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Assessing the Potential of Qatari House Roofs for Solar Panel Installations: A Feasibility Survey

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Abstract: Qatar's ambitious Vision 2030 includes a major shift towards clean energy, and residential solar PV installation can be an obvious option, given its abundant sunlight and high power for residential cooling. Despite significant solar panel farm investment, there has been limited progress in deploying solar panels on home roofs, and further research is needed to identify the potential for such an initiative and its impact on the country's move towards clean energy. This field survey assesses the potential for residential rooftop solar panel installation across Qatar, considering space availability, currently utilized space, remaining space, shading, and roof type. It also provided indications of potential obstacles and shading that might affect panel sunlight exposure. The results showed that there is significant potential for installing solar panels on Qatari homes, which could contribute to a considerable portion of the energy consumed by households during peak usage periods, particularly in the summer months. Moreover, excess energy generated could be exported to other countries with high demand during periods of low demand in Qatar. The study's findings complement previous research efforts and provide insights for policymakers and stakeholders to develop strategies that endorse the vision for 2030 and promote the transition towards clean energy in Qatar.

Keywords: renewable energy; solar panels; Qatar; roof solar panels; roof survey; installation feasibility; solar panel installation drivers

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1. Introduction

Qatar is committed to achieving its Vision 2030, which aims to create a sustainable and diversified economy as well as a healthy and secure society. One of the key strategies to achieve this vision is through a major shift towards clean energy [1]. Given the country's geographic location, Qatar is well-suited to harnessing the power of the sun to achieve its sustainable electricity goals. The country has abundant sunlight throughout the year, making it an ideal location for the installation of solar PV arrays [2]. Qatar has already taken significant steps towards achieving its vision of clean energy and has invested heavily in solar panel farms, such as the 800 MW Al-Kharsaah Solar Power Plant, which is expected to power around 10% of the country's energy needs [3]. These farms are a critical component of Qatar's clean energy strategy, but more can be undertaken. The majority of Qatar's energy load is domestic use, especially for cooling during the summer months, as noted by the Annual Statistics Report 2021 of Qatar General Electricity & Water Corporation (KAHRAMAA), accounting for 38,284,270 MWh out of the total amount of electricity generated nationally per year (Figure 1) [4]. It is clear from the figure that domestic users account for nearly four times the number of industrial consumers. This fact supports the objective of this study, indicating that residential buildings have the potential to play a significant role in the transition toward clean energy and achieve milestones toward the national net-zero target. At the time of this study, there is still limited progress in deploying solar panels on home roofs, despite the country's high levels of sunshine and the potential benefits that such installations can bring [2].

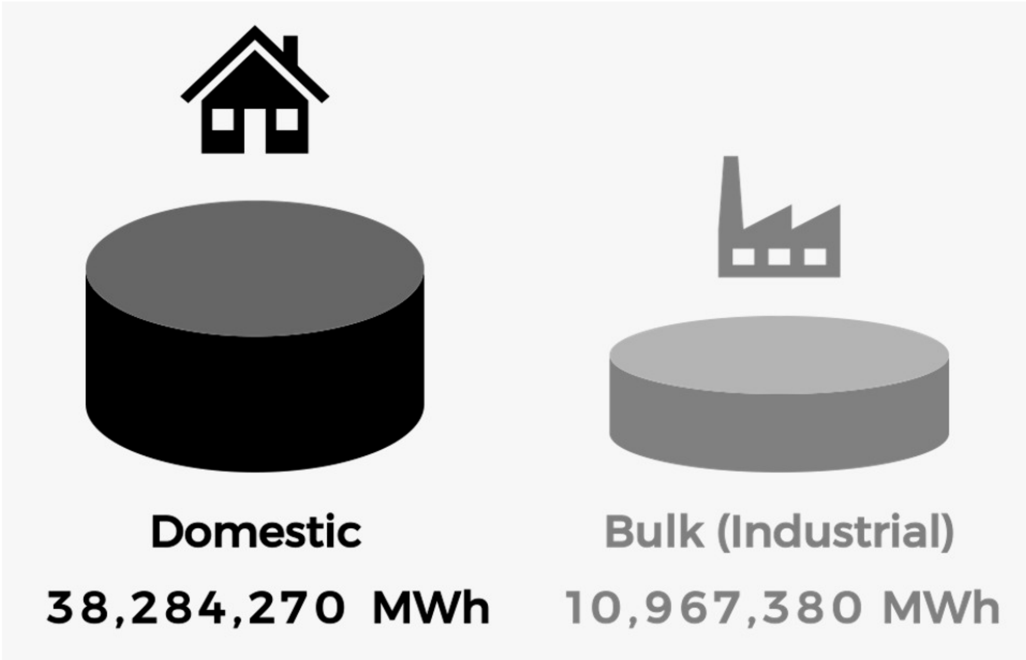

Figure 1. Domestic energy consumption [4].

Deploying solar panels on home roofs can contribute to the country's clean energy goals by creating a distributed network of clean energy production. This can help reduce the country's dependence on fossil fuels (as well as the cannibalization of its primary national exports), lower carbon emissions, and create a more resilient energy system. Given that the country is one of the main energy exporters and experiences a high number of sunny days, it can enable significant clean energy generation that can be exported [2]. However, further research is needed to identify the potential for this initiative and its impact on the country's move towards clean energy. This includes examining factors such as the availability of suitable roof space, the orientation of the roofs, and the presence of any shading or obstructions that might limit the effectiveness of the solar panels. By conducting such research, stakeholders can better understand the potential of solar panels on residential roofs and develop strategies to accelerate and optimize their deployment.

2. Drivers for Roof Solar Panels in Qatar

Qatar has made progress in large-scale solar farm investments, but residential solar panel deployment is still needed to achieve the nation's clean energy vision by 2030 [1]. Previous research has identified key challenges, as summarized in Figure 2, that must be addressed before scaling up solar panel deployment in Qatar [5]. These challenges include a lack of interest in renewable energy, competition from other energy sources, uncompetitive pricing due to subsidized conventional electricity, limited awareness of renewable energy, insufficient government initiatives, and a lack of environmental concern. Similar challenges exist in other Gulf Cooperation Council (GCC) countries. Thus, addressing these issues is necessary before considering residential and commercial solar panel deployment in Qatar. A national roadmap for sustainable energy is crucial for achieving this long-term goal.

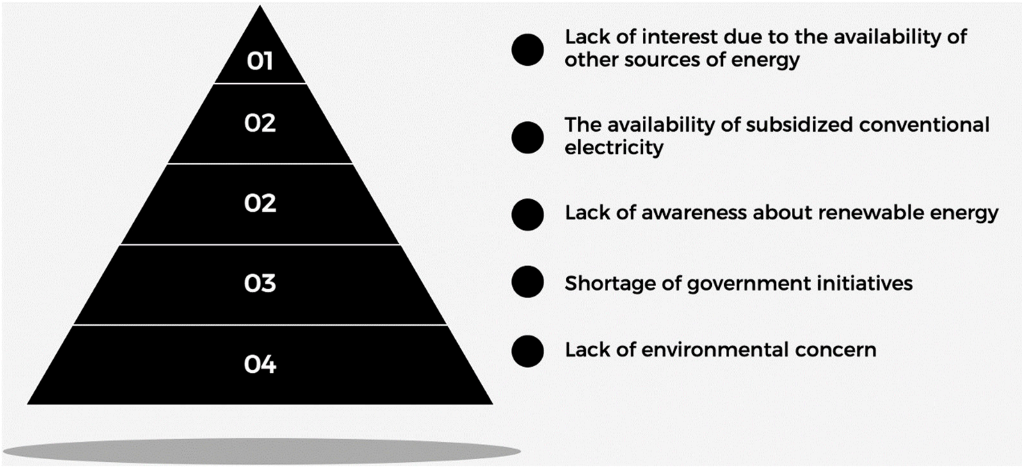

Figure 2. Five key challenges to residential solar PV adoption [5].

By considering the six drivers for promoting solar panel adoption, namely potential, awareness, the net-zero pathway, energy efficiency, lowering subsidies, and sustainability, stakeholders can develop effective strategies to encourage the installation of solar panels and achieve the vision of a sustainable future (Figure 3).

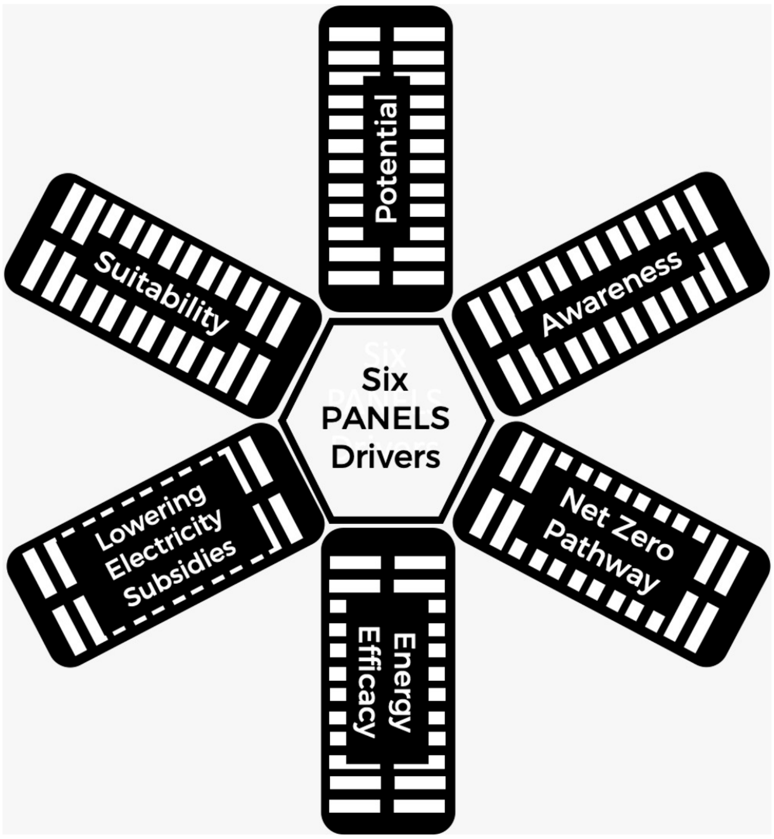

Figure 3. Six PANELS drivers [authors].

2.1. Potential

Qatar has vast potential for solar energy investment, positioning itself as a leader in clean energy exports. Factors such as high sun hours, market experience, and financial capacity make Qatar an ideal location for solar energy ventures [6]. Qatar is well-suited for solar energy investments, with an average of 3600 h of direct solar radiation annually [7].

The country is committed to reducing its carbon footprint and aims to generate 20% of its energy from renewables by 2030, with solar energy playing a significant role [8].

A recent feasibility study explored various scenarios of solar panel deployment in Qatar's residential and commercial buildings, considering panel sizes, efficiency, and daily sun exposure. Results indicated substantial potential for rooftop solar panels, generating significant energy during peak usage, particularly in hot summer months. Surplus energy could be exported to countries with high energy demands, positioning Qatar as a major contributor to solving global energy crises [2].

Qatar's extensive experience in the energy market, particularly in the oil and gas industry, can be leveraged to develop the solar energy sector and gain a competitive advantage in the global clean energy market [9]. The country's financial capacity and resources enable large-scale solar energy investments [10]. Notably, Qatar has already invested in significant solar energy projects, including the Al-Kharsaah Solar Power Plant, one of the world's largest [11]. With its potential for solar energy investment and clean energy exports, Qatar can contribute to its own energy needs, reduce carbon emissions, and address global energy demands [12]. Its high sun hours, market experience, and financial capacity make it an ideal destination for solar energy investment [2].

2.2. Awareness

Awareness plays a vital role in promoting the adoption of renewable energy resources. In Qatar, a lack of awareness has been identified as a significant challenge hindering the deployment of renewable energy [13]. To address this challenge, the government should implement projects that allow households to actively participate and experience the benefits of installing solar panels. This can effectively raise awareness throughout the nation [14]. Given Qatar's socially connected society, visible solar panels on homes would initiate conversations and spark interest in renewable energy, leading to a snowball effect of adoption [15]. The installation of solar panels serves as a strategic tool to raise awareness and drive the transition toward clean energy use [16]. Not only does it offer tangible benefits like reduced energy bills, but it also visually demonstrates individuals', businesses', and nations' commitment to reducing carbon emissions and contributing to global climate change mitigation efforts [17]. This visual representation can generate public interest and awareness of renewable energy, inspiring more individuals and businesses to embrace clean energy sources [18].

Moreover, increasing public awareness about renewable energy can garner support for policies and initiatives promoting clean energy adoption [17]. This creates a favorable environment for renewable energy investment and deployment in Qatar, encouraging businesses to invest in renewable energy projects. Therefore, enhancing public understanding of the nature and significance of clean and renewable energy sources is a crucial step in establishing them as a normative and primary component of the national energy mix. In Qatar, the installation of solar panels on homes acts as a catalyst for raising awareness and driving the transition to clean energy. By generating public interest and support for renewable energy, Qatar can contribute to global climate change mitigation efforts and foster a more sustainable future for all.

2.3. Net-Zero Building Pathway

To achieve more sustainable and energy-efficient buildings, implementing a net-zero strategy is crucial. Net-zero buildings have the capability to generate as much energy as they consume, resulting in a neutral or net-zero energy balance [19]. Currently, homes in Qatar heavily rely on external energy sources, but the installation of solar panels on rooftops can pave the way towards net-zero buildings [20]. By incorporating solar panels, homes in Qatar can reduce their dependence on conventional energy sources and promote the use of renewable energy. The region's abundant sunshine makes solar energy an ideal solution for meeting residential energy needs [13]. Local energy production allows homes to decrease their reliance on grid-supplied electricity, which is often costly and contributes to carbon emissions [2].

Apart from the environmental advantages, transitioning to net-zero buildings can lead to significant cost savings for homeowners. By generating their own energy, homeowners can reduce their electricity bills and even potentially sell surplus energy back to the grid [19]. This introduces a new revenue stream and helps offset the upfront costs of solar panel installation [2]. Additionally, adopting a net-zero strategy improves overall energy efficiency in buildings, resulting in reduced energy consumption and lower carbon emissions. These efforts align with global initiatives to combat climate change [21]. Therefore, installing solar panels on homes in Qatar serves as a strategic step towards achieving net-zero buildings. Through localized energy production, homeowners can decrease their reliance on conventional energy sources, lower energy expenses, and contribute to global climate change mitigation [20]. Thus, implementing a net-zero strategy is essential for creating a more sustainable and energy-efficient built environment in Qatar.

2.4. Energy Efficiency

Energy efficiency is crucial for a sustainable energy strategy in Qatar, where all homes currently rely on fossil fuel-generated energy. Promoting energy efficiency is vital to reduce consumption, lower carbon emissions, and create a sustainable built environment [22]. By installing solar panels and implementing a net-zero strategy, homeowners are expected to shift towards using energy-efficient appliances and monitoring their energy usage [23]. Solar panel installation on Qatar's homes can transform the way homeowners consume energy. Producing their own energy raises awareness about consumption and environmental impact, fostering a greater appreciation for energy efficiency and a willingness to invest in low-energy appliances [23].

Furthermore, a net-zero strategy incentivizes energy efficiency through a feedback loop between production and consumption [23]. As homeowners become adept at generating their own energy, they become conscious of consumption patterns and take steps to reduce energy usage. This includes adopting energy-efficient habits, investing in efficient appliances, and monitoring consumption for potential savings. Therefore, promoting energy efficiency is vital for a sustainable energy strategy, especially in Qatar, where homes solely rely on fossil fuel-generated energy. Through solar panel installation and a net-zero approach, homeowners can enhance awareness, invest in efficient technologies, and contribute to a sustainable built environment [24]. Energy efficiency is essential for achieving a sustainable and energy-efficient future in Qatar.

2.5. Lowering Electricity Subsidies

Qatar can transition to a sustainable energy future by deploying solar panels on homes. Energy subsidies pose a challenge as the government provides free energy to citizens, hindering solar panel installation. However, the government can support panel installation to reduce non-clean energy use and subsidies [10,13]. This empowers homeowners to generate their own energy, reducing their reliance on non-clean sources [25]. It shifts the energy production burden from the government to individuals, lowering subsidies [10]. Homeowners can contribute to the grid and export excess energy, generating revenue [2]. Government support for solar panels demonstrates a commitment to sustainability and emission reduction, fosters environmental consciousness, and encourages investment in sustainable energy [25,26].

2.6. Suitability

The deployment of solar panels in Qatar can contribute significantly to achieving sustainability across the three main pillars: the economy, society, and the environment. Solar energy is a clean and renewable source of energy that can support the economy by providing a new source of energy and sustaining the other available sources for future generations [10]. By investing in solar energy, the country can reduce its reliance on non-clean sources of energy, which can reduce the costs associated with importing and transporting non-renewable fuels. This can, in turn, support economic growth and development [27]. Moreover, solar energy can benefit society by minimizing pollution, particularly carbon emissions. The use of solar panels can help reduce the amount of carbon particles in the air, which can lead to a healthier and more sustainable society. This can contribute to the overall well-being of the population, as reducing pollution can lead to a reduction in respiratory illnesses and other health issues [28]. By reducing the generation of CO_2 from clean sources of energy, solar panels can contribute to a more sustainable environment that can be kept for future generations. This can also help reduce the negative impact of climate change on the environment and support the preservation of natural resources [29].

In order to effectively facilitate the implementation of the six drivers for solar panel deployment in Qatar, it is essential to carry out a field survey aimed at evaluating the viability of installing solar panels on different types of residential buildings. This survey will provide valuable insights to homeowners and decision-makers, enabling them to develop suitable scenarios for the installation and effective utilization of solar panels on domestic roofs in Qatar [30].

3. Materials and Methods

To evaluate the feasibility of installing solar panels on homes in Qatar, a survey was conducted using a manual approach with a structured interview sheet with closed-ended questions as the data collection method, based on the previous literature (as explained in Table 1). The reason for opting for manual surveying instead of remote sensing methods, such as the use of satellite images [31], is primarily due to cost, accessibility, and issues related to legal and ethical approvals. Additionally, the use of drones has been considered; however, as of now, drone surveying is not yet allowed in Qatar [32].

The survey aimed to gather data on the availability of space for solar panel installation, currently utilized space, remaining space, shading, and roof type. The use of a structured interview sheet with closed-ended questions provided a standardized approach to data collection and made the process more efficient. Closed-ended questions were used to collect quantitative data, which could be easily analyzed statistically to identify patterns and relationships in the data [33]. As shown in Figure 4, the research design consisted of four stages to complete the research project. The first stage was designing and testing the data collection instrument, which was the most important part of the research design. It involved identifying the main aspects to be included within the data collection instruments, and an interview sheet was established. Each item included had a justification, as shown in Table 1.

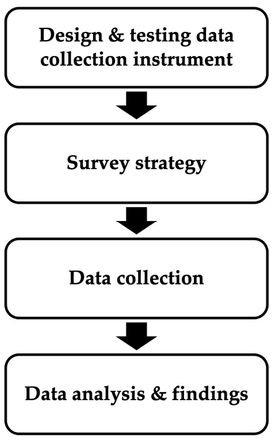

Figure 4. Research design [authors].

Table 1. Collected data and justification.

Interview Question	Rationale
House location	The location of a house in the field survey is essential to obtaining accurate geographical representation [3,34].
Number of similar houses in the street or compound	Knowing the number of similar houses in the same area is essential for a wider and more representative study. It helps with solar panel installation planning, as a community solar setup can be considered [34].
Number of bedrooms in the house	The number of bedrooms in a house is crucial for solar panel installation. It helps estimate energy consumption and the correct number of panels needed. Also, analyzing energy usage patterns identifies areas for conservation measures, reducing consumption, and enhancing solar panel effectiveness [35].
Items on the roof	Before installing solar panels, it is essential to identify existing objects that may hinder the process or limit available space. These can include AC units, chimneys, skylights, and other structures. Assessing their current use and placement on the roof helps determine the best solar panel installation approach [3].
Approximate total roof size in square meters	Determining the approximate size of a roof (in square meters) is essential when considering the installation of solar panels. This information can be used to calculate the amount of viable free space available for solar panel installation [3].
Average remaining empty space on the roof	To install solar panels on a roof effectively, assess the available space for optimal energy generation. Utilize the average remaining empty space, avoiding obstructions like vents or chimneys, to maximize panels and energy output. Plan and design carefully for an aesthetically pleasing integration with the roof's architecture [3].
Recreational use of the roof	Before installing solar panels on a recreational roof, assess their potential impact on leisure activities. The size and orientation of the panels might obstruct or limit recreational use [3]. However, with careful planning, solar panels can serve a dual purpose by providing shade and protection for leisure activities while generating renewable energy for the home [34].
Roof type	To install solar panels on a house, assess the roof type, condition, orientation, and angle for sufficient sunlight. Evaluating the roof's suitability ensures the maximum benefits of renewable energy for the home [3].
House height	When assessing the feasibility of solar panels for a house, consider the building height compared to surrounding structures. If taller neighboring buildings block direct sunlight from the east or west, optimal sun exposure may be challenging [3]. Also, evaluate the roof angle and orientation. Proper assessment ensures efficient solar panel installation, maximizing the benefits of solar energy for the home [34].
Solar shading	Solar shading is the process of identifying potential obstructions, like nearby buildings or tall trees, that may block sunlight from reaching a rooftop or solar panel installation. By understanding shading risks, effective measures can be taken to optimize sunlight exposure, maximize energy generation, and reduce the need for additional energy sources [3].

The second stage of the research design was the survey strategy. Since the majority of the country's population is based in Doha, the study selected areas to be included in the survey. Moreover, due to the fact that homes in similar neighborhoods typically have many similarities, the interview included asking the homeowners if nearby homes are similar to their own. This enabled achieving geographical representation as well as statistical representation to represent the whole number of homes in Qatar, which is expected to be around 365,000 domestic customers, according to KAHRAMAA's Annual Statistics Report 2021 [4].

The third stage of the research design involved data collection. To facilitate this process, the interview questions were digitized into an electronic form that allowed for convenient and efficient data collection on the spot [36]. This eliminated the need for further processing and streamlined the data collection process. Additionally, using an electronic form allowed for anonymous data storage, thereby ensuring the confidentiality of the participants [37]. Electronic data collection methods have become increasingly popular in recent years as they offer a range of advantages over traditional paper-based methods. For example, electronic forms can reduce the risk of errors and inconsistencies as well as improve the speed and efficiency of data collection. Furthermore, electronic forms can be easily stored and accessed, making it easier to analyze and interpret the data.

The final stage of the research design involved data analysis and the presentation of the findings. To achieve this task, Excel was used to plot graphs and perform the necessary statistical analyses to convert the collected data into meaningful information. Excel is a widely used spreadsheet software that can be used for data analysis and has many built-in statistical functions that can aid in the analysis process [38]. The use of Excel in data analysis has several advantages, such as the ability to handle large amounts of data, perform calculations efficiently, and present data in an easily understood way using graphs and charts [39]. Furthermore, the use of objective data in presenting research findings helps draw meaningful conclusions.

4. Results

Given the homogeneity of homes in Qatar [40], the use of a cluster sampling plan [41] enabled the surveying of 10 different areas in Doha, with a total of 50 homes physically surveyed from these areas, resulting in a total sample of 1068 similar homes in the same street or compound, as shown in Table 2. This sample size is considered larger than the typically required sample of 384 from the total population of 365,000, ensuring a statistically representative sample [42].

Table 2. Areas and number of houses surveyed.

Surveyed House Area	Number	Similar Houses in the Street or Compound
Al-Kheesa	20	700
Al Waab	10	240
The Pearl-Qatar	4	25
Al Waab	3	20
Musheireb	3	20
Al Sadd	3	20
Abu Hamour	2	13
Ain Khaled	2	12
Lusail	1	8
Al-Hilal	2	10
Total	50	1068

Table 3 summarizes the survey results.

Table 3. Survey results.

Survey Item	Outcome				
Average number of bedrooms per house	4				
Average total roof area [m^2]	244				
Average remaining total roof area [m^2]	144				
Average house height [m]	9				
Use of roof for recreational purposes	Yes 10%		No 90%		
Possibility for shading	Yes 30%		No 70%		
Type of house roof	Flat roof 100%	Gable roof 0%		Bonnet roof 0%	
Items on the roof	External AC units 80%	Satellite dishes 80%	Water tank 100%	Storage shed (box) 10%	Solar panel for water heating 20%

The survey findings indicate that the majority of homes in the area are relatively spacious, with 40% being five-bedroom homes and 20% being four-bedroom homes. The remaining 40% comprise three- and two-bedroom homes. The average total size of the homes is 244 square meters, which is quite substantial.

Regarding the features on the roofs of these homes, all houses have water tanks, and a significant majority (80%) have external AC units and satellite dishes installed. However, storage sheds are less common, present on only 10% of houses, and solar panels for water heating are found on 20% of homes.

Approximately 59% of the roof space remains empty after accounting for the mentioned items, suggesting that over 50% of houses have enough available space to potentially accommodate solar panel installations.

Furthermore, it appears that roofs are rarely used for recreational purposes, with 90% of respondents confirming that their roofs are not utilized for any other activities, likely due to the hot climate and modern indoor lifestyles. This means that if solar panels were installed on the roofs, they would not interfere with daily activities in the homes.

An important consideration for solar panel installation is the roof orientation. Fortunately, all the roofs in the area are flat, making them suitable for solar panel placement to maximize energy generation.

Moreover, the majority of houses have a height ranging from 7 to 10 m, with an average height of 9 m. This height distribution indicates that there is a low likelihood of shading or obstruction of sunlight, which is favorable for solar energy generation.

Finally, the survey revealed that 70% of surveyed houses do not have nearby buildings, trees, or other objects that may cause shading, while 30% reported potential shading issues. Overall, these results demonstrate a high potential for solar PV installation in the area to generate an optimal amount of clean energy.

5. Discussion

The presented results indicate that Qatari homes are highly germane to the installation of solar panels due to their relatively large area and spaciousness. The study found that 50% or more of the roof space is available for solar panel installation without interfering with the daily activities of the homeowners. This is in line with a previous study, which reported that most Qatari homes have spacious rooftops with significant potential for solar panel installation [43]. Moreover, the study found that there are limited problems caused by shading from trees or tall neighboring structures. This is because most Qatari homes are of similar height in wholly residential neighborhoods; thus, they are not typically in proximity to obstructions that could otherwise block sunlight, as reported by the homeowners. However, if there is latent shading, solar panels can be installed in locations that provide a minimum degree of shading and the best sun view. This is consistent with the findings of a study [43], which indicated that shading can be minimized by choosing the best location for solar panel installation. Additionally, solar PV arrays can themselves be used as shading devices, thus reducing direct solar heat gain by homes (while having unimpeded exposure to sunlight for power generation) and thus reducing the latent energy demand required for cooling [44].

The study also discovered that the prevalence of flat roofs on Qatari homes offers several benefits for solar panel installation, as depicted in Figure 5. These flat roofs offer easy access for technicians during installation and allow for the adjustment of panel orientation to maximize energy generation, a crucial factor impacting performance. Moreover, flat roofs support the use of automatic platforms for sun tracking, significantly enhancing energy generation—unlike angled roofs, which have limitations in this regard. Tracking systems can boost energy production by up to 25%, a valuable advantage, particularly in regions with high solar irradiance like Qatar [45,46].

Furthermore, the high similarities between homes in Qatar [40], as shown in Figure 6, enable the establishment of an easy strategy for technical teams to replicate the installation design in similar homes, which can reduce time costs and achieve the intended deployments within a realistic timescale. The similarities between homes can make it easier for homeowners to make the decision to install solar panels, as they can see examples of installations on homes similar to theirs, and installers will become highly proficient in installing required arrays and equipment in similar types of structures. This is in line with previous research on the benefits of standardization in building design for renewable energy adoption. For example, a study [47] found that standardizing building design can facilitate the integration of renewable energy systems, particularly in residential buildings. Another study [47] found that standardizing building design can reduce the cost of renewable energy systems by streamlining the installation process.

Figure 5. Example of a surveyed home roof.

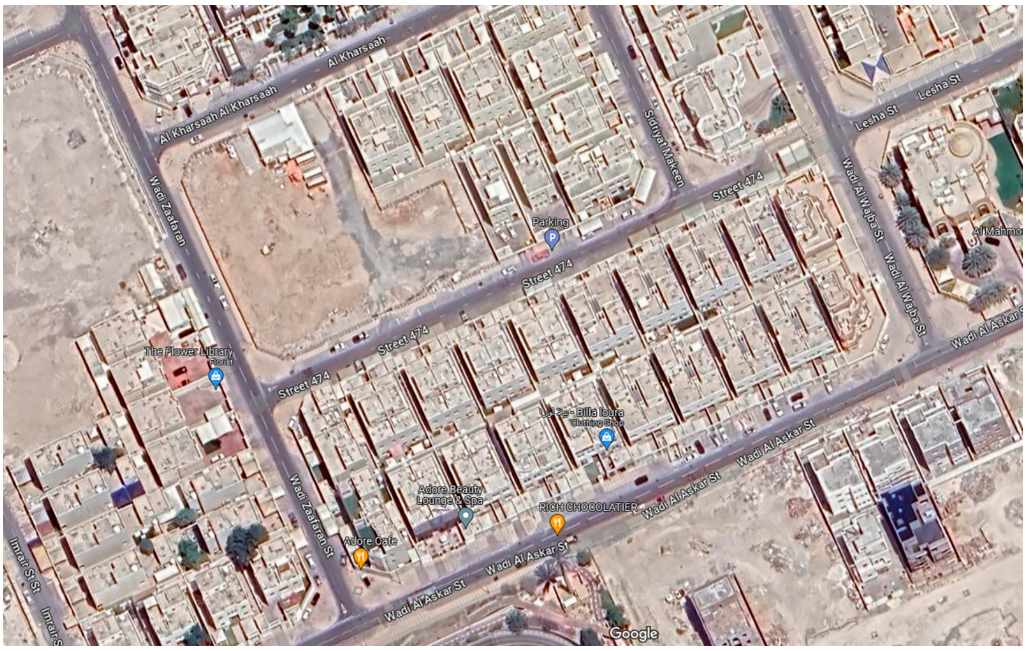

Figure 6. Example of structural homogeneity of Qatari homes.

The outcomes from this study complement previous research conducted by the authors, aimed at establishing the analytical feasibility of deploying solar panels on Qatar's houses [2]. The primary objective was to calculate various solar panel deployment scenarios using analytical methods, considering different panel sizes, efficiency, and daily sun exposure. These scenarios were then compared to estimate the generated energy and its comparison with actual consumption over a twelve month period. The findings revealed the most viable scenarios that enable homes in Qatar to sufficiently generate solar energy to cover their consumption. Moreover, there is a high possibility that surplus energy generated during the low season can be exported to areas experiencing high energy demands, such as the Western world. This potential not only benefits Qatar but also supports global efforts towards transitioning to clean energy, providing a valuable solution for energy crises [48].

Hence, the findings of this study support the potential for solar panel installation on Qatari homes. With their spaciousness, limited shading, and flat roofs, Qatari homes are ideally suited for solar panel installation. This aligns with the Qatari government's ambitious goal of generating 200 MW of solar energy by 2022 [49]. By encouraging and facilitating the installation of solar panels on homes, Qatar can move towards a more sustainable future. This should begin with pilot projects involving the installation of solar panels on real homes to gather actual information on their performance, taking into account factors such as solar radiation, temperature, and dust that might reduce generation potential. This is essential to ensure optimal and sustainable performance [50].

6. Conclusions

The study has successfully achieved its primary objective of assessing the suitability of Qatari homes for solar panel installation. The obtained results are highly promising and offer significant value to various stakeholders involved in decision-making regarding the deployment of solar panels in residential areas. Furthermore, these findings hold invaluable importance for the parties responsible for the deployment, as they can utilize them to develop a comprehensive national strategy for replicating the deployment plan in different regions, considering the high similarities observed among homes in Qatar. These findings also complement and align with past research efforts conducted using analytical means.

However, to draw a definitive conclusion, it is recommended to conduct real pilot projects involving the installation of solar panels on actual homes and gather additional information on their performance in situ. This should include aspects like solar radiation, temperature, air quality (as dust can reduce generation potential), connectivity with the main grid, storage, and all relevant variables. Such an approach will yield crucial insights into potential challenges that may arise during installation and usage, thereby enabling the formulation of practical solutions based on user experiences and operational evidence.

Despite the potential difficulties that may arise, the positive outcomes of this study indicate a promising future for solar panel installation on Qatari homes. By implementing such initiatives, Qatari households can effectively reduce their carbon footprint and contribute to the creation of a greener and more sustainable environment for future generations. This will undoubtedly play a significant role in Qatar's commitment to clean energy and global efforts towards combating climate change.

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