3	24
B10	The efficiency of the PV system	3	5	7	0	0	0	2	3	20
B11	Absence of policy to encourage people to install the PV system	3	5	8	1	3	6	0	3	29
B12	No regulation for PV	3	5	8	1	3	6	0	3	29
B13	Lack of standards	2	5	7	0	0	0	2	3	19
B14	Absence or inadequate governmental subsidies	3	4	5	1	2	6	2	3	26
B15	Poor after-sale service	3	5	3	0	2	5	2	3	23
B16	In appropriate marketing strategies	0	0	8	1	3	6	2	3	23
B17	Inactive education campaigns	1	5	5	1	3	4	1	3	23
B18	Poor collaboration between the building industry and the PV industry	2	3	7	0	3	6	0	2	23
B19	Lack of PV infrastructure and policy backing this technology	3	5	4	1	3	6	0	0	22
	Eliminated Barrier									
B20	Inadequate knowledge of costing system	2	1	0	0	0	2	0	1	6
B21	Turbulent economic growth	0	0	0	0	0	0	0	0	0
B22	Lack of access to diversified technology	0	0	2	0	0	1	0	0	3
B23	Local weather condition	0	0	0	1	0	0	0	0	1
B24	Low customer education level	1	0	0	0	0	0	0	0	1

Table 4
Factors and sub-factors affecting the importance level of PV system.

Economic barriers	Policy barriers
High price for PV System	Absence of policy to install PV
Payback time	No regulations for PV
Maintenance	Absence or inadequate govt. subsidies
Subsidized tariffs	Lack of standards
Socio-technical barriers	**Management barriers**
Education level	Poor after-sale service
Lack of Awareness	Inappropriate marketing strategies
Architectural dimension	Inactive education campaigns
Lack of technical and human resources	Poor collaboration
Lack of after-sale services	Lack of PV infrastructure
Efficiency of PV	

were clear and easy to understand, and it did not take more than ten minutes. The questionnaire was principally designed with closed-ended questions to guide the respondents in terms of potential answers/options as well as to save their time. However, an option was also provided to add comments if they wanted. A follow-up regime was also adopted to help with the survey response. The important constructs included in the questionnaire in addition to the barriers, as listed in Table 4, involved some demographic information about the respondents like position, experience, background and the level of familiarity with the PV systems. Another considered aspect was whether the respondents were willing to install PV in their building or not, and if affirmative, how much saving in electricity bills would convince them to invest in a PV system.

The designed questionnaire measures the responses on barriers using a scale of 1 to 5 while 0 is attributed for 'No answer' as shown in Table 5.

Table 5
Level of importance- questionnaire response.

Scale	Coded
No answer	0
Not Important at all	1
Fairly unimportant	2
Neutral	3
Fairly important	4
Very important	5

4.3. In-depth interviewers

To develop a comprehensive understanding of barriers and challenges facing the application of PV in the Saudi building sector, a selected group of experienced and insightful survey respondents were contacted for their willingness to give an interview. In the interviews, conducted in person, detailed discussions

Table 6
Reliability statistics.

Factors	Economic	Sociotechnical	Policy	Management	Overall reliability
Cronbach alpha	0.838	0.852	0.639	0.895	0.842
No. of items	4	6	4	5	19

Table 7
Percentage of respondents.

Respondent characteristics	Percentage	Respondent characteristics	Percentage
Position		Background	
Contractor	34	Architectural	44
Designer	38	Civil	18
Developer	28	Electromechanical	38
Experience		Familiarity	
Less than 5 years	26	Not familiar at all	24
5–10 years	40	Slightly familiar	42
10–20 years	32	Fairly familiar	34
Over 20 years	2		

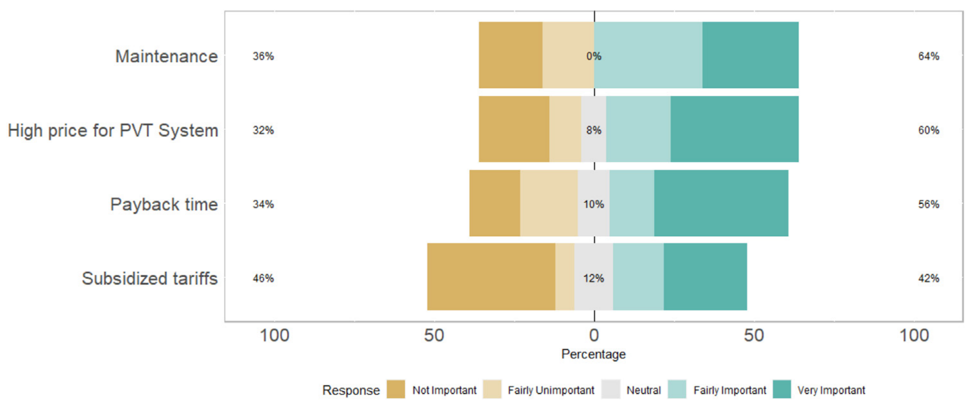

Fig. 2. Likert divergence bar chart for economic barriers.

were held with the interviewees also taking into account the survey -responses. Interviews also helped to develop detailed insight into critical issues which needed further deliberation on top of the survey results.

Interviews were conducted with two representatives from each of the three respondent categories — design engineer, developer, and contractor. To make the exercise more useful, the interview agenda was conveyed to the interviewees beforehand. Interviews were based around the broader categories of the barriers as investigated in the survey with the main focus on inquiring about the most important barriers they perceive towards the adoption of PV in the KSA building industry.

5. Results and discussions

5.1. Statistical analysis

This section discusses the results of the questionnaire survey and interviews. The data gathered from the respondents was imported into the Statistical Package for the Social Sciences (SPSS) for further analysis. R statistical language was also used for the presentation of useful graphs. Cronbach alpha measures the internal consistency of a questionnaire. It measures how closely a set of items are as a group. In our study, Cronbach alpha is calculated separately for each of the barriers by including the set of related items. Moreover, an overall Cronbach value is also reported. Some researchers including Moss et al. (1998), Hair (1998) and Ursachi et al. (2015) supported the view that a Cronbach alpha value greater than 0.6 is considered as acceptable, particularly for groups with a small number of items. Cronbach alpha values in Table 6 are all higher than 0.8 except for Policy barriers which is greater than 0.6 and hence termed acceptable.

5.1.1. Descriptive statistics

Descriptive statistics are applied to the demographic indicators such as position, experience, background, and familiarity of the respondents. A total of 50 participants responded to the questionnaire survey and the percentage of respondents lying in each of the categories is listed in Table 7.

It is noted that 40% of respondents have work experience between 5 to 10 years while 24% of them are not familiar with PV systems. In terms of skillset, architectural and electromechanical professionals account for 44% and 38% of the respondents respectively.

5.2. Economic barriers

The results of the responses to the economic barriers are shown in Fig. 2. It can be observed that the maintenance cost of PV systems is regarded to be the most critical factor with 64% of the respondents considering it as very important or fairly important. It is followed by the initial price of PV systems and the long payback period, with 60% and 56% of the respondents regarding them as very important or fairly important respectively. Subsidized tariff is ranked to be the least critical factor, with 42% of the respondents regarding it as very important or fairly important, which is appreciable given the steep rise in energy prices over the last few years.

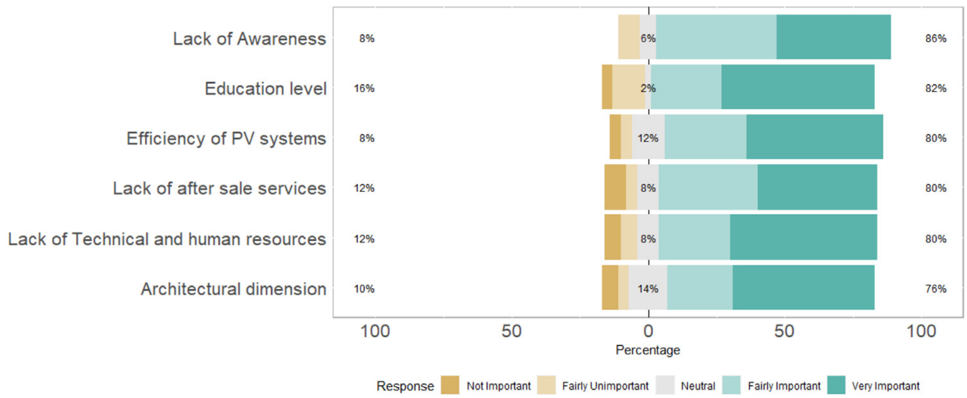

Fig. 3. Likert divergence bar chart for socio-technical barriers.

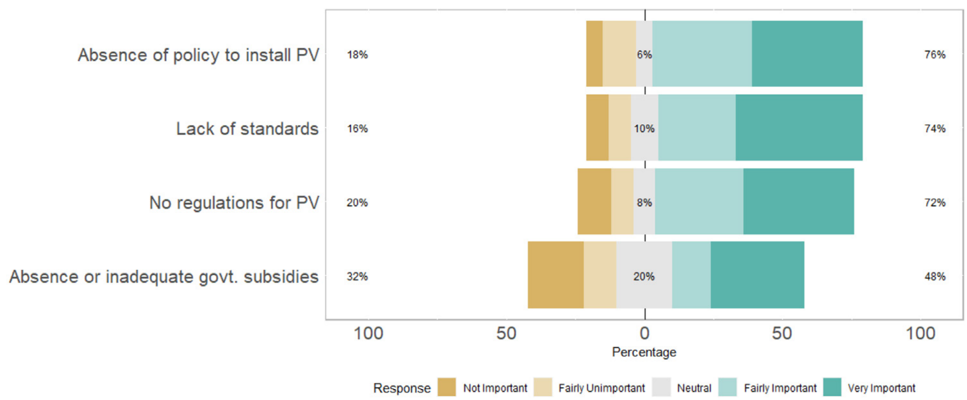

Fig. 4. Likert divergence bar chart for policy barriers.

5.3. Socio-technical barriers

Lack of awareness and public education has been regarded to be the most critical socio-technical barrier with 86% of respondents considering it as very important or fairly important as shown in Fig. 3. Solar PV is a relatively new technology in KSA as the country has traditionally relied on abundant and heavily subsidized fossil fuels. Public awareness about PV technology is therefore not mature enough which is an impending issue for the technology. The next most critical socio-technical barrier is the client's education level followed by the efficiency of PV systems, lack of after-sale services, lack of technical/human resources, and architectural dimensions. It can be observed that overall the socio-technical barriers have been given a high degree of importance and all of the six barriers have been ranked in close proximity, in the range of 76%–86%.

5.4. Policy barriers

Globally, the progress solar PV has made in recent years has been strongly propelled by supportive policy frameworks. The results on the policy questions indicate that lack of policy support is deemed important by the respondents. The absence of support policies towards the installation of PV systems, lack of standards, and absence of regulations have been ranked important by 76%, 74%, and 72% of respondents respectively as shown in Fig. 4. In recent years KSA has made some progress on the policy side with the announcement of net-metering in 207–2018 and the plans to install smart meters. Survey results suggest that more needs to be done on the front of policies and their implementation.

5.5. Management barrier

In terms of management barriers, lack of PV infrastructure has been ranked as the most significant factor closely followed by a poor collaboration between the PV industry and the building industry, inappropriate marketing strategy, and inadequate education campaigns as shown in Fig. 5. It is observed that overall management-related barriers are rated relatively less important as compared to other categories of barriers.

5.6. Socio-technical barriers and respondents' background

As socio-technical barriers have been ranked more important than other types of barriers, the received responses are examined in terms of respondents' portfolio/characteristics: position, background, familiarity with technology, and work experience. Diversity can be observed in respondents' opinions in terms of their portfolio. For example, it can be noticed from Fig. 6(a) that designers are more concerned about socio-technical barriers compared to developers and contractors. This corroborates with the fact that typically designers are more knowledgeable and familiar with technologies and solutions as compared with the other two groups. It is also observed that respondents familiar with PV technology are more concerned about the socio-technical barriers as shown in 6(c).

5.7. Comparison of barriers

For the overall comparison of barriers, the individual responses for the sub-factors of each barrier were summed up to form four new overall quantitative variables (namely Economic,

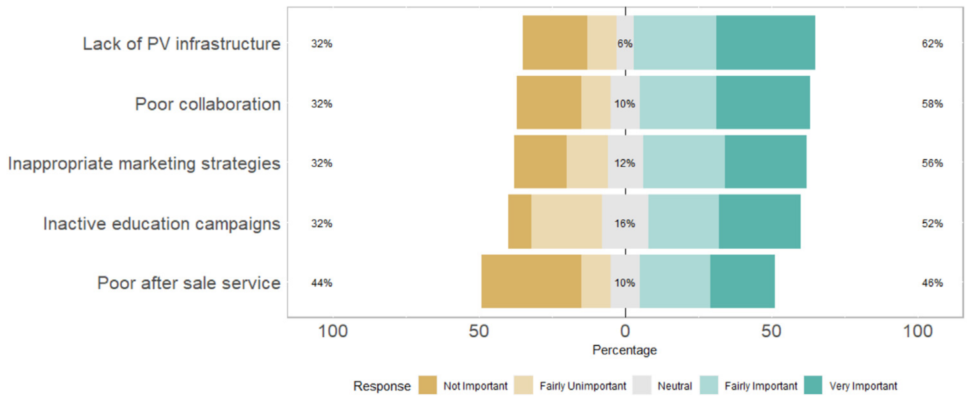

Fig. 5. Likert divergence bar chart for management barriers.

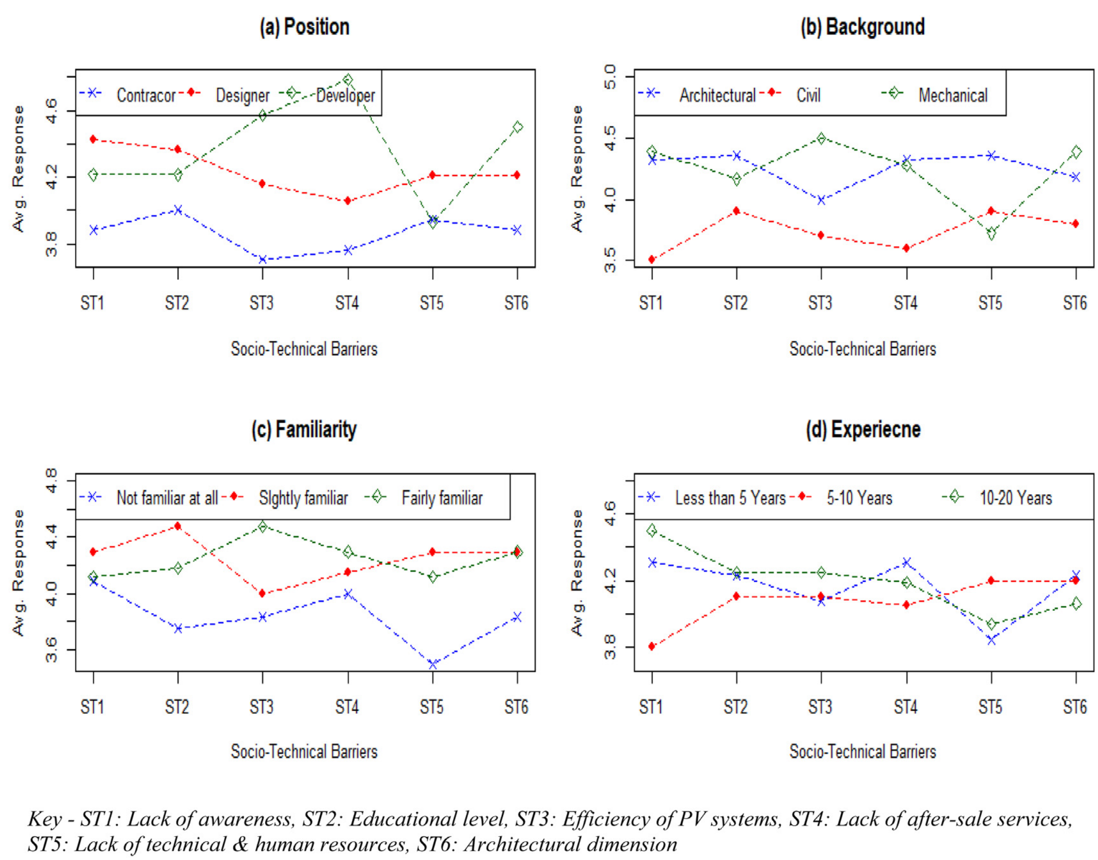

Fig. 6. Socio-technical barriers for varying levels of respondents' positions. Key — ST1: Lack of awareness, ST2: Educational level, ST3: Efficiency of PV systems, ST4: Lack of after-sale services, ST5: Lack of technical & human resources, ST6: Architectural dimension.

Socio-technical, Policy, and Management) which were again assigned ranks according to the Likert scale, as defined in Table 8. The bar charts for these variables are plotted in Fig. 7, which shows that most of the respondents rank socio-technical barriers as the most important barrier followed by policy, management, and economic barriers. The mean and standard deviation, as summarized in Table 8, reveals that in terms of the four broader barrier categories – economic, socio-technical, and policy and management – respondents regard the socio-technical barriers as the most significant one with a mean value of 4.50 on a scale of 1 to 5. Policy barriers are ranked as the second most important category with a mean value of 4.06. Management and the economic barriers are near each other in terms of significance with respective values of 3.66 and 3.60, respectively.

5.7.1. Spearman rank correlation

To evaluate the relationship between the barriers under four categories the Spearman rank correlation test is used. The numerical results (correlation and P values) reported in Table 9, indicate the significant relationship between most of the barriers of the PV system as the p-value is <0.05. It shows that there is a significant positive correlation between the economic barriers, and management and policy barriers. The relationship between management and policy barriers is also significantly

Table 8
Descriptive statistics for the barriers.

Factors	Economic	Sociotechnical	Policy	Management
Mean	3.60	4.50	4.06	3.66
Std. deviation	1.2936	0.7889	0.9348	1.1885
Importance level	Fairly important	High important	Fairly important	Fairly important

Table 9
Spearman rank correlation.

		Economic	Sociotechnical	Policy	Management
Economic	Correlation	1.000	.090	.441**	.570**
	P-value		.532	.001	.000
Sociotechnical	Correlation		1.000	.435**	.046
	P-value		.	.002	.754
Policy	Correlation		.*	1.000	.589**
	P-value			.	.000
Management	Correlation				1.000
	P-value				

**. Correlation is significant at the 0.01 level (2-tailed).

Table 10
Chi-square test results for the association of familiarity with respondent's position, background, and experience.

Position		Background		Experience	
Chi-sq.	P_{value}	Chi-sq.	P_{value}	Chi-sq.	P_{value}
10.46	0.033	12.781	0.012	4.326	0.633

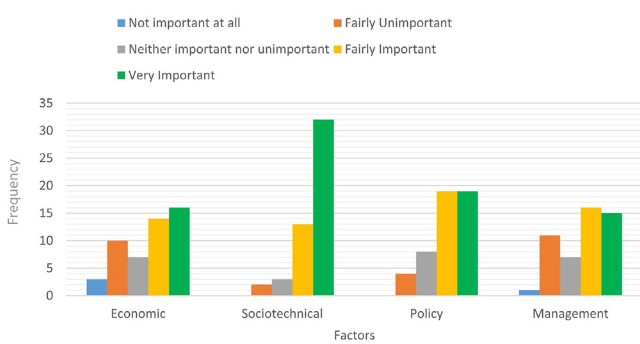

Fig. 7. Frequency bar chart for the importance of different barriers.

positive while the correlation between sociotechnical and policy barriers is insignificant (cf. Table 9).

5.7.2. Respondents' familiarity with PV technology

This question aimed to investigate a critical factor in the promotion of PV in the building sector. It is the awareness of the technology. Results suggest that 24% of the respondents are not at all familiar with PV technology and 66% are fairly or slightly familiar. None of the respondents are highly familiar with the technology. The familiarity level of respondents is also related/associated with their position, background, and experience. To check this relationship, chi-square tests are conducted. For example: to test the association between familiarity and position, the following set of hypotheses are used:

H_0: Respondent's familiarity and position are independent
H_1: Respondent's familiarity and position are related/associated

Similar hypotheses are set for the other two tests. The test results (chi-square and p-values) are reported in Table 10.

The test results indicate that the familiarity of the respondents is significantly related/associated with their position and background while one fails to reject the hypothesis of independence for familiarity and experience at a 5% significance level.

5.8. Interviews

The first point was: *Ultimately whose decision is to incorporate PV in buildings and how?* There was consensus in the response from all of the interviewees that it was the choice of the building owner/client. One of the interviewees shared his experience that in a new building project he was involved in, it was decided to install PV on the building. During the project, however, the owner changed his mind and scrapped the idea of having PV as he was advised by some of his staff that the PV system would occupy the whole area of the roof and still would not suffice the building's needs, which was not the case. It implies not only a lack of understanding on the part of his team about PV systems but also the fact that the owner has the final decision. The interviewees also agreed that awareness amongst building owners, designers, and developers is a key factor to promote the use of PV.

Another point that surfaced during the interviews was from building owners' and developers' perspectives as: *Why would I install PV in my building and incur more costs while I have a cheaper alternative?* This question sums up why the building industry is still largely reluctant to adopt solar PV when electricity is available at subsidized tariffs.

Another point discussed was: *Does the building industry have the expertise and skillset to deal with PV systems in terms of design, installation, and operation & maintenance?* The answer was negative. All the interviewees were of the view that the overwhelming majority of the building sector companies do not have the personnel and expertise to deal with PV projects. The reasons were identified to be a lack of demand in the market, consequently, companies are not prompted to equip themselves with this skillset. The absence of in-house or easily available expertise is thus a discouraging factor for the building industry to go for solar PV.

Overall, the in-depth interviews substantiated the findings of the survey. As illustrated in Fig. 8, subsidized electricity tariffs are reported to be the driver for lack of public awareness which in turn leads to other restrictions like lack of technical expertise, and low level of awareness in society.

6. Conclusions and recommendations

Saudi Arabia has set out a road map for the national transition program. The energy sector has been given important priority in this regard. Renewable energy is one of the promising areas in this plan as the country aims to develop 58 GW of solar and wind power projects by 2030. The building sector consumes around 80% of the total national electricity. Special attention needs to be

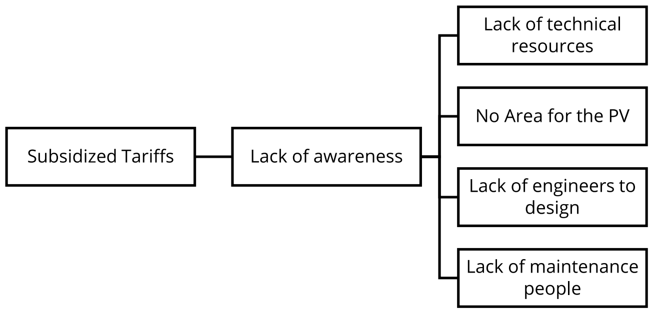

Fig. 8. Root cause of low intake of PV in the KSA building industry.

paid to promote renewables in the building sector. Solar PV is an optimum technology to be used in the Saudi building sector. Despite the global success of solar PV, the building sector in KSA is still largely reluctant to incorporate the technology. This study investigates the key barriers facing the application of PV in the Saudi building sector. It uses secondary data through a literature review as well as empirical data collected from relevant building industry stakeholders through online surveys and interviews. The 23 potential barriers identified through the literature review were further examined by interviewing local experts. This process helped validate the identified barriers, ratifying 19 of them while rejecting four.. The study also ranked the barriers in terms of their significance. In this respect, the confirmed barriers were classified under four categories – economics, socio-technical, policy, and management – to develop an online questionnaire-based survey. A total of 50 responses were received from design engineers, developers, and contractors. The survey results suggest that socio-technical barriers are considered to be the most critical with a mean weightage of 4.50 on a scale of 1 to 5, followed by policy barriers with a mean value of 4.06. Management and economic barriers are in 3rd and 4th place with respective values of 3.66 & 3.60. In terms of individual barriers, lack of awareness about PV is the most critical factor as it was rated by 86% of the respondents as fairly important to very important. Lack of awareness seems to have a knock-on effect on other hurdles including the lack of available technical skills and expertise. Subsidized tariffs and insufficient policy support are all important hurdles. In the interviews, the interviewees stressed the importance of the building owners' conviction in the economic viability of PV systems as an important factor to promote the technology's application in the building sector. Given the similarities in the energy mix, socio-economics, and climatic conditions, the barriers identified in this study are significantly applicable to all GCC countries. Subsequently, potential solutions to these challenges for all GCC nations would also have commonalities. The results of the online questionnaire regarded the lack of public awareness as the most significant factor, which was also confirmed by interviews, however, it was considered a consequence of subsidized electricity tariffs. Collectively, the survey and interviews helped conclude that the most critical barriers are: a lack of awareness and public education; concerns about the economic viability of PV systems, and a lack of a conducive policy framework. Lack of awareness still being a major hurdle and a matter of concern given the Saudi government's Vision 2030 plans and significant developments around PV projects in recent years. It is therefore important to address the issue as a matter of priority as improvements on this front can have a positive impact in terms of overcoming several other hurdles. Embedding the concepts of sustainability and introduction to solar technologies in academic curricula at all levels – schools, colleges, and universities – can be a helpful approach to improving public awareness. Industry-, and trade and commerce-focused dedicated activities such as workshops, seminars, and awareness campaigns can also play an important role in this respect. Economic viability and policy frameworks have a close relationship and can significantly be addressed through integrated efforts. Solar PV systems, like other renewable energy technologies, have high capital costs. Low power density and the impact of harsh climate conditions such as temperature affect the perception of PV systems in buildings with high energy demand (mainly due to HVAC systems). To promote the application of PV systems in KSA/GCC, especially in the building sector, conducive policies are imperative. Countries across the world have come up with supportive policies and standards such as feed-in-tariff, net metering, and capital cost and taxation subsidies. KSA has announced a net-metering scheme, and technical arrangements including the installation of smart meters are being planned to implement the policy. It is an important step in the right direction. Given the involved price structure, the benefit of the net-metering policy to small users such as residential and typical commercial buildings, however, may not be as attractive as to customers with larger energy loads. It is recommended to also consider the feed-in-tariff (FIT) policy which is regarded as one of the most successful policies to promote the small-scale application of renewable technologies around the world. The FIT policy will also help PV systems tackle the inherent disadvantage they are subject to due to heavily subsidized conventional energy types. Policy interventions are also needed to improve the utilizability of building rooftops for the installation of PV panels. GCC countries are facing a common challenge of heavy reliance on fossil fuels. To make their building sectors more sustainable, and to diversify their energy mix, it is important for them to adopt technologies like building applied solar PV (BAPV) systems. In the wake of the Paris Agreement, carbon-neutrality targets are being adopted by nations across the world as KSA has also pledged to be carbon-neutral by 2060. BAPV systems can also help the GCC countries towards carbon-neutrality.

CRediT authorship contribution statement

Belal Ghaleb: Data collection, Methodology, Formal analysis, Writing. **Saddam Akber Abbasi:** Data analysis, Discussion. **Muhammad Asif:** Conceptualization, Supervision, Review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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