Towards Solar Panels for Qatar Homes: Challenges, Feasibility Assessment, and Proposed Data Driven Framework for Deployment, Performance Monitoring, and Energy Management

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

by

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Abstract

Despite Qatar's obvious massive latent solar power potential, panel deployment has primarily occurred in major plants, with negligible residential deployment in homes, despite inherent advantages and government subsidies. Therefore, this research explores reasons behind the low deployment of solar panels, conducts a feasibility study, and recommends a deployment framework to encourage solar panel adoption within Qatar. This initiative aims to contribute to the country's transformation towards clean energy, and align with Qatar's National Vision 2030, as well as global efforts to reduce carbon emissions.

Following an initial review of related literature, challenges facing solar panel deployment in Qatar were identified, followed by an analytical feasibility study to assess different scenarios involving varying numbers of panels with different efficiencies. This analysis compared the generated energy against typical home consumption and explored the feasibility of selling surplus energy locally or internationally during periods of low consumption. Subsequently, a field survey was conducted in Qatari homes to determine the practicability of solar panel rooftop installation. This led to the development of a data-driven model to enable dynamic decision-making for monitoring and efficiently managing and maintaining deployed solar panels, ensuring sustainable energy generation.

The research outcomes demonstrated a high potential for deploying solar panels within Qatar using medium or high-efficiency panels, which could meet local energy needs and potentially export surplus energy. Furthermore, Qatari house roofs were found to have approximately 50 percent of available space, with good accessibility and orientation for maximising energy generation.

The data-driven model proved to be instrumental in monitoring dust accumulation, planning cleaning operations, and tracking energy degradation due to panel aging, among other data requirements for analysis, forecasting, and management purposes. Integration with the proposed deployment framework provides stakeholders with a clear roadmap to achieve their clean energy goals and facilitate the transition towards cleaner energy sources.

Declaration

“I declare that the research in this thesis is the author’s work and submitted for the first time to the Post Graduate Research Office at Brunel University London. The study was originated, composed and reviewed by the mentioned author in the Department of Electronic and Computer Engineering, College of Engineering, Design and Physical Sciences, Brunel University London, UK. All information derived from other works has been referenced and acknowledged.”

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List of Abbreviations

A/C	Air conditioning
ANN	Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANOVA	Analysis of variance
BI2U	Behavioural intention to use
BIPV	Building-integrated photovoltaic
CSR	Corporate social responsibility
DD-DM	Data-driven decision-making
DDM	Data-driven model
DPBP	Discounted payback period
EEI	Energy Efficiency Index
FIT	Feed-in tariff
GCC	Gulf Cooperation Council
GHG	Greenhouse gas
GHI	Global horizontal irradiance
$\mathbf{G_{to}C}$	Generated-to-consumed energy ratio
HPE	High panel efficiency
HPN	High panel number
IES	Integrated Energy System
IWSN	Intelligent Wireless Sensor Network
KAHRAMAA	Qatar General Electricity & Water Corporation
LPE	Low panel efficiency
LPN	Low panel number
MENA	Middle East and North Africa
MPE	Medium panel efficiency
MPN	Medium panel number
MSE	Mean squared error
NPC	Net present cost
O&G	Oil and gas
PDSA	Plan–Do–Study–Act

PEoU	Perceived ease-of-use
PU	Perceived usefulness
PV	Photovoltaic
PV-ESS	Photovoltaic energy storage system
RE	Renewable energy
RES	Renewable energy source
ROI	Return on investment
SD	Standard deviation
SP	Solar panel
SPV	Solar photovoltaic
TAM	Technology Acceptance Model
UTCI	Universal Thermal Comfort Index

CHAPTER 1
INTRODUCTION

1.1. Background

The peninsula of Qatar in Eastern Arabia is bordered by the Persian Gulf and Saudi Arabia. The region lies between the latitudes 24° N and 27° N and the longitudes 50° E and 52° E. Low, barren plains are covered with dunes and salt flats throughout the country (Zainaa *et al*., 2021). Qatar has an arid climate, high summer temperatures (>40 °C), low summer humidity, low rainfall (annual average 71 mm) with a high evaporation rate (average yearly 2200 mm), and low soil fertility. During the brief winter, the weather I conversely has low temperatures and high humidity. A high temperature of 32.6 °C is moderate, and a low temperature of 21.4°C (Zainaa *et al*., 2021). Qatar’s traditionally challenging weather presents an amazing opportunity to place Qatar among the leading providers of clean energy, using photovoltaic (PV) technology. As can be seen from Figure 1.1, Qatar is blessed with massive amounts of solar exposure throughout the year, ranging from a low of 10:37 h per day for December to the highest of 13:45 h in June. With the proper solar photovoltaic (SPV) technology, Qatar can guarantee sustainable and clean energy from solar panels (SPs) throughout the year (World Data, 2024).

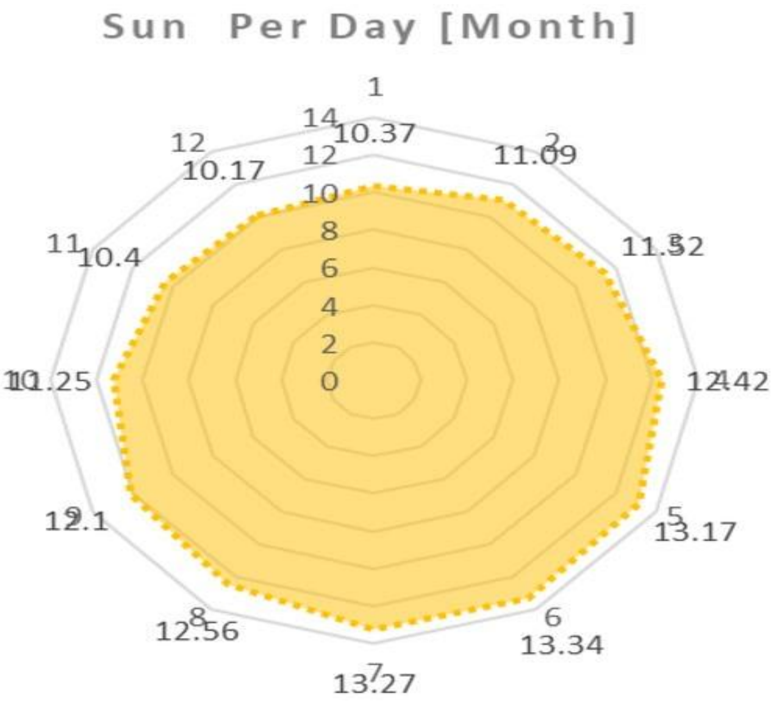


Figure 1.1: Average sun hours per month in Qatar

Source: Banibaqash, Hunaiti and Abbod (2022)

Qatar is committed to achieving its national development roadmap, 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 (Zainaa *et al.*, 2021). Given the country's geographical 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 SPV arrays. Nevertheless, Qatar has already taken significant steps towards achieving its vision of clean energy, and has invested heavily in SP farms, such as the 800 MW Al-Kharsaah Solar Power Plant, which is expected to power around 10% of the country's energy needs (Torcellini and Crawley, 2006).

These farms are a critical component of Qatar's clean energy strategy, but more can be done. 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 and Water Corporation (KAHRAMAA, 2022), accounting for 38,284,270 MWh out the total of electricity generated nationally per year (Figure 1.2) (KAHRAMAA, 2022). This means that residential buildings can potentially play a major role in the transformation towards clean energy and achieve milestones towards net-zero national target. However, at the current juncture, there is still limited progress in deploying SPs on homes roofs, despite the country's high levels of sunshine and the potential benefits that such installations can bring .

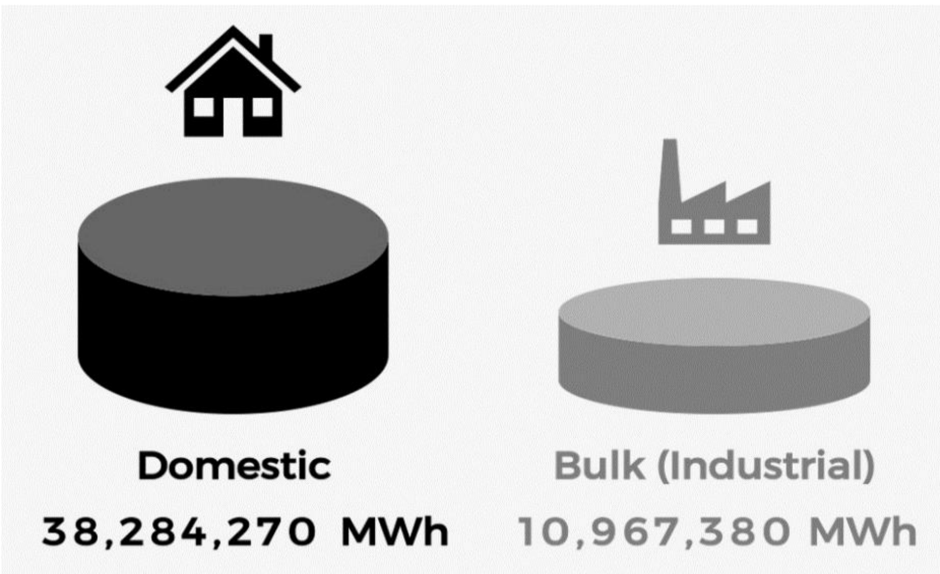


Figure 1.2: Domestic energy consumption

Source: KAHRAMAA (2022)

Deploying SPs on homes roofs can contribute to the country's clean energy goals by creating a distributed network of clean energy production. This can help to reduce the country's dependence on fossil fuels (and cannibalisation of the main national exports), lower carbon emissions, and create a more resilient energy system (Zainaa *et al*., 2021). However, further research is needed to identify the potential for this initiative and its impact on the country's move towards clean energy. By conducting such research, stakeholders can better understand the potential of SPs on residential roofs and develop strategies to accelerate and optimise their deployment.

1.2. Aim

This study's aim is to determine the feasibility and possible barriers to residential SPV deployment in Qatar, and to offer a data-driven decision-making model to drive the national clean energy transformation.

1.3. Objectives

To achieve the above aim, the research has been divided into six objectives, specifically to:

1. Conduct a comprehensive background and literature review.
2. Identify challenges facing SP energy deployment within Qatari houses.
3. To perform an analytical feasibility study for SP installation in Qatar.
4. Perform a feasibility survey to assess the potential of Qatari house roofs for SP installations.
5. Develop a data-driven model (DDM) to facilitate decision making on SP systems.
6. Propose a framework to foster SP deployment on Qatari house roofs.

1.4. PhD Research Project Design and Methodology

This research is falling under interdisciplinary research methodology, because simply it involves different elements of research. Where in short, interdisciplinary research is a mode of research by groups or individuals that combines information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge in order to advance fundamental understanding or solve problems that are beyond the scope of a single discipline or area of research practise. Furthermore, the value of interdisciplinary research comes from integrating different disciplines and programmes, where vital research ideas normally transcend the scope of a single discipline (National Research Council, 2004). Therefore, the following steps were designed to achieve the study objectives.

Step 1: A narrative review to explore previous research and establish the study's contextual framing.

Step 2: A quantitative questionnaire to discern stakeholder-identified residential solar deployment barriers in Qatar.

Step 3: A mathematical feasibility study to analyse SP technical implementation and potential in Qatar.

Step 4: A field survey feasibility survey with interviews of residents in Qatar to determine practical demand and potential for rooftop SP installations.

Step 5: Cyclical information system development was undertaken to develop the DDM for SP system decisions.

Step 6: Developing a framework based on change theory to kickstart SP implementation, evaluated using the "Technology Acceptance Model" (TAM).

Details about each particular step's associated methodology are presented within the respective thesis chapters.

1.5. Contributions to Knowledge

1.5.1. General

This PhD project provides contributions to knowledge in various forms, as explained below.

The outcome of the literature review identified gaps in knowledge, particularly in the area of SP deployment in homes in Qatar. Therefore, the findings from this research have been instrumental in filling these gaps, particularly in the context of Qatar. These findings can also be applied to similar climates in other states and countries.

The findings from the analytical feasibility study provide valuable information that can benefit other researchers and stakeholders to get insight on different deployment scenarios and can be useful for academic purposes.

The results of the field survey on Qatari house roofs will be essential for establishing realistic and pragmatic strategies for the practical deployment of SPs. They will also contribute to developing strategic plans for deploying SPs within homes, thereby making significant strides towards achieving national targets for reducing carbon emissions and transitioning to cleaner energy sources.

The proposed DDM offers a practical methodology for monitoring and managing home SP systems to ensure sustainable clean energy generation. This model can also be applied to other renewable energy (RE) platforms, providing practical mechanisms for monitoring and sustaining clean energy generation. Other researchers can further develop this model to establish artificial intelligence-based systems for RE systems.

The proposed framework serves as a realistic roadmap for overcoming challenges and driving SP deployment in Qatar. Additionally, it holds value for other countries within the Gulf Cooperation Council (GCC), the Middle East and North Africa (MENA), and globally.

Furthermore, the research outcomes have been disseminated to the public through various publications, which can be highly beneficial for other researchers and stakeholder.

1.5.2. Publications

1. **Banibaqash, A**., Hunaiti, Z. and Abbod, M. (2022) ‘An analytical feasibility study for solar panel installation in Qatar based on generated to consumed electrical energy indicator’, *Energies*, 15(24), p. 9270. Available at: https://doi.org/10.3390/en15249270.

2. **Banibaqash, A.,** Hunaiti, Z. and Abbod, M. (2023) 'Challenges facing solar panel energy deployment within Qatari homes and businesses', *Advances in Science, Technology and Engineering Systems Journal*, 8(2), pp. 38-43. Available at: https://doi.org/10.25046/aj080205.

3. **Banibaqash, A**., Hunaiti, Z. and Abbod, M. (2023) ‘Assessing the potential of Qatari house roofs for solar panel installations: A feasibility survey’, *Solar*, 3(4), pp. 650-662. Available at: https://doi.org/10.3390/solar3040035.

1.6. Thesis Structure

This PhD thesis is structured into eight chapters. Each chapter will cover the following:

- **Chapter 1:** Introduction

Provides an overview of the thesis.

- **Chapter 2:** Background and Literature Review

Identifies and explores challenges to SP deployment within Qatari houses.

- **Chapter 3:** Challenges Facing SP Energy Deployment Within Qatari Houses

Presents the findings derived from the study, aimed at understanding the real lived and practical challenges faced in implementing SP energy solutions in Qatari residential settings.

- **Chapter 4:** Analytical Feasibility Study for SP Installation in Qatar Based on Generated to Consumed Electrical Energy Indicator

Present the mathematical analyses to assess the feasibility of deploying SPs in Qatar and explores opportunities for exporting excess energy.

- **Chapter 5:** Assessing the Potential of Qatari House Roofs for SP Installations: A Feasibility Survey

Presents the outcomes obtained from a field survey conducted on Qatari houses to determine the feasibility of installing SPs on rooftops.

- **Chapter 6:** Solar System Performance Data-Driven Model: Assessing the Impact of Dust Accumulation and Panel Efficiency Degradation Over Time

Proposes a DDM to aid decision-making in managing SP systems efficiently, including performance evaluation, feedback mechanisms, and maintenance considerations.

- **Chapter 7:** DRIVE Framework for Fostering SP Deployment on Qatari House Roofs

Introduces a framework designed to facilitate the adoption and integration of SPs into Qatari houses, providing guidance and strategies for stakeholders.

- **Chapter 8:** Conclusions and Recommendations

Presents the thesis conclusion, outlines the limitations of the research, and offers recommendations for future studies and practical applications.

CHAPTER 2
BACKGROUND AND LITERATURE REVIEW

2.1. Introduction

This chapter presents the background and literature review to achieve the second objective of the research or project. The following section explains the chapter methodology, and then an overview of challenges facing RE deployment in Qatar is provided. Subsequently, 19 major studies pertaining to Qatar identified by the literature search are reviewed, pertaining to challenges facing the deployment of RE. Subsequently, methods for monitoring the performance of home SPs are explored, and current challenges in decision-making within the RE industry are identified.

2.2. Chapter Methodology

To achieve the objectives of this chapter, the narrative or traditional review methodology as described by Mitchell and Egudo (2003) was employed. This approach facilitated a comprehensive critical analysis of current knowledge and relevant literature pertaining to the topic, which constituted an essential part of the research process. It aimed to develop a thorough understanding of the research area, identify patterns, and discern trends to pinpoint gaps in knowledge. This, in turn, provided a clear focus for the research endeavour, and it was imperative to delineate the scope of the review from the outset.

As illustrated in Figure 2.1; the initial step in this project involved identifying the challenges confronting RE in Qatar, supplemented by insights from other studies within the GCC region. Subsequently, attention shifted to the primary focus of this review: examining relevant studies concerning SP technology specifically within Qatar, with additional insights drawn from studies across the GCC. Following this, the review delved into the mechanisms for monitoring energy generated by SPs, with particular emphasis placed on employing a data-driven approach to facilitate informed decision-making.

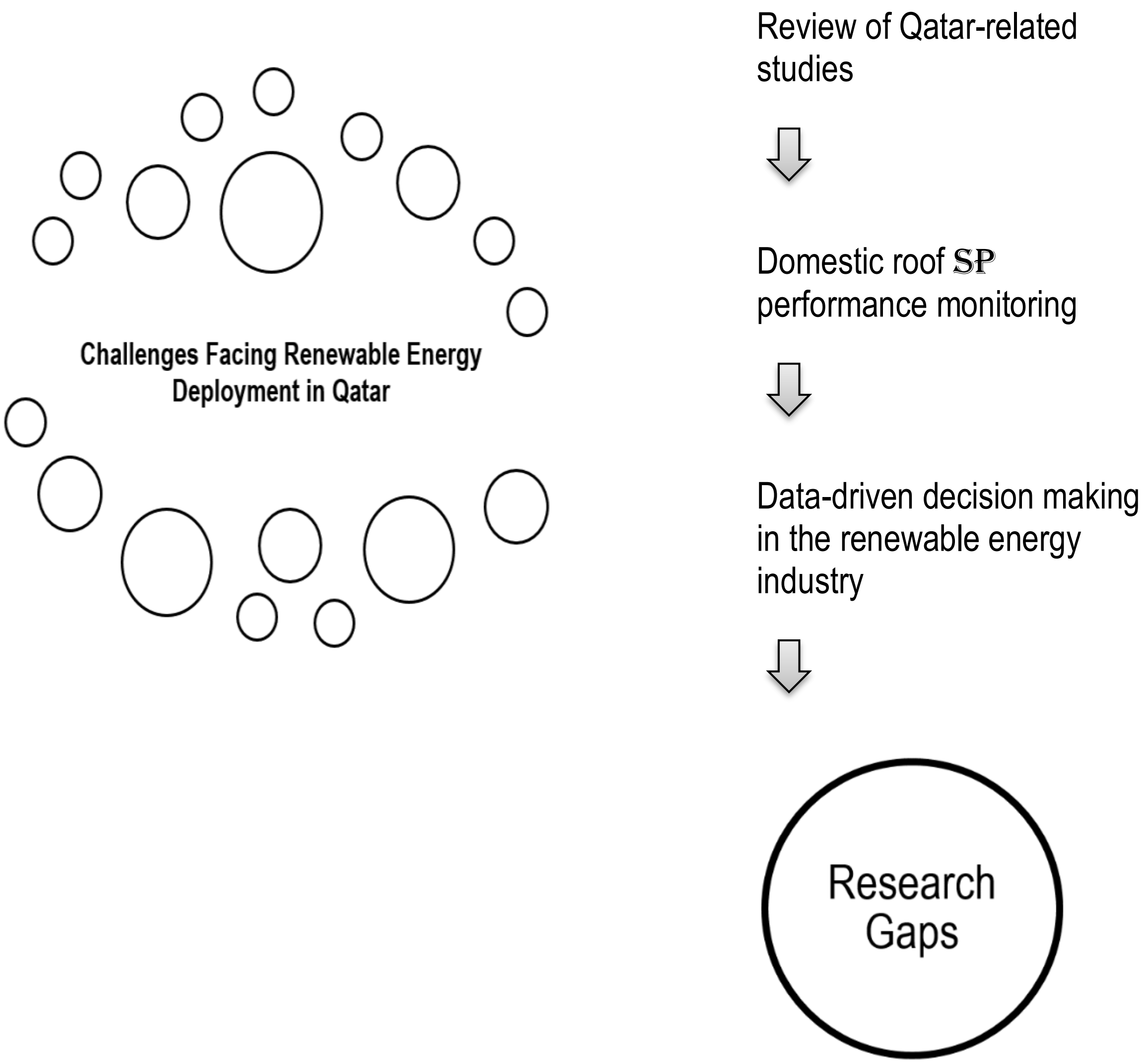


Figure 2.1: Plan for background research and literature review

Source: Author

2.3. Challenges Facing Renewable Energy Deployment Within Qatar

Despite many factors conducive to renewable energy (RE) investment in Qatar (e.g., the fact that the state is a major gas exporter whose long-term prosperity depends on economic diversification), there is very low uptake of SP adoption among home and business owners. Major challenges implicitly face the deployment of solar and other renewables in Qatar. This section summarises possible challenges delaying the development of RE in general and solar energy within the GCC and in particular at Qatar, based on analysing eight notable studies.

The first study comprised an up-to-date assessment of GCC solar energy efforts and listed some recommendations for the following key challenges as; technical challenges, lack of public/private initiatives, dependency on oil and gas (O&G), lack of research and development capabilities, lack of legislation and regulatory framework, and inadequate application of building integrated RE technology (Mas'ud *et al*., 2018).

The second study examined issues affecting residential rooftop SP adoption in Qatar, analysing public levels of awareness and knowledge towards domestic solar systems. The study reported that there was latent acceptance among the general population for using solar energy, but government initiatives were needed to improve awareness, reduce electricity price subsidies, and increase subsidies for solar energy installations (Alrawi *et al*., 2022).

The third study aimed to look at present situation of pollution and RE in Saudi Arabia as per the national development plan, Vision 2030, which seeks to expand RE use and to present possible obstacles facing the deployment of solar and wind energy. It identified the following major barriers to solar energy use:

- **Environmental Challenges:** Effect of high temperature on performance of solar system, power loss due to UV rate, effect of humidity on SP performance, degradation of performance due to dust, possible damage to SPs due to dust storms, strong winds, and heavy rain.
- **Economics/ Managerial Barriers:** Low price of natural gas, lack of legal and regulatory framework to support investors, low revenue from RE in comparison to oil, lack of education and training on RE, lack of specialised manpower and issues related to connecting generated renewable to the main grid (Al Zohbi and AlAmri, 2022).

The fourth study was conducted to assess the current electricity supply grid in Qatar and to explore the potential of incorporating different RE sources (RES) into the main grid. The study simulation results presented promising possibilities to increase the share of RES in electricity production by up to 80%. Reaching 100% would require the integration of electricity storage systems into the main grid, grid stability and electricity access, availability of significant funding for investment in installations, and effective awareness campaigns (Okonkwo *et al*., 2021).

The fifth study aimed to pinpoint the key gaps in the current system and the obstacles facing the development of RE technologies in Kuwait. The study highlighted that Kuwait is unlikely to meet the announced target of 15% of its local energy need from RE generated sources by 2030 due to a lack of effective legal and regulatory frameworks, a lack of support for RE infrastructure, and inadequate financing policies (Alsayegh, 2021).

The sixth study amid to statistically examine the challenges and requirements for RE implementation in the UAE from the opinions of 94 participants. The study found positive attitudes towards governmental efforts and RE infrastructure, and solid public awareness for achieving UAE 2050 RE goals (Al Shehhi *et al*., 2021).

The seventh study was conducted in Qatar, with an aim to experimentally examine the ecumenical loss due to the SPs environmental challenge associated with dust. The data from the study showed that without clearing SPs the output power would be reduced by 43% following six months of exposure to dust with average density of 0.7 mg/m^3, which leads to economic losses if panels remain uncleaned (Zeedan *et al*., 2021).

The eighth study aimed to answer the question of why there is “almost no RE in Oman” and argued that government subsidies for electricity produced from O&G resources are a key obstacle to RE technologies development in Oman (Al-Sarihi, 2017).

It can be summarised from the review of the challenges facing RE in the GCC fall within five interrelated key dimensions, as illustrated in Figure 2.2: technical issues related to the performance of SPs in the local environment (i.e., dust issues); government initiatives and policies; the low return on investment (ROI) from RE; low citizen awareness and willingness to adopt RE; and the availability of subsidised electrical energy generated from O&G (provided free or at very cheap prices). The key impetus to foster RE in these countries remains with governments; once the right regulations and initiatives are in place, other challenges will dissipate. Moreover, it can be also concluded that challenges related to monitoring the execution and sustainability of SP energy generation projects, to meet existing, emergent, and future national and global targets. Therefore, there is a need for further investigation, particularly given the dynamic nature of developments in RE technologies and the renewables industry in general in relation to increasing public and private sector interest.

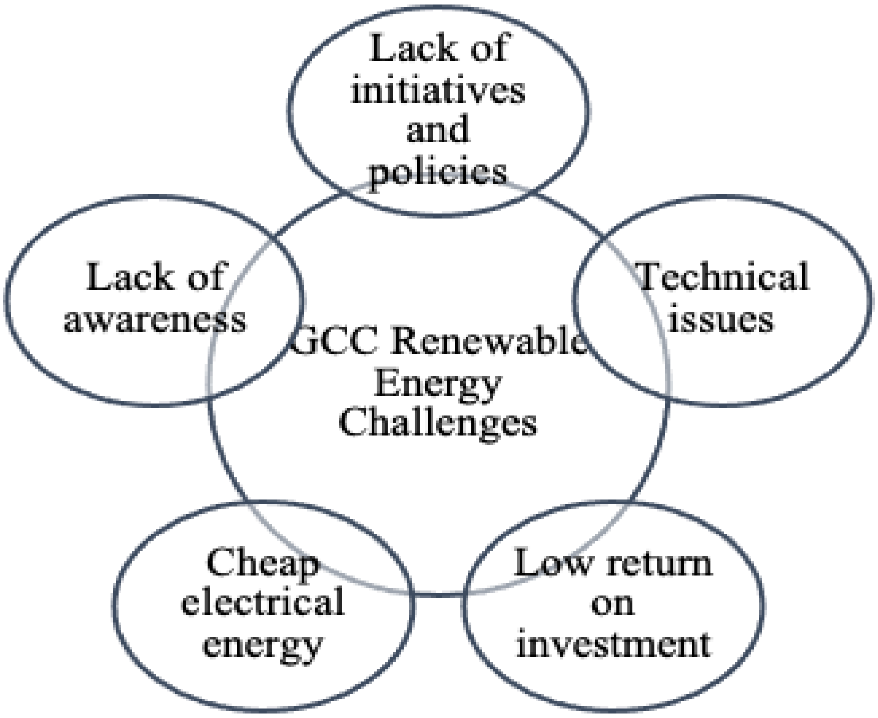


Figure 2.2: Five key challenges for RE in the GCC countries

Source: Author

2.4. Review of Studies Related to Qatar

2.4.1. Overview

Renewable energies are defined by the sustainable nature of sources of electrical energy – in other words, electricity obtained from natural resources that are not expected to run out. While wind and hydro energy are widely applied worldwide, the light of the sun is the most ubiquitous and potent of all natural sources used to generate electricity (Lewis, 2007). This can be seen via systems on rooftops on homes, which gather solar radiation to be used as energy to power electrical devices. Utilising such RE has become increasingly popular due to consumer and political pressure seeking to reduce greenhouse gas (GHG) emissions in order to mitigate global climate change and improve environmental health (Alrawi *et al*., 2022).

Renewable energies have shown their uses and benefits in mitigating the risks and hazards associated with climate change, and their use is seen as essential for sustainable socio-economic development. The sustainability paradigm seeks to enable achieving economic needs while not depleting natural resources for future generations (Kalogirou, 2004). The most significant (though not the only) benefit of RE such as solar energy is providing a carbon-neutral source of electricity to facilitate sustainable development with minimal environmental impacts. In this context, renewables can be considered to be "social energy", and solar energy is increasingly acknowledged to be an economically viable power source (Alrawi *et al*., 2022).

Switching to solar energy is potentially viable for developing and developed countries due to its benefits, economically sound nature, and major social impacts on many communities and the globe (Alrawi *et al*., 2022). Positive outcomes such as reduced GHG emissions, particularly carbon dioxide, is increasingly augmented by the more prosaic concern of savings on electricity bills. Now governments around the world are acknowledging the broad implications of such technologies, including Qatar, where the government has long sought to reorient economic activities on a more sustainable basis, with a reduced carbon footprint and positive contribution to climate change mitigation (Kamal, Al-Ghamdi and Koç, 2019). Many factors have influenced their need to reduce their carbon footprint. For example, in Qatar, energy security is a concern due to the demands of energy by its populace. Their production of power is approaching production capacity (Miller, 2020). However, there is limited literature concerning the use of SPV systems in Qatar. The most recent relevant research is reviewed below.

2.4.2. "Climate change implications for optimal sizing of residential rooftop solar photovoltaic systems in Qatar"

Rationale and Background

Khan et al. (2023) observe that residential use accounts for most energy consumption in Qatar, and the heat and aridity of the Peninsula are exacerbated by global warming, increasing the demand for AC cooling. This is ubiquitous across MENA, especially the GCC (International Energy Agency [IEA], 2021, 2022).

Aim

Focusing on villas, of which there are over 100 thousand in Qatar, Khan et al. (2023) explored global warming mitigation by carbon reduction using SPV, in relation to Vision 2030.

Methods Used

"Design Builder" was used for energy demand modelling relative to future climate scenarios. "HOMER Pro" was utilised to analyse financial and technological rooftop PV viability.

Outcomes

Higher Energy Demand for Cooling: Electricity demand per year in villas (i.e., family residences) could increase by over a fifth by the end of this century, with peak demand in midsummer being 26% greater than the current demand (Khan et al., 2023).

Lower SPV Yield: The amount of electricity that can be sourced from SPV installations would fall by 2% (to 16%) due to lower operational efficiency ascribed to atmospheric gases (reduced solar exposure) and increased temperatures (Khan et al., 2023).

Cost-Benefit Analysis: The high efficiency of rooftop SPV for the initial eight years of installation renders them a viable solution to offset increased demand for cooling (Khan et al., 2023).

Implications for Practice

Widespread adoption could help achieve Vision 2030 targets for reduced carbon (Khan et al., 2023). Policymakers should encourage residents to invest in SPV to mitigate global warming (IEA, 2021, 2022).

2.4.3. "Determining the influencing factors in the residential rooftop solar photovoltaic systems adoption: evidence from a survey in Qatar"

Rationale and Background

Alrawi et al. (2022) acknowledged the essential role of consumer acceptance in adopting SPV, and noted that economic and sustainability benefits are insufficient in themselves without public comprehension of the technological rationale.

Aim

To examine Qataris' public awareness of rooftop SPV systems and discern adoption drivers and barriers for residential application.

Methods Used

Using a survey method, the study ascertained residents' attitudes, awareness, experience, and behavioural intention to adopt residential SPV.

Outcomes

Low Awareness: There was low awareness of SPV potential. While only 5% expressed no comprehension whatsoever, only 16% considered that they fully comprehended residential solar use.

Interest and Use: 80% had never experienced solar systems in residences, but the same proportion were interested in their adoption.

Future Orientation: The vast majority (89%) thought that increased SPV in Qatar's energy portfolio would support national development goals.

Low Saving Motivation: Due to free or subsidised electricity, Qatari citisens are not inspired by electricity bill savings (unlike consumers in other countries where this is a key driver).

Implications for Practice

Public awareness can be increased by education campaigns, focusing on explaining compelling advantages of solar and moulding cultural acceptability.

Practical education and instruction on residential adoption, installation, and transition to SPV is necessary.

Albeit financial incentives are not applicable, SPV's function in improving sustainability and national development can foster grassroots buy-in for renewables (Alrawi *et al*., 2022).

2.4.4. "Economic viability of rooftop photovoltaic systems in the Middle East and Northern African countries"

Rationale and Background

The worldwide average residential cost of electricity is USD 0.13/kWh (IEA, 2019). However, Qatari residential uses only pay USD 0.049/kWh, as public subsidies are applied (Alrawi and Al-Ghamdi, 2020). The low cost of energy is conducive to high consumption of electricity, and nullifies the financial driver of SPV adoption that is instrumental in most countries worldwide.

Aim

The research sought to ascertain the extent to which subsidised, cheap electricity undermines SPV cost-effectiveness motivation, to consider policies to incentivise SPV installation in homes.

Methods Used

The study did not mention a particular model or survey method, but it apparently synthesised publicly available data (e.g., electricity prices) to formulate recommendations for residential PV adoption-related policy in Qatar.

Outcomes

Electricity Subsidy Barrier: The cheapness of electrical energy disincentivises residents from "investing" in SPV, as it does not provide a compelling return on investment.

Policy Suggestions: The researchers indicate that policy interventions could potentially make PV installations more cost competitive, such as paying residents for feedback systems during peak hours, and increasing carbon prices for conventional electricity.

Implications for Practice

Recommended Policies: The study suggested carbon pricing or tax; gradually phasing out subsidies for electricity; and subsidising solar installation to promote adoption, alongside financially incentivising adopters.

Sustainable Transition: The authors claims that such solutions can facilitate a shift of residential energy use away from subsidised traditional energy toward sustainable RE alternatives like solar.

2.4.5. "Residential rooftop photovoltaic adoption using a sequential mixed methods approach in Qatar"

Rationale and Background

Alrawi and Al-Ghamdi (2023) also explored residential PV installation feasibility in Qatar, with a focus on policy facilitation, public demand and acceptance, and market perceptions. They also noted that Qatar still has massive public subsidy and various kinds of electricity payment structures, which influence residents' adoption attitudes toward REs.

Aim

The research sought to develop an all-encompassing PV adoption framework for Qatari homes, analysing public awareness and attitudes toward related technologies and market factors, along with the policy framework pertaining to SPV.

Methods Used

The researchers employed *sequential mixed methods*, comprising a quantitative general survey of public attitudes, and qualitative expert interviews and focus groups with public and private sector stakeholders to explore policy objectives.

Outcomes

From a total of 3,000 surveyed participants, the majority (52%) did not pay for electricity due to residential or employment subsidies and situations, while those who did pay bills expressed interest in minimising costs using SPV, and receiving subsidies or fiscal rebates.

Over half had some knowledge of SPV, of whom most thought that rooftop SPV arrays were desirable purchases. However, over a third (35%) had negligible knowledge of SPV.

Adoption barriers included rental agreements and short-term leases, and other factors precluding SPV installation, the current absence of bills, and the high upfront installation cost of SPV. SPV was generally regarded as user-friendly and beneficent.

Implications for Practice

It is recommended to incentivise SPV adoption, such as through subsidies or fiscal rebates, and to particularly encourage commercial adoption to spearhead the development of installation infrastructure. Regulation can be developed to support solar development, and sustainable national development can be addressed by financial incentives (e.g., RE subsidies or fiscal rebates), with supportive regulations for rooftop installations. It is essential for Qatar's sustainable development to increase awareness and financially encourage residential SPV (Alrawi and Al-Ghamdi, 2023).

2.4.6. "Cost benefit analysis of a net-zero energy housing in Qatar"

Rationale and Background

Gowid, Musharavati and Hamouda (2019) explored net zero residential potential in Qatar in terms of environmental and financial implications, given that national per capita energy use is so high compared to global norms (at 34,000 kWh/year for residential villas).

Aim

The research sought to explore economic implications and viability of residential net zero designs for Qatari residential villas, with reduced conventional energy use, to ameliorate climate change and air pollution.

Methods Used

Gowid, Musharavati and Hamouda (2019) conducted an economic and environmental analysis of a 25-year window for scenarios testing solar energy (including to heat water, thermal insulation enhancement, and lifecycle costs, using *average electrical use* data for a representative average Qatari villa.

Outcomes

Financial Savings: Net zero residential designs could save QAR 299 per dwelling per year, representing QAR 21 million for Qatar's 70,320 villas.

Sustainability: A net zero transition using SPV and solar heating for water would significantly reduce energy use from oil, gas, and coal combustion, reducing healthcare costs.

Implications for Practice

The financial analysis indicates long-term economic benefits of net zero villar using SPV. Policymakers can use this to develop supportive regulations, helping attain national carbon reduction goals (Gowid, Musharavati and Hamouda, 2019).

2.4.7. "Energy storage sizing and photovoltaic self-consumption in selected households in Qatar"

Rationale and Background

Bayram and Koç (2017) analysed SPV use and electrical storage needs among four residential dwellings in Qatar, pioneering the use of precise and calibrated measurements in the GCC.

Aim

The research sought to identify capacity and needs for homes' use of their self-generated SPV power, considering low-, medium-, and high-income housing units and their yearly electricity use.

Methods Used

Electricity Use Profiling: monitors (Smappee) were set up in four studied dwellings, and they recorded usage over 11 months (July 2017 to June 2018).

Solar Irradiance (GHI): A dataset from Doha for one year of global horizontal Irradiance was utilised to model SPV contributions.

Dwellings (socio-economic status type): High-income large (n = 1), middle-income medium (n = 2), low-income small (n = 1).

Outcomes

The results using electricity usage data relative to GHI assays concerning storage and generation revealed the prevalence of low surplus and high consumption, mainly due to cooling demands. Medium villas could benefit from storage, while low-income small dwellings had some surplus that could potentially be sold back into the grid. Cooling demand during the summer was egregious (one dwelling consumed sevenfold more electrical energy in August compared to December).

Implications for Practice

Dwellings: Storage costs relate to dwelling electrical use and seasonal demand (with more feedback potential in the winter, when national demand is lower). Dwellings with continually great and unabating demand have little to gain from storage, while low-income housing could potentially benefit, due to more surplus, potentially helping mitigate dependence on the grid.

Planning and Policy: Low- and medium-income family units could potentially be targeted for interventions to improve storage and surplus harvesting. Consumption patterns by dwelling type must be used in planning for SPV to optimise electrical generation and use efficiency (Bayram and Koç, 2017).

2.4.8. “High-resolution electricity load profiles of selected houses in Qatar”

Rationale and Background

Alrawi, Bayram, and Koc (2018) analysed residential electricity use in Qatar with high-resolution data to determine the impacts of technological and demographic variables, based on the premise that A/C is the foremost reason for residences’ use of electrical energy in the country.

Aim

The research gathered data from 10 dwellings (reflecting varying socio-economic status levels) with Smappee monitors, to explore how villa size, socio-economic status, and A/C variety affect load profiles, especially in the summer.

Methods Used

Smappee monitors were set up in the studied dwellings’ main circuit panel, to log usage (including current and voltage data) every five minutes from July-November, 2017.

Outcomes

The result revealed the preponderance of A/C use for summer cooling load, with higher use by larger villas. Non-subsidised residential and split versus central A/C systems exhibited differing usage patterns.

Implications for Practice

Policymakers can attain greater efficiency by targeting larger homes. More research is needed to explore impacts of dwelling types and socio-economic variables on electricity consumption (Alrawi, Bayram, and Koc, 2018).

2.4.9. “A techno-economic study of rooftop grid-connected photovoltaic-energy storage systems in Qatar”

Rationale and Background

Elbeheiry *et al*. (2020) analysed the potential of residential “PV-energy storage systems (PV-ESS)” on Qatar’s roofs in relation to electrical subsidies and the poor financial rationale for SPV and storage installation in the country.

Aim

The study undertook a *technological and economic analysis* of residential PV-ESS utilisation in Qatar, considering tactics for controlling loads and optimising multiple objectives for cost-effectiveness and efficiency.

Methods Used

Multiple Objective Optimisation: Including load and generation profiles, expenses of grid consumption, and network costs.

Pareto frontier plots were used to compare capital and expense considerations.

Load Modulation Strategies: Tactics to minimise or alter demand were tested, to reduce initial and long-term costs.

Outcomes

Financial Viability: PV-ESS cannot compete on cost grounds due to subsidised mains electricity in Qatar, failing to offer a compelling ROI. Electrical costs would have to expand exponentially (10x) to render PB-ESS competitive.

Implementation Roadmap: The researchers identified sizing, cost, and load management steps to make PV-ESS more appealing and realistic.

Implications for Practice

A price escalator (e.g., gradually increasing the cost of grid electricity while subsidising PV-ESS) could render SPV more appealing in terms of ROI (Elbeheiry *et al*., 2020).

2.4.10. "The feasibility of using rooftop solar PV fed to the grid for Khalifa Town houses in the Kingdom of Bahrain"

Rationale and Background

EzzEldin *et al*. (2022) analysed SPV installation potential in Khalifa Town (Bahrain), including modern architecture and urban planning pertinent to rooftop installation in Qatar. The increasing heat and energy demand of GCC states warrants exploration of rooftop SPV to meet cooling needs and mitigate global warming.

Aim

The research sought to determine financial and technological scope to install 17 kW PV panels on Khalifa Town's villas, and determine harvesting potential and economic and environmental outcomes.

Methods Used

AutoCAD was used to plot the practical area of rooftop for SPV modelling (expedient for residents' needs), and *PVsyst* software was used for simulations of electrical generation. ROI was evaluated for differing electrical prices, along with carbon reductions.

Outcomes

17 kW PV installations on residential units could produce *44,953 MWh* annually, meeting almost half (*43%*) of Khalifa Town's demand. This would reduce annual carbon emissions by *34,794 tonnes*, comprising over a fifth (*21%*) of current net emissions from the Town. This would cost *USD ¢7.5 per kWh*, resulting in a payback (ROI) of almost a decade (*9.6 years*), which could be shortened with a *feed-in tariff (FIT)* policy .

Implications for Practice

FIT payments can drive adoption, and future residential developments can pre-emptively include rooftop SPV while enabling conventional space usage. Residential SPV van seriously reduce carbon emissions (EzzEldin *et al*., 2022).

2.4.11. "Impact of climate change on solar monofacial and bifacial photovoltaics potential in Qatar"

Rationale and Background

Tahir, Baloch, and Al-Ghamdi (2022) analysed the impacts of climate change on solar mono-facial and bifacial PV potential in Qatar.

Aim

The study compared the performance of mono-facial and bifacial PVs and their dependence on climate conditions. It also also analysed the performance of bifacial PV for climate change scenarios.

Methods Used

The study developed mathematical models of mono-facial and bifacial PVs are developed to estimate PV output. The study used ambient conditions for 2050 and 2080 for the model and analysed average hourly responses of solar irradiance and energy production. Doha was used as the reference location, while June was chosen as the month to study. CCWorldWeatherGen was used to collect data on surface air temperature and solar insolation for the years 2050 and 2080, based on a moderate global emissions scenario.

Outcomes

The study observed that ambient air temperature will increase hourly by 2080. On the other hand, solar irradiance is expected to decrease by 2050 and 2080. It was discovered that solar insolation would also decrease by 2050 and 2080.

Implications for Practice

Bifacial PV panels demonstrate an energy yield higher than that of mono-facial PV panels on an hourly basis, thus they ought to be prioritised in Qatar.

2.4.12. “Feasibility study of solar power system in residential area”

Rationale and Background

Abul Kashem *et al*. (2020) explored residential PV installations’ viability in relation to user convenience in Sekama, Kuching (Malaysia), considering climate and solar factors.

Aim

The study sought to determine practical and financial benefits of residential installations for homeowners, and to determine possible lifecycle costs and carbon reduction.

Methods Used

An *analytical* and *experimental* model were used, harvesting site information (e.g., energy consumption, gable structure, climate, and solar irradiance). Cost estimation was undertaken using data from local companies’ PV installations. Collated data was analysed to determine technical and financial efficiency.

Outcomes

Sekama receives sufficient sunlight to make residential SPV an intrinsically feasible option as a long-term investment, mainly due to reducing conventional electricity payments. Such replacements for conventional energy would significantly reduce lifecycle carbon emissions.

Implications for Practice

SPV is recommended for tropical climates with adequate irradiance, to drive national energy transition (Abul Kashem *et al*., 2020).

2.4.13. "Assessment of rooftop solar power generation to meet residential loads in the city of Neom, Saudi Arabia"

Rationale and Background

Alqahtani and Balta-Ozkan (2021) analysed rooftop SPV and battery potential in the Neom project in Saudi Arabia, seeking to explore ways to minimise conventional electricity use by determining the best battery options, system size, and PV orientation in varying types of dwelling.

Aim

The research sought to explore villas, heritage homes, and flats to help design specific models for the most technically and cost-effective SPV solutions, including with regard to battery and panel orientation.

Methods Used

HOMER Pro software was utilised for net present cost (NPC) calculation, with levelled energy cost, and ideal PV size and orientation. The PV system was investigated in terms of capacity (kW), monthly consumption, and battery storage (kWh).

Outcomes

The study determined the ideal system sizes for the studied unit types: 14.0 kW PV with 12 kWh battery for villas; 11.1 kW PV with 12 kWh battery for heritage housing; and 10.3 kW PV with 12 kWh battery for flats.

Economic Viability: Given the current electrical cost (*0.06 USD/kWh*) the studied systems are not financially attractive for the given consumption threshold (6000 kWh/month). However, increasing conventional electricity to *0.08 USD/kWh* would render the systems viable for all three dwelling types.

Implications for Practice

Increasing conventional electricity pricing could spur rooftop residential PV adoption in Neom, helping achieve sustainability goals and reducing carbon emissions (Alqahtani and Balta-Ozkan, 2021).

2.4.14. "Smart building-integrated photovoltaics (BIPV) for Qatar"

Rationale and Background

Mühlbauer (2017) analysed ways in which to integrate PV arrays in Qatari smart homes, relative to the architecture and climate of the country, and RE's cultural associations. It noted the barrier of subsidised electricity from the outset, and considered gentrification implications of using “building-integrated PV” (BIPV) to improve RE acceptability.

Aim

The research analysed *smart BIPV systems* for the hot arid climate, and the *socio-cultural appeal* of BIPV adoption relative to Qatari socio-cultural mores and values.

Methods Used

The proposed system incorporated SPV, energy management, and controls for smart homes in a BIPV topography to assess energy consumption reduction and APV adoption encouragement via IoT and monitoring technologies.

Outcomes

BIPV was found to be feasible to lower net consumption of electricity while providing ubiquitous and constant monitoring, aligned with increasing smart home consumer interest. While RE is increasingly desirable, BIPV is not necessarily ubiquitously attractive to Qatari homeowners, albeit associated social value can encourage adoption by some.

Implications for Practice

Smart BIPV can offer homeowners the chance to monitor and regulate their energy consumption while maximising comfort, and increase public awareness of SPV. BIPV products should be sensitive to prevailing climate and architectural expectations and conditions, aligned with socio-cultural values, in order to make SPV adoption attractive in contexts where cost competitiveness is weak due to subsidised electricity tariffs (Mühlbauer, 2017).

2.5. Domestic Roof SP Performance Monitoring

It is expected that the use of PV will have proliferated by the year 2050, providing an estimated 11% of electricity production worldwide, and reducing approximately 2.3 Gt of CO2 emissions per year. With that in mind, GCC countries have looked into this technology due to the high daylight and sunshine they receive (Touati *et al.*, 2016). Solar plants are located in desert lands or semi-arid areas due to the ease of access to sunlight as well as how abundant the sunlight is in those areas, making it suitable for SPs to work and provide clean energy. However, PV systems can have their proficiency reduced by several factors, ranging from obstructed sunlight due to soiling, to prolonged exposure to solar radiation itself (Zeedan *et al.*, 2021).

Touati *et al*. (2016) looked at the effect on commercial PV panels regarding their exposure to extreme Doha weather, in particular the soiling of panels (dust settlement). To this end, a cost-effective measurement system enhanced with wireless monitoring and data logging has been developed. This system is suited also for remote or unattended PV installations. The main outcome of this work is that the developed system can be deployed anywhere (or in a pilot study) to alert or recommend intervention (e.g., PV panel cleaning) when the efficiency drops below a given threshold, for any reason. This provides a way for these PV systems to be used efficiently when implemented in residential homes without losing their efficiency.

Thus, monitoring the performance of SPs is necessary to ensure the optimisation of the panels and that no damage has been sustained which can hinder them from being efficient. Due to this, effective techniques or equipment or procedures must be in place to monitor the technology to help quickly indemnify any issues with the technology before the issue worsens. This will help with maximised energy and reduce any maintenance costs that could increase if the issue worsens over time and is not dealt with quickly (Zhao *et al*., 2013). The issues that can face this type of technology can be categorised into two groups, as delineated by Bizzarri *et al*. (2015):

- “Soft failure” issues such as dust accumulating on the surface of the PV panel, or if the panel is covered by shade, thus only half of the panel is in contact with the sun (Bizzarri *et al*., 2015).
- “Hard failure” (also known as “catastrophic”) issues, such as cables being completely broken, blown fuses, or being disconnected from the electrical grid.

Hard failures are easy to identify as they quickly result in total loss of functionality, and they are thus seen almost immediately, and can be addressed quickly in most circumstances. However, soft failures take more time to be recognised, as their issues are not seen rapidly like hard failures. Soft failures can take a while before any issues are identified, and thus can gradually exert a more sustained negative impact on panels over a prolonged period.

Different monitoring systems have been made to monitor the performance of PV systems, whether on small-scale domestic roofs or major power plant. The main objective of monitoring in all cases is to identify any issues and issue warning signals automatically, which are delivered to maintenance or operational experts. However, it is important to note that false alarms can happen during the monitoring of PV system performance, which can make the entire monitoring system redundant (Bizzarri *et al*., 2015). This can happen when there is too much raw data, and the human experts are comparing them, which is not an approach that is viewed as beneficial. Functions used in monitoring systems such as figures of merits or aggregate efficiency indices are the preferred methods to measure the performance of the technology. Such methods present actual performance and in case of a breakdown from the technology, raise an alarm (Bizzarri *et al*., 2015).

Another method for monitoring PV systems used at homes is Enphase (n.d.), which allows homeowners to see information about the peak power or output power of the SP on their roof while measuring the energy consumption of the house and calculating the net energy. Moreover, it offers information on how this technology is helping the environment. For a more experimental model, Al-Nuaimi *et al*. (2018) examined the construction of inexpensive monitoring systems for residential solar systems online using laptops or phones. As a stand-alone system, the study's suggested solution reduces worker or human involvement and exposure to risks associated with PV monitoring systems.

Important performance-controlling characteristics of the PV system, including irradiance, ambient temperature, PV surface temperature, output power, battery charge level, and PV surface condition, may be monitored wirelessly and online. The goal is to provide the homeowner with an overall overview of the PV generator's health state, including any signs that indicate a system needs to be repaired if it changed completely To ensure a straightforward design, Al-Nuaimi *et al*. (2018) split the system into components and subsystems. The monitoring unit, the first subsystem, consists of sensors, a WiFi transceiver and an Arduino microcontroller. The components which are called sensors include detecting variables such as changes in ambient temperature, irradiance level, voltage, current, etc. A camera was also installed, offering homeowners visual monitoring into their panel by taking photos. This is seen as the monitoring component. Via a WiFi Arduino shield, any data and results found are sent wirelessly to a laptop or phone the homeowner has used to link their device to the monitoring system (Al-Nuaimi *et al*., 2018).

2.6. Data-Driven Decision-Making (DD-DM) in the RE Industry

As alluded to above, data plays a crucial role in solar decision making, providing valuable insights and evidence to support informed choices. DD-DM is the process of using objective data to inform business decisions, rather than relying on intuition or personal judgment. This approach has become increasingly important in modern business environments, where vast amounts of data are available from various sources such as social media, customer data, and reports (Chen and Zhao, 2012).

Research has shown that DD-DM leads to more accurate and effective outcomes (Davenport, 2014). By collecting and analysing relevant data, decision makers gain a deeper understanding of the underlying patterns, trends, and relationships within their domain. This empirical evidence enables them to make well-informed decisions that are grounded in objective information rather than subjective opinions or biases. Moreover, basing decisions on data minimises the risk of making erroneous judgments influenced by personal biases or gut feelings. Intuition alone may lead to flawed conclusions, as cognitive biases can cloud judgment and lead to suboptimal outcomes (Kahneman, 2011).

Relying solely on intuition may result in subjective decisions that lack a solid foundation in empirical evidence. As illustrated in Figure 2.3, benefits of DD-DM include valuable insights, continual growth, improved program outcomes, optimised operations, prediction of future trends, and actionable insights (Smith, Johnson and Anderson, 2020). One of the key advantages of DD-DM is its ability to uncover patterns and trends that may not be immediately apparent through other means. Data analysis enables the identification of correlations between different segments, allowing for tailored strategies for different groups (Davenport and Harris, 2007). Additionally, DD-DM helps organisations mitigate the risk of errors or bias that can arise when decisions are based solely on subjective judgment. By relying on objective data, businesses can minimise the potential for decision-making errors and ensure that they make the best choices possible with the information at hand (Kudyba, 2011).

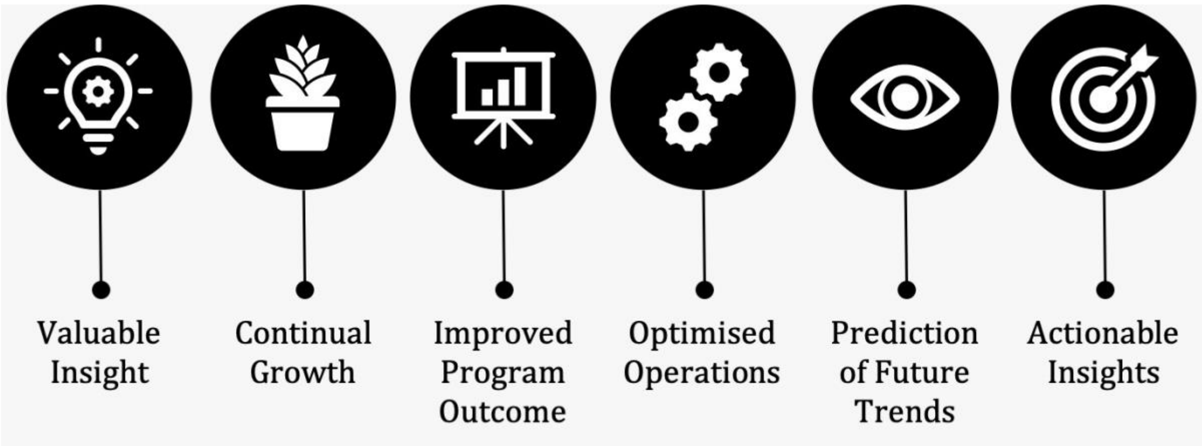


Figure 2.3: Benefits of data-driven decision making

Source: Author

Hence, decision makers across various fields and industries recognise the significance of relying on data-driven approaches to enhance their decision-making processes (Davenport, 2014). DD-DM in the RE industry has been widely recognised for its significant role in improving planning, optimisation, and management of RE resources (Ahmad *et al.*, 2022). By utilising data and advanced analytics, decision makers can gain valuable insights to support informed choices and drive the transition towards a sustainable and clean energy future.

Moreover, RE industry, like other organisations, implementing data-driven decision support systems can greatly enhance decision-making processes by harnessing large amounts of data and advanced analytical tools. In the context of the RE industry, the following key elements are vital for the effectiveness of systems (Chen and Zhao, 2012):

- **Data collection:** Relevant data must be gathered from various sources specific to the RE industry, including internal databases, external sources such as RE generation data, environmental factors, market trends, and customer data. Ensuring the quality of collected data is crucial to obtain accurate and reliable insights.
- **Data Cleaning**: Original “raw” data typically needs to be “cleaned” and refined, due to lacking some values, or having duplicate or inconsistent values and basic errors. In order to avoid such problems undermining subsequent analysis, data is cleaned to remove duplicates and address missing values, to standardise the dataset used in subsequent evaluation. By ensuring the integrity of analysed data, data cleaning improves the reliability of the subsequently generated conclusions including with regard to RE adoption and implementation (as in this study’s context).
- **Data storage:** Once collected, RE industry data needs to be stored in a manner that is easily accessible and facilitates quick analysis. This may involve storing data in specialised databases or cloud-based storage solutions designed for RE applications.
- **Data analysis:** Advanced analytical tools and techniques are employed to analyse the data specific to the RE industry. This includes using machine learning algorithms, statistical analysis, and energy modelling techniques to uncover patterns, trends, and insights relevant to RE generation, optimisation, and forecasting.
- **Data visualisation:** Results of data analysis in the RE industry are presented in a visually intuitive manner to facilitate easy understanding and interpretation. This includes interactive dashboards, charts, maps, and other visualisations that help stakeholders grasp the complex relationships and make informed decisions regarding RE projects and investments.

One key aspect where DD-DM is valuable in the RE sector is resource assessment and site selection. Through the analysis of historical weather data, topographical information, and other relevant data sources, decision makers can identify optimal locations for RE projects such as wind farms or solar installations (Liang *et al*., 2021). By considering factors such as wind speed, solar radiation, and land suitability, DDMs can help maximise the energy generation potential and improve the overall efficiency of RE systems. Furthermore, data-driven approaches can aid in the prediction and forecasting of RE generation. By utilising real-time monitoring data, weather forecasts, and predictive modelling techniques, decision makers can estimate the expected RES output with greater accuracy (González-Ruiz, González-Prida and Zazo, 2018). These forecasts enable effective grid integration, better resource allocation, and improved energy management, ultimately optimising the utilisation of RE resources.

DD-DM also plays a critical role in monitoring and maintenance of RE infrastructure (González-Ruiz, González-Prida and Zazo, 2018). By of RE systems (Motlagh *et al*. 2020). This proactive approach allows for early detection of issues, timely maintenance, and improved operational efficiency, ensuring the optimal functioning of RE assets (Gao and Dong, 2018). Therefore, DD-DM is instrumental in the RE sector, facilitating resource assessment, forecasting, and monitoring of RE systems. By leveraging data and advanced analytics, decision makers can optimise the deployment and management of RE resources, contributing to a more sustainable and environmentally friendly energy landscape (Liang *et al*., 2021).

Overall, there are many monitoring systems used in practice or being designed and developed to monitor the performance of a PV. These can be in the form of human experts or via the use of devices or apps in the digital space to make the monitoring process easier for homeowners. However, they are still need for new approaches based on DDMs that needed to be investigated.

2.7. Summary

Based on the review of the background and related literature for this research project, several key points emerge. It is evident that the deployment of RE, particularly SPs in Qatari houses, still lags behind that of other countries and faces numerous challenges. While there is a growing interest in SP deployments, as evidenced by large-scale solar projects, this interest has not translated to widespread adoption on home roofs, despite Qatar's increasing focus on clean energy initiatives.

Moreover, the current mechanisms for monitoring SP performance, crucial for enabling sustainable clean energy generation, are expensive and challenging to implement. There is a distinct need for a modernised, revenue-based monitoring system that facilitates performance meter monitoring and informs decisions regarding SP systems and homes, through the use of DDMs, to sustain the desired environmental and economic benefits.

However, there remains a lack of research addressing these issues, particularly the absence of studies on establishing frameworks to guide stakeholders in the deployment of SPs. Consequently, there is a pressing need for further research to enhance the visibility and future deployment of SPs in Qatar. Additionally, a comprehensive framework is required to stimulate the deployment of SPs in Qatar, ensuring environmental and socio-economic benefits.

CHAPTER 3
CHALLENGES FACING SP ENERGY DEPLOYMENT WITHIN QATARI HOUSES

3.1. Introduction

This chapter aims to identify the key challenges to the deployment of SPs in Qatar, related to achieving the research objectives. Despite several factors conducive to RE investment in Qatar, such as being a major O&G exporter with a need for economic diversification, there is low uptake of SP adoption among homeowners. Implicitly, major challenges hinder the deployment of solar and other renewables in Qatar, prompting this research to explore potential obstacles. This chapter encompasses two research phases: interviews to pinpoint challenges and using the outcomes from the interviews to obtain a broader response. This chapter highlights the primary challenges facing SP deployment in Qatar, offering valuable insights for diverse stakeholders, policymakers, and future researchers.

3.2. Chapter Methodology

In order to achieve the main objective of this study, a mixed-method approach was selected, using both qualitative and quantitative methods (Weller *et al*., 2018), as illustrated in Figure 3.1.

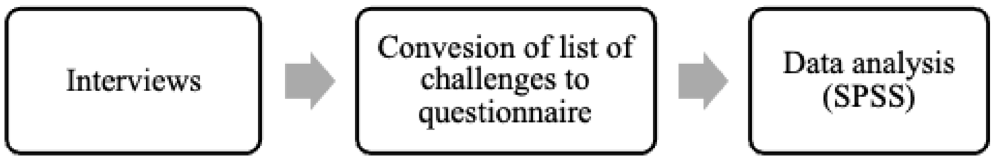


Figure 3.1: Study research design

Source: Author

The first method was open-ended interviews conducted by phone with 10 key stakeholders from the energy sector in Qatar, to answer the question posed by existing research of "what the possible challenges are facing SP deployment within homes and businesses" (Hagen and Pijawka, 2022). Qualitative interviews enabled exploring participants' perceptions and experiences in depth, whereby common challenges could be identified from different perspectives. Moreover, the outcomes of these interviews are used to establish the quantitative questionnaire used in the second part of the study (Appendix 1). Likert-type questions were used to elicit views from a wider sample, to obtain the opinions of 1140 households and business owners regarding the challenges identified from the qualitative phase. The Likert items assessed participants' level of agreement with the listed challenges, facilitating data analysis (Hinton *et al*., 2016). SPSS v.20 was used to analyse the study data, answer its questions, and test the hypothesis: "There is no difference due to the nature of ownership (at the level of statistical significance $p \leq 0.05$) in the degree of challenges facing SP deployment in Qatar" (Sekaran and Bougie, 2016).

3.3. Overview of Findings

Interview participants were shown the "Five Key Challenges for RE in the GCC" (Figure 2.2),and were subsequently asked two questions: if these challenges are still valid for Qatar, and if they would suggest adding any other challenges. Subsequently, thematic analysis was selected as the most suitable analysis method to analyse participants' responses from different interview sessions (Riger and Sigurvinsdottir, 2016). It was applied to move beyond the pre-identified five main themes (identified below in bold, rephrased slightly from their rendering in Figure 2.2 to reflect the working arising from the thematic analysis) to add a further ten themes identified as the main challenges to SP adoption among homeowners and business owners in Qatar:

1. **Lack of awareness of RE**
2. **Lack of environmental interest**
3. **Lack of government initiatives**
4. **Lack of interest due to the availability of other sources of energy**
5. **Subsidised conventional electricity makes RE uncompetitive**
6. Barriers related to connecting generated energy to the main electrical power grid
7. Fear of changes in the look of the building due to installation
8. Fear of damaging buildings
9. High upfront cost of SP installation
10. Lack of available SP technology
11. Lack of technical support for SPs
12. Possible cultural barriers to SPs installation
13. Safety concerns of SP installation
14. SPs give low ROI
15. Unclear law and regulations governing SPs

3.4. Findings from Questionnaire

Using SPSS enabled reliability testing of the quality of responses, generating descriptive data with mean and standard deviation (SD) values, to provide a general overview of the results from each group. One-way analysis of variance (ANOVA) was used for comparative analysis between different groups, to establish any significant differences (Sekaran and Bougie, 2016). The statistical assumptions displayed in Table 3.1 were used in this analysis.

Table 3.1: Statistical assumptions

Descriptive statistics:
Frequencies and percentages: To measure the distributions of the characteristics of the sample members.
Mean: to measure the average answers of the sample members to the questions of the study questionnaire, which used a five-point Likert scale, weighted as follows:

Score	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Approval	5	4	3	2	1
Relative weight	81~100%	61~80%	41~60%	21~40%	1~20%

$$\text{Length of the period} = \frac{\text{Upper} \sim \text{lower}}{\text{The number of levels}} = \frac{5 \sim 1}{3} = 1.33$$

Number of levels:

Level	Period
Low	1~ 2.33
Medium	2.34 ~ 3.67
High	3.68 ~ 5

SD: To measure the dispersion of the answers of the sample members from their arithmetic mean
Inferential statistics:
One-way ANOVA
Consistency coefficient (Cronbach's alpha for the variability of the stability of the study instrument)

Source: Author

3.4.1. Study sample reliability

To avoid the data collection method shortcomings when participants fill the questionnaire, it was essential to perform reliability of the study sample. Hence, SPSS Cronbach's alpha reliability was test conducted. It is important that Cronbach's alpha coefficient values are at least 0.6, which indicates that the questions from the questionnaire measure the appropriate variables, signifying a consistent and dependable instrument. The Cronbach's alpha coefficient of the survey used in this study was 0.88, indicating good valid for study purposes (US-Qatar Business Council, 2020).

3.4.2. Data analysis

Participant characteristics (i.e., their status as either home or business owners, or both) are shown in Table 3.2. It can be seen that the majority were exclusively homeowners (n = 804, 70.5%), a quarter were exclusively business owners (n = 276, 24.2%), and a small proportion (n = 60, 5.3%) owned both homes and businesses.

Table 3.2: Nature of the ownership of the study sample

Nature of ownership	n	%
Business owner	276	24.2
Homeowner	804	70.5
Home *and* business owner	60	5.3
Total	1140	100.0

Table 3.3 shows the means, SDs, percentages, and degrees of participant responses concerning challenges facing SP deployment in Qatar. The average score for all items (3.38) indicates a medium level of challenges, and most of these related to "a lack of interest due to the availability of other sources of energy", "the availability of subsidised conventional electricity", and there is "a lack of awareness about renewable energy", which received high scores. The remaining challenges received medium degrees of agreement: "There is a shortage of government initiatives", "there is a lack of environmental concern", "there is a lack of technical support for SPs", "there are barriers related to connecting the generated energy to the main electric power grid", "law and regulations are unclear regarding SPs", "there is the possibility of cultural barriers to the installation of SPs", "the upfront cost of SP installation is too high", "there is a lack of available SP technology", "the SPs give a low ROI", "there is a fear of changes in the appearance of the building due to installation", "there is a fear of safety when considering SP insulation", and "there is a fear of damaging buildings".

These outcomes are attributable to any the availability of very cheap or free electricity, as in most GCC countries, being a primary reason for *not* installing SPs, and rendering PV systems relatively much more expensive than in comparable markets with expensive energy prices (e.g., Europe). Users in Qatar would therefore perceive the cost of installing SPs to be very prohibitively expensive for the home, and particularly in a business context, given the abundant availability of cheap electricity. Put simply, from a financial perspective, there is no benefit of installing SPs in terms of reducing costs for users in Qatar.

Table 3.3: Challenges facing SP deployment in Qatar

Challenges	Mean	SD	%	Degree
Lack of interest due to availability of other sources of energy	4.03	1.261	80.6	High
Subsidised conventional electricity makes renewable energy uncompetitive	3.74	1.401	74.7	High
There is a lack of awareness of renewable energy	3.68	1.284	73.7	High
There is a lack of government initiatives	3.62	1.275	72.4	Medium
There is a lack of environmental interest	3.52	1.231	70.3	Medium
There is a lack of technical support for SPs	3.48	1.239	69.7	Medium
There are barriers related to connecting generated energy to the main electrical power grid	3.45	1.255	69.1	Medium
Unclear law and regulations governing SPs	3.40	1.252	68.0	Medium
There are possible cultural barriers to SPs installation	3.35	1.344	66.9	Medium
The upfront cost of SP installation is high	3.26	1.348	65.3	Medium
There is a lack of available SP technology	3.26	1.409	65.3	Medium
SPs give low return on investment	3.16	1.309	63.2	Medium
There is fear of changes in the look of the building due to installation	2.96	1.399	59.2	Medium
There are safety concerns of SP installation	2.89	1.302	57.9	Medium
There is fear of damaging buildings	2.87	1.332	57.5	Medium
Average	3.38	.842	67.6	Medium

Source: Author

3.5. Testing Hypothesis on No Difference Due to Ownership Nature

To test the hypothesis that "there is no difference due to the nature of ownership (at the level of statistical significance $p \leq 0.05$) in the degree of challenges facing SP deployment in Qatar", one-way ANOVA was conducted. The results are shown in Table 3.4, indicating that the F value is not statistically significant ($p \leq 0.05$), so we conclude that the nature of ownership does not significantly affect the degree of challenges facing the deployment of SP in Qatar. This result reflects that businesses and people employed in business roles are primarily motivated by material costs of activities, and future results in terms of financial savings and profitability. Such thinking is prevalent among everyone, regardless of the nature of ownership, but it is particularly acute in business contexts. Consequently, all users can be expected to agree on the same challenges that they will face in the event of installing SPs, albeit with varying degrees of prioritisation, depending on particular circumstances.

Table 3.4: One-way ANOVA to test study hypotheses

	n	Mean	SD	df	Mean Square	F	Sig.
Business owner	276	3.37	0.824	2	0.310	0.438	0.646
Homeowner	804	3.39	0.843				
Combined	60	3.28	0.907				
Total	1140	3.38	0.842				

Source: Author

3.6. Summary

As anticipated, the findings reveal various key challenges facing SP deployment in Qatar, with no differences in degree according to the nature of ownership. The comprehensive factors arising from the analysis presented in this chapter are shown in Table 3.3.

It is clear that these challenges are in line with the main challenges facing RE in other GCC countries. These and the other challenges remain to be tackled before considering deploying SP energy for houses and businesses in Qatar, with a national roadmap toward a sustainable energy profile within the medium to long term, in addition to driving progress and setting the agenda for future research. Moreover, the outcomes from this study can be useful for other stakeholders in other GCC countries to revisit their own challenges and see if new emerged ones are worth consideration.

CHAPTER 4
ANALYTICAL FEASIBILITY STUDY FOR $\mathbf{SP}$ INSTALLATION IN QATAR BASED ON GENERATED TO CONSUMED ELECTRICAL ENERGY INDICATOR

4.1. Introduction

The main objective of this chapter is to analyse the feasibility of the deployment of $\mathbb{SP}$s in Qatar houses and other organisations, including by calculating different $\mathbb{SP}$ deployment scenarios with different panel sizes, efficiency rates, and sun exposure per day, in order to estimate generated energy and compare that with an actual consumption over period of twelve months. In addition, the study aims to provide a comparative indicator, the generated-to-consumed energy ($\mathbf{G_{to}C}$) ratio, in order to enable the possibility of a new RE rating index. The research reported in this chapter has applications for RE investment and sales forecasting, maintaining comparison between different installation scenarios, and in upgrading planning and decision making. This study's analytical solutions might be correlated with data from *in situ* $\mathbb{SP}$ installation scenarios in order to fully establish the performance under operational scenarios. The study will be beneficial to support roadmaps to foster $\mathbb{SP}$s deployment in Qatar, though demonstrating scenarios that can enable economic and environmental incentives. In addition, the study can be useful for other GCC states with similar weather and economic conditions. Moreover, the $\mathbf{G_{to}C}$ indictor can be used as a new source of data to enable establishing data Introduction.

4.2. Chapter Methodology

The research reported in this chapter is based on analytical research method, which enables understanding the relationship between the two or more variables. $\mathbb{SP}$ efficiency and $\mathbb{SP}$ size for each specific month with given sun per day are the main variables pertinent to this chapter (Goundar, 2012), which was accomplished through four stages, as outlined in Figure 4.1.

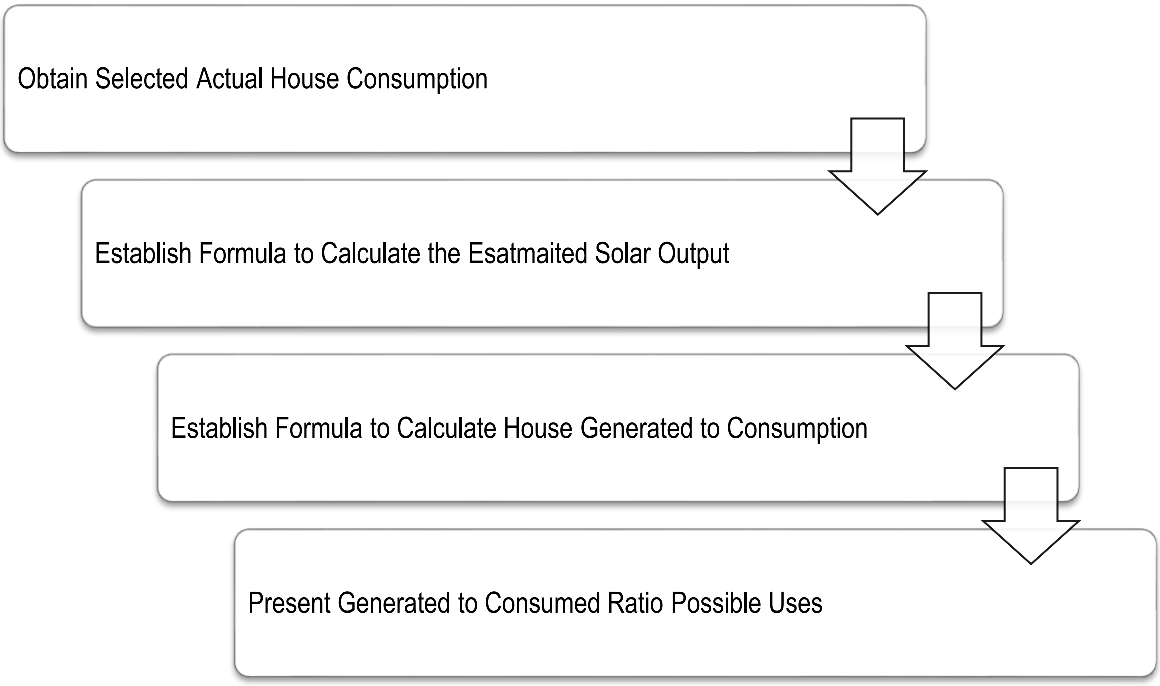


Figure 4.1: Research design

Source: Author

4.3. Annual Energy Consumption Data

The first task was to obtain the *actual* consumption data for a selected home for a period of twelve months, as reported in Table 4.1 and shown in Figure 4.2, to provide an indication of current (baseline) monthly and annual energy consumption. The estimated energy generated from SPs was then calculated for different scenarios to reflect the impact of SP efficiency and the size of the panels on the generated energy for each month; the resultant data was then compared with the actual consumption for each month. The third stage was to compare the amount of generated energy with the consumed energy to provide a comparative factor that can be used as an indicator to reflect the performance of that specific house. The final stage was to present possible uses of the $\mathbf{G_{to}C}$ ratio.

Table 4.1: Home specifications

Item	Measurement	Remarks
Total area	900	m^2
Penthouse roof area	56.72	m^2
Total roof area	65.47	m^2
No. bedrooms	10	Excluding lounges
No. inhabitants	15	Including 3 children
No. A/C units	19	114 kW

Source: Author

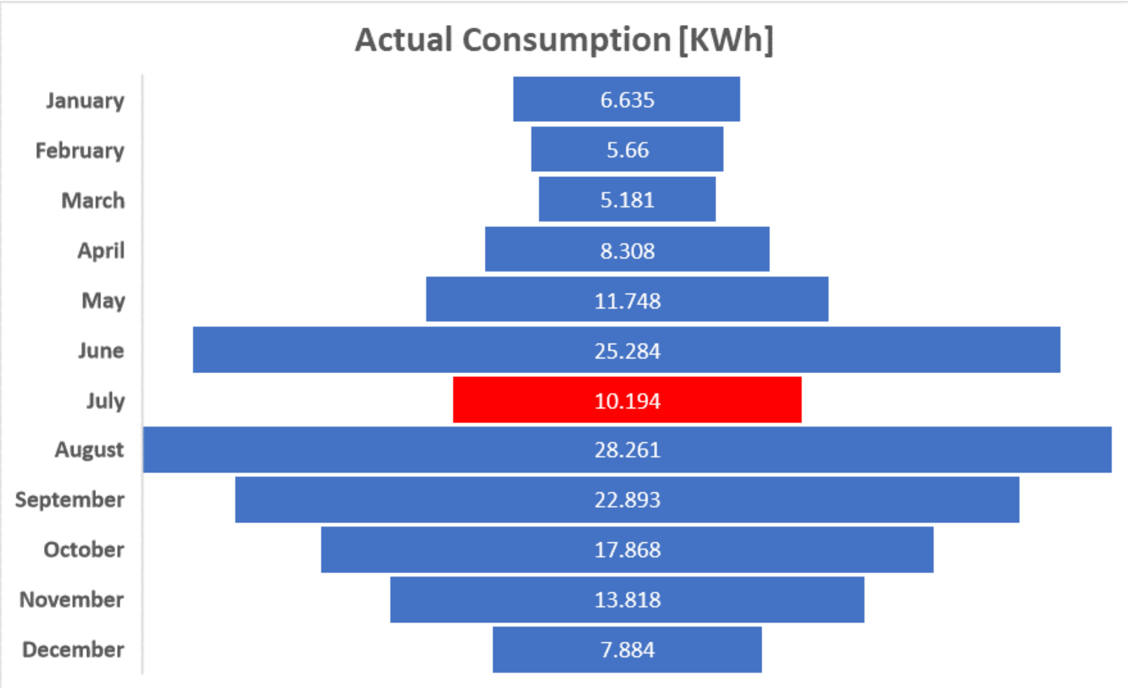


Figure 4.2: Example of Qatari house daily electrical consumption by month

Source: Author

Figure 4.2 shows the actual daily home consumption over the period of twelve months. It can be seen that consumption is much less for the period December to March, which reflects the relatively cold winter period. July (shown in red) is also egregiously low, reflecting that the majority of the native population go on vacation abroad (and many expatriate workers take their annual vacations) to escape the intensity of the hottest period of the year. It is expected that July would otherwise have similar consumption to August, this finding agrees with other study included 10 homes (Alrawi *et al*., 2018).

4.4. Mathematical Modelling Solution

Mathematical equations used in this analysis were derived primarily from YES Energy Solutions (2022). The selected method for calculating the variable “G” — representing the total electrical energy generated by solar panels (in kWh) — is based on a widely adopted formulation used in solar energy feasibility assessments and preliminary design studies. This equation integrates key influencing factors such as panel efficiency, solar irradiance, panel surface area, and duration of exposure. It provides a reliable and straightforward approximation of daily energy generation under standard conditions, facilitating scenario modelling across multiple locations and system configurations. This approach is particularly useful in strategic planning and policy analysis contexts, where empirical field data may be limited, and a scalable estimation method is required to explore deployment viability and energy return expectations.

4.4.1. Estimated daily SPs’ energy generation formula

$$G = \frac{(p_S 1000\, p_n\, p_e\, s_{PD})}{1000} \tag{4.1}$$

where G is the total generated electrical energy from SPs (kWh), p_s is the SP area (m^2), p_n is the number of SPs, p_e is solar efficiency, and $s_{PD}$is sun hours per day.

4.4.2. Generated to consumed electrical energy ratio ($\mathrm{G_{to}C}$) formula

$$G_{to}C = \left(\frac{G}{C}\right) \times 100\% \tag{4.2}$$

where G is the total generated electrical energy from SPs in KWh, and C is the consumed electrical energy by the house in KWh.

4.4.3. Average $\mathrm{G_{to}C}$ for number of homes in city or district formula

$$(G_{to}C)_A = \frac{\left(\sum_{i=1}^{n}(G_{to}C)_1 + (G_{to}C)_2 + \cdots + (G_{to}C)_n\right)}{n} \tag{4.3}$$

where *n* is the total number of houses in the city or district.

4.4.4. National $\mathrm{G_{to}C}$ formula

$$(G_{to}C)_N = \frac{\left(\sum_{i=1}^{n}(G_{to}C)_{A1} + (G_{to}C)_{A2} + \cdots + (G_{to}C)_{An}\right)}{n} \tag{4.4}$$

where *n* is the total number of cities or districts in country.

4.5. Calculation of Scenarios

In reality, SPs do not provide their 100% theoretical efficiency; in practice, they typically provide three levels of efficiency (20%, 40%, or 50%), depending on their technological capacity and ambient conditions. Therefore, these three levels of efficiency were used for three numbers of panels (2, 4, and 6), with a standard panel area of 1.6 m^2 (each), to enable meaningful comparison between efficiency and number of panels in each house during each month of the year, based on the sun per day for each month, as shown in Table 4.2. The parameters "low, medium, and high panel efficiency" (LPE/ MPE/ HPE) and "low, medium, and high panel number" (LPN/ MPN/ HPN) were used for comparative purposes, as reported in the following subsections.

Table 4.2: Calculation scenarios

Scenario	Panel efficiency (%)	No. panels	Panel area (m^2)
LPE vs. LPN	20	2	3.2
LPE vs. MPN		4	6.4
LPE vs. HPN		6	9.6
MPE vs. LPN	40	2	3.2
MPE vs. MPN		4	6.4
MPE vs. HPN		6	9.6
HPE vs. LPN	50	2	3.2
HPE vs. MPN		4	6.4
HPE vs. HPN		6	9.6
Key: LPE/MPE/HPE – Low/ Medium/ High Panel Efficiency LPN/MPN/HPN – Low/ Medium/ High Panel Number			

Source: Author

4.5.1. LPE vs. LPN (20% vs. 2 panels)

Figure 4.3 shows that the energy generated is very low, and it does not substitute the consumed energy in the majority of months around the year. This cannot be considered a practical scenario.

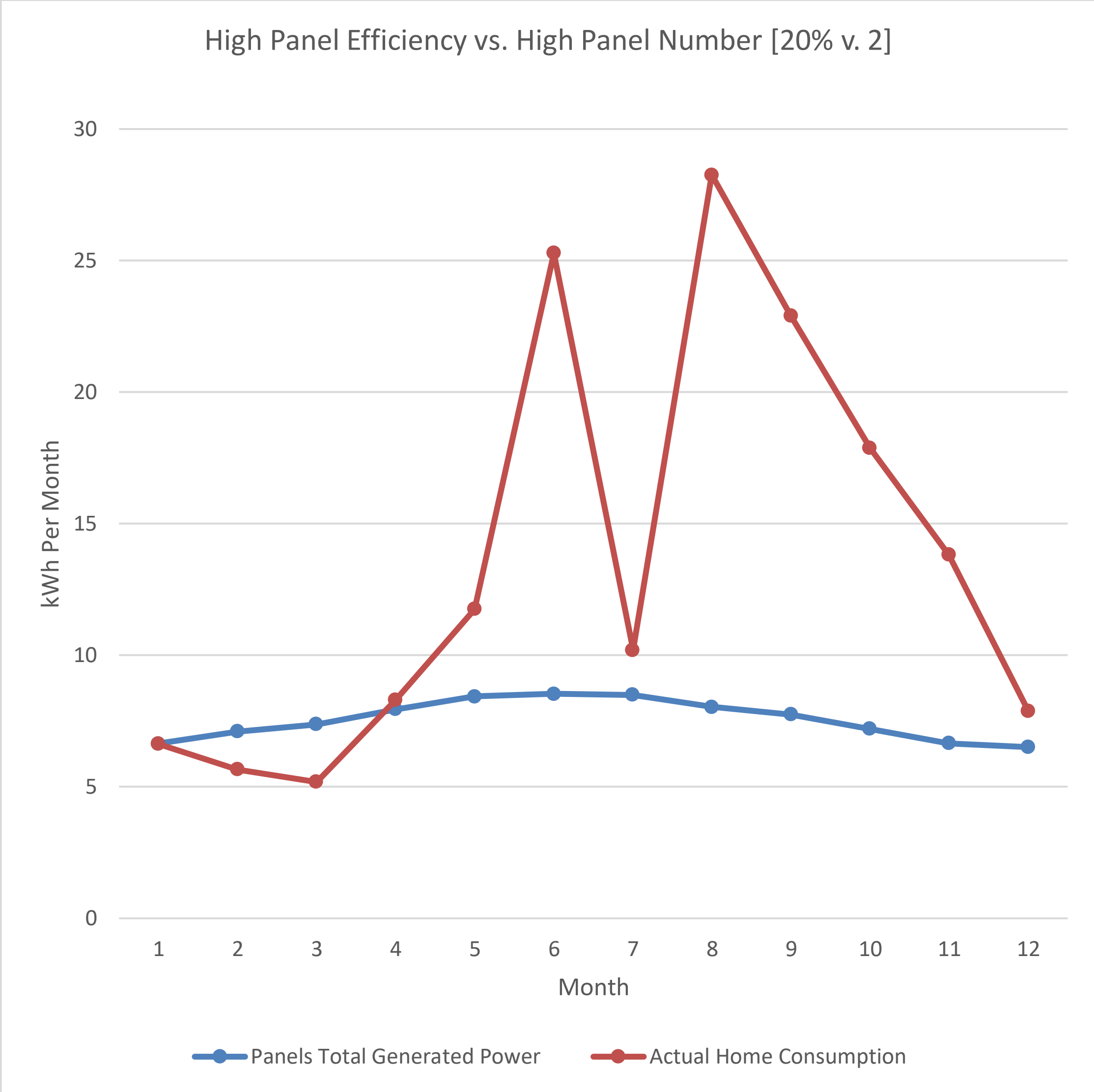


Figure 4.3: LPE vs. LPN

Source: Author

4.5.2. LPE vs. MPN (20% vs. 4 panels)

Figure 4.4 shows that the energy generated is still not enough to substitute the consumed energy in the majority of the months of the year. This cannot be considered a practical scenario.

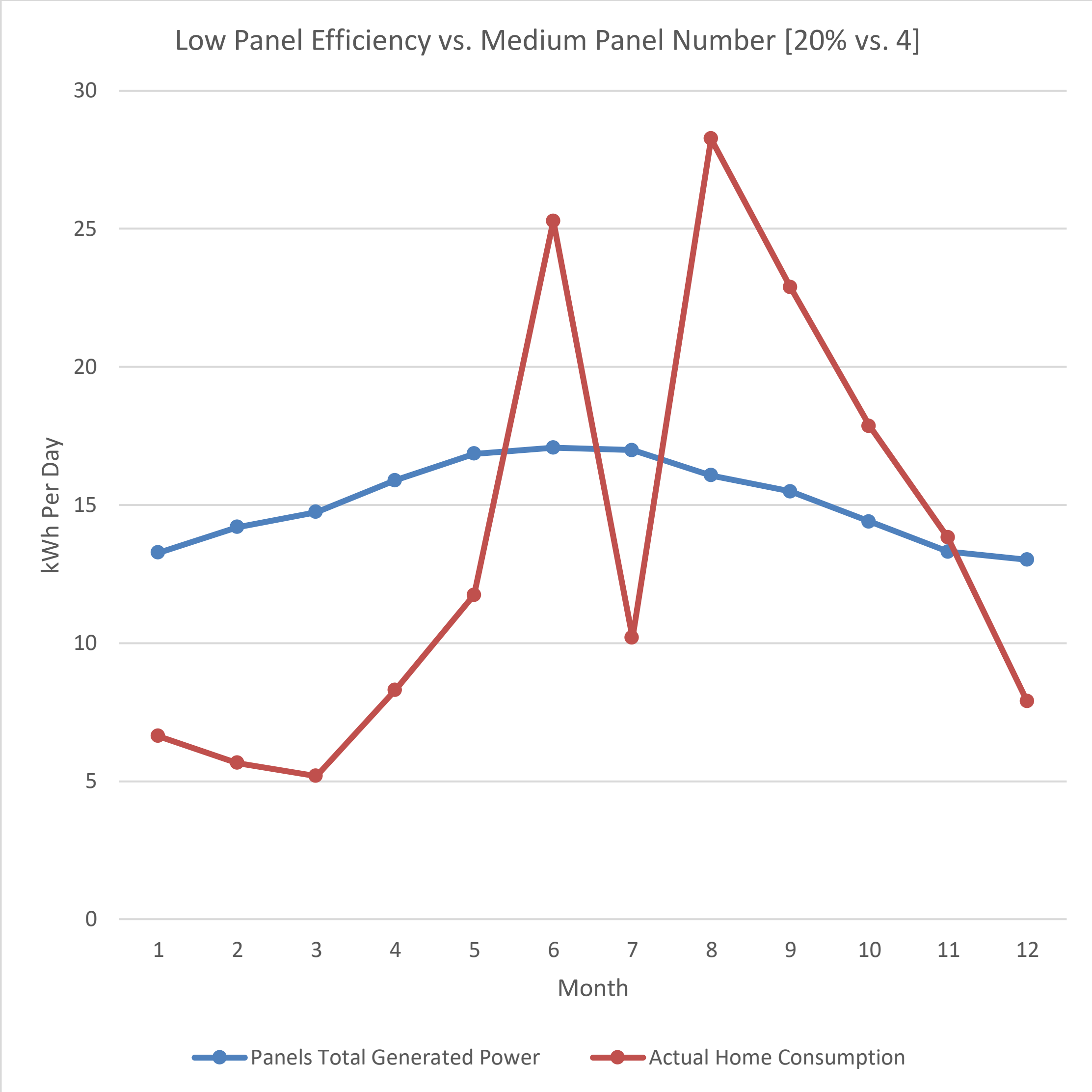


Figure 4.4: LPE vs. MPN

Source: Author

4.5.3. LPE vs. HPN (20% vs. 6 panels)

Figure 4.5 shows that the energy generated is enough to substitute the consumed energy in the majority of months throughout the year. This can be considered as a practical scenario, but there is still a necessity to obtain energy from other sources to maintain latent capacity and cover times of peak demand.

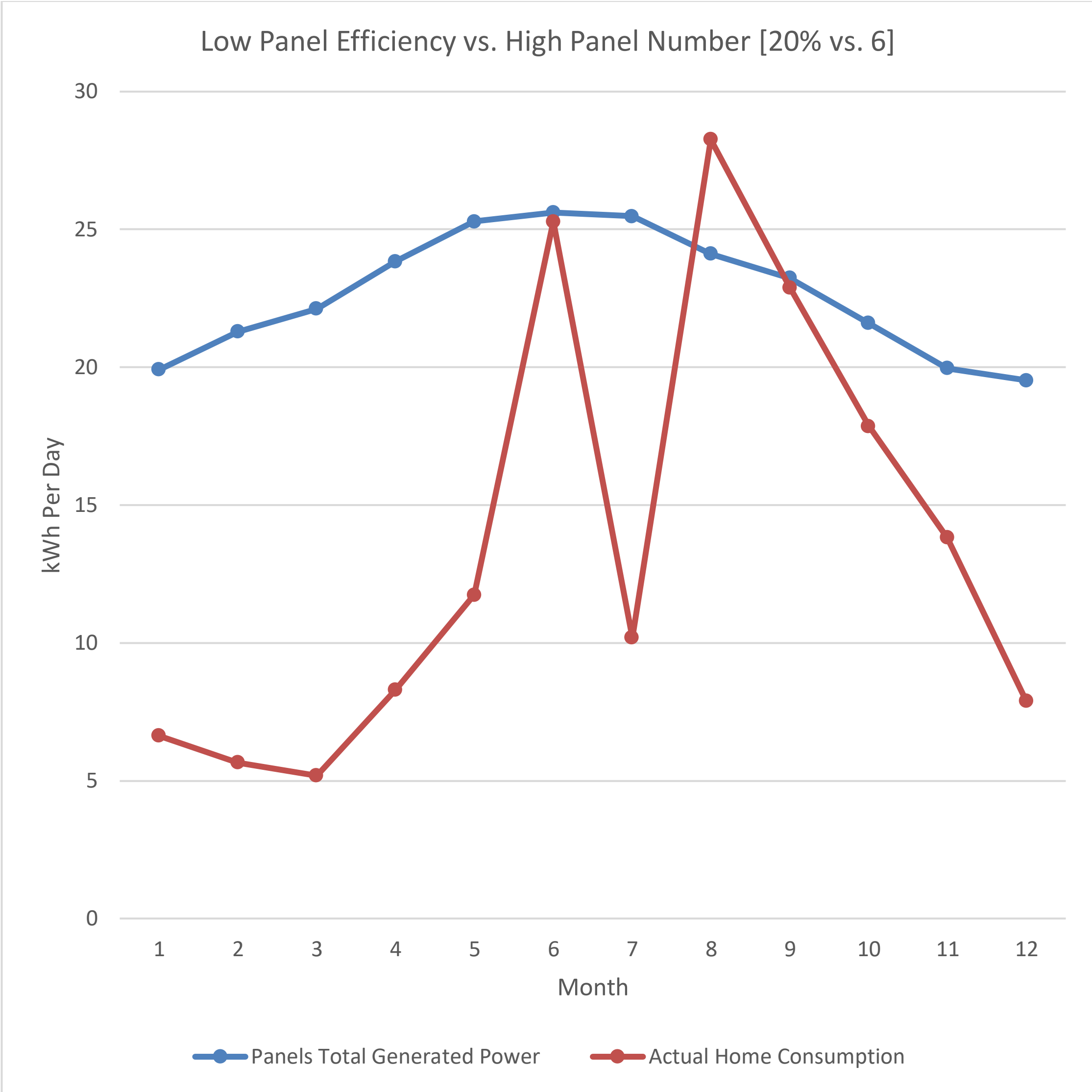


Figure 4.5: LPE vs. HPN

Source: Author

4.5.4. MPE vs. LPN (40% vs. 2 panels)

Figure 4.6 shows that it is not possible to substitute the consumed energy by the house from the generated energy from the SPs in the majority of months around the year, which indicates that this is not considered a practical scenario.

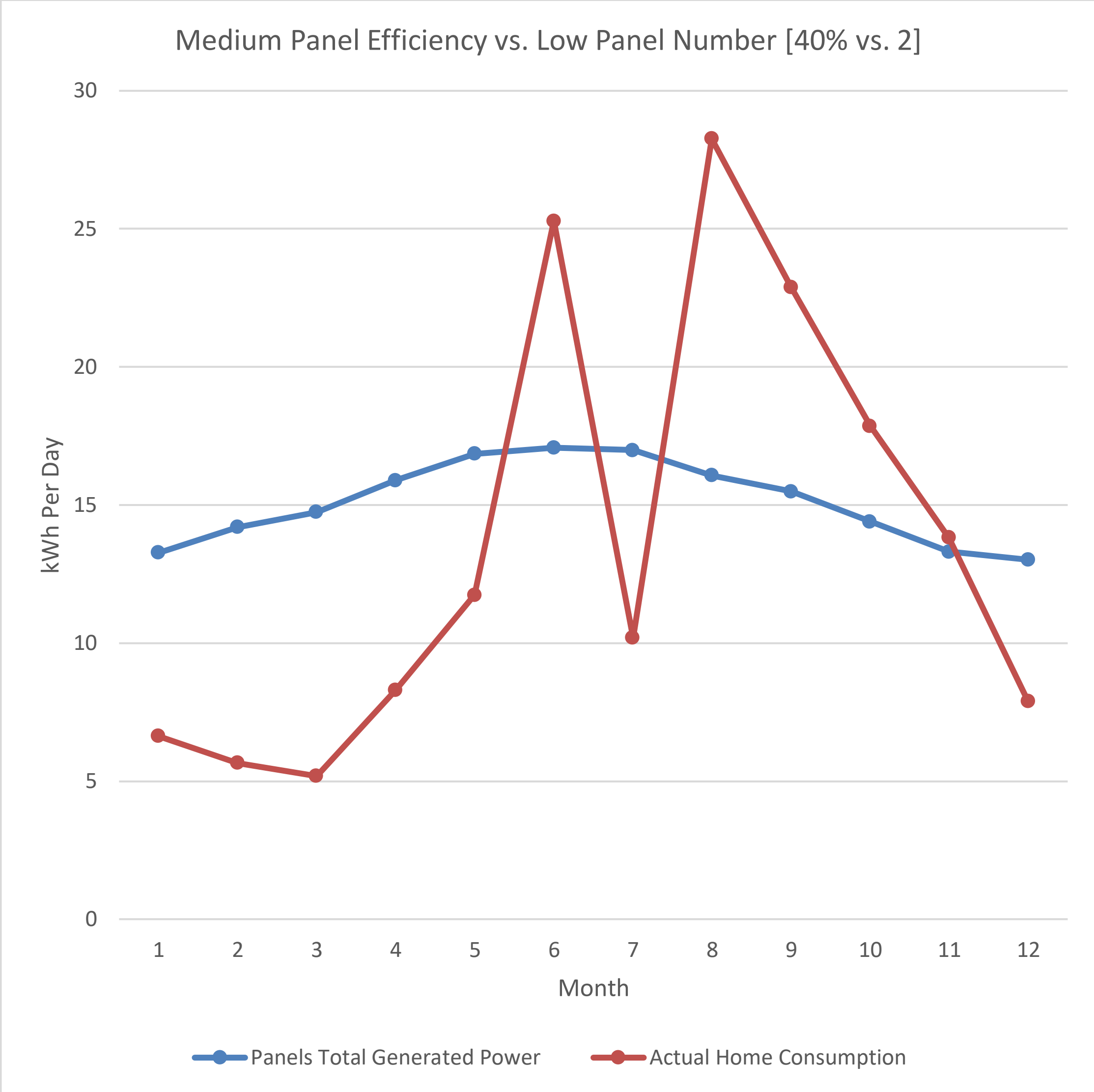


Figure 4.6: MPE vs. LPN

Source: Author

4.5.5. MPE vs. MPN (40% vs. 4 panels)

Figure 4.7 shows that the expected amount of generated energy from SPs is consistently higher than the actual home electrical consumption, which means that the home can likely depend on the generated energy from SPs in each month of the year. Therefore, this scenario can be considered as an ideal one, which reflects huge investment with a good return in terms of energy.

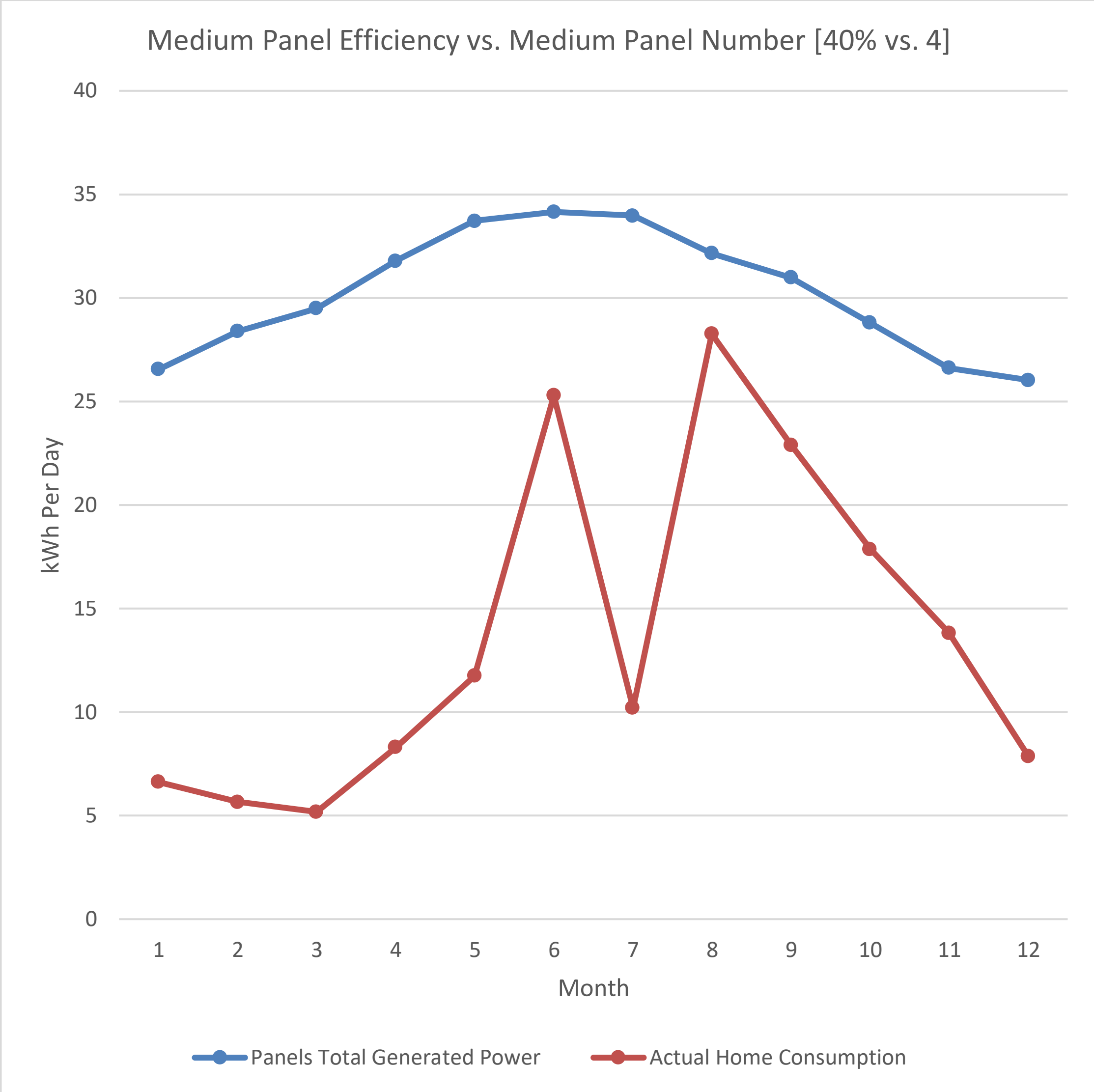


Figure 4.7: MPE vs. MPN

Source: Author

4.5.6. MPE vs. HPN (40% vs. 6 panels)

Figure 4.8 shows that the expected amount of generated in energy from SPs is much higher than the actual home conception, which means that the home can cover the monthly consumption from the SPs generated energy and supply the main grid with the extra generated energy. Therefore, this scenario can be considered ideal for both homeowners and energy companies, with sufficient latent capacity to allow for the companies to buy energy (at reduced rates) from consumers (usually via subsidised prices during periods when households rely more on conventional electricity from power plants).

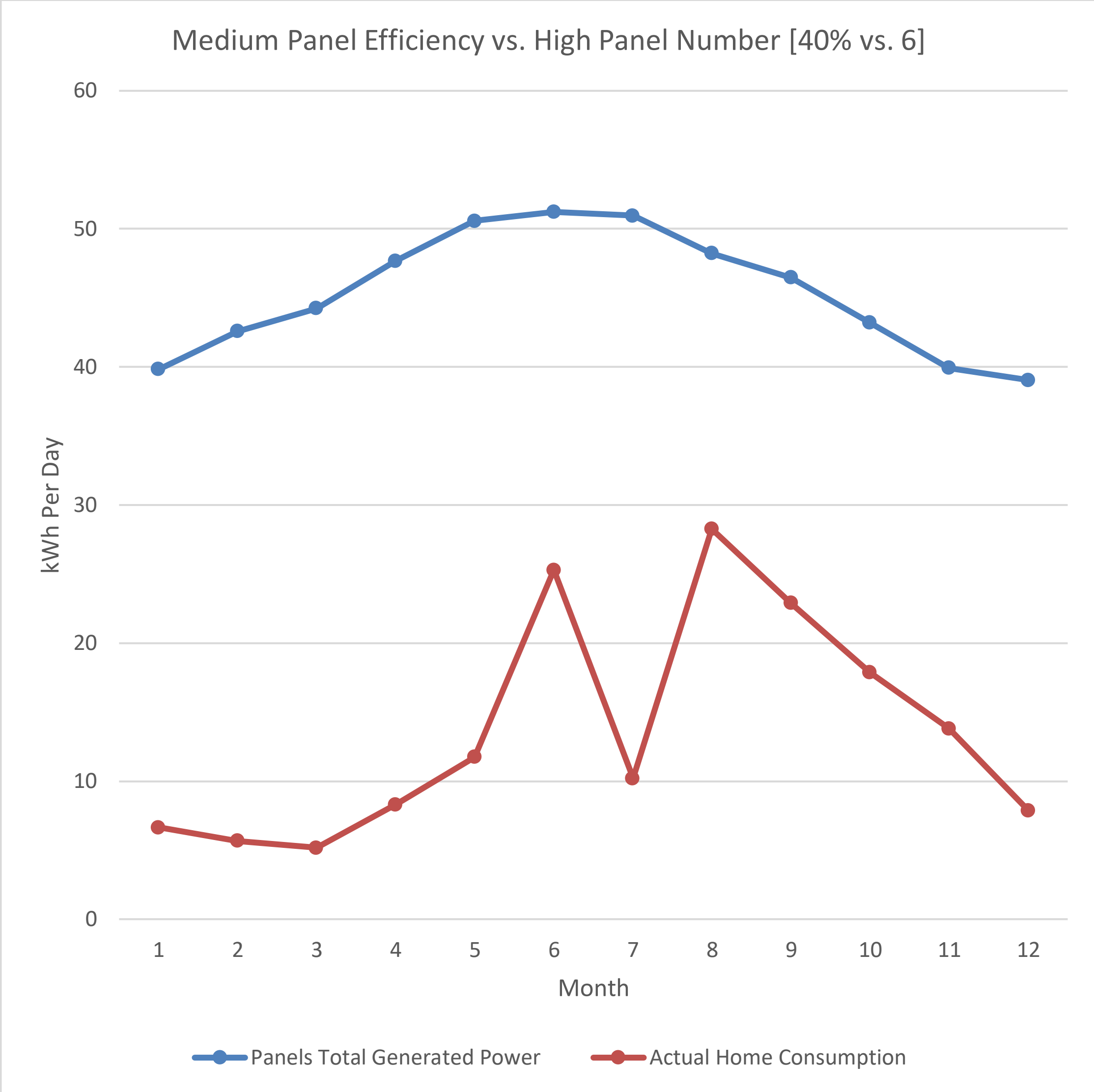


Figure 4.8: MPE vs. HPN

Source: Author

4.5.7. HPE vs. LPN (50% vs. 2 panels)

Figure 4.9 shows that high efficiency could not manage to compensate for LPN, which means that the home still requires extra sources of energy for some months around the year, as the generated energy does not cover most of the months. Therefore, this scenario cannot be considered practical, especially due to the absolute outstripping of supply during the hottest period (from June to September, excluding the July dip in demand, which as explained previously is attributable to the national vacation exodus during the hottest time of year).

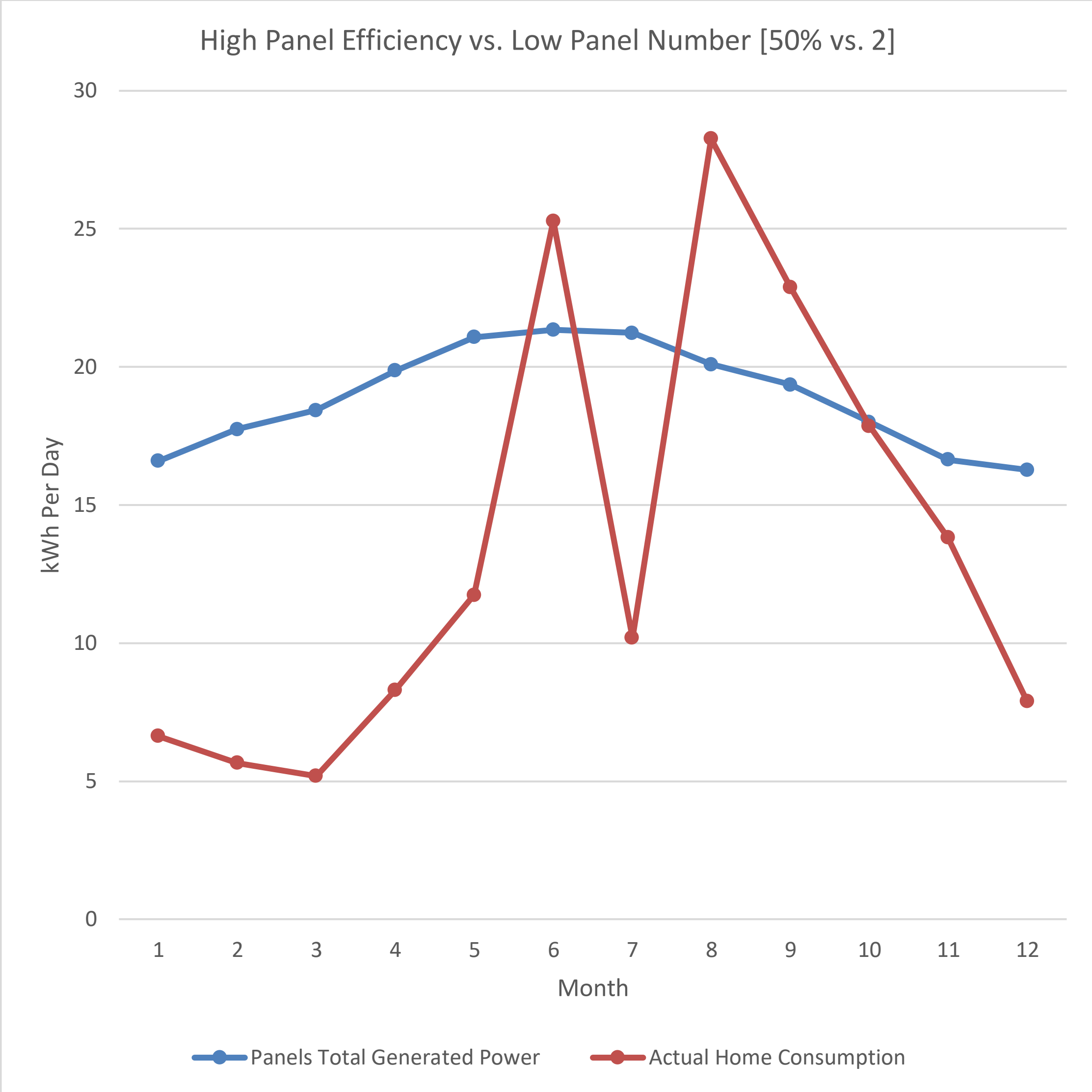


Figure 4.9: HPE vs. LPN

Source: Author

4.5.8. HPE vs. MPN (50% vs. 4 panels)

Figure 4.10 shows that the home can depend on the generated energy from SPs around the year without the need of external sources of energy, and there might be a possibility of having extra energy to supply back to the main grid. Therefore, this scenario can be considered as a very good scenario for homeowners.

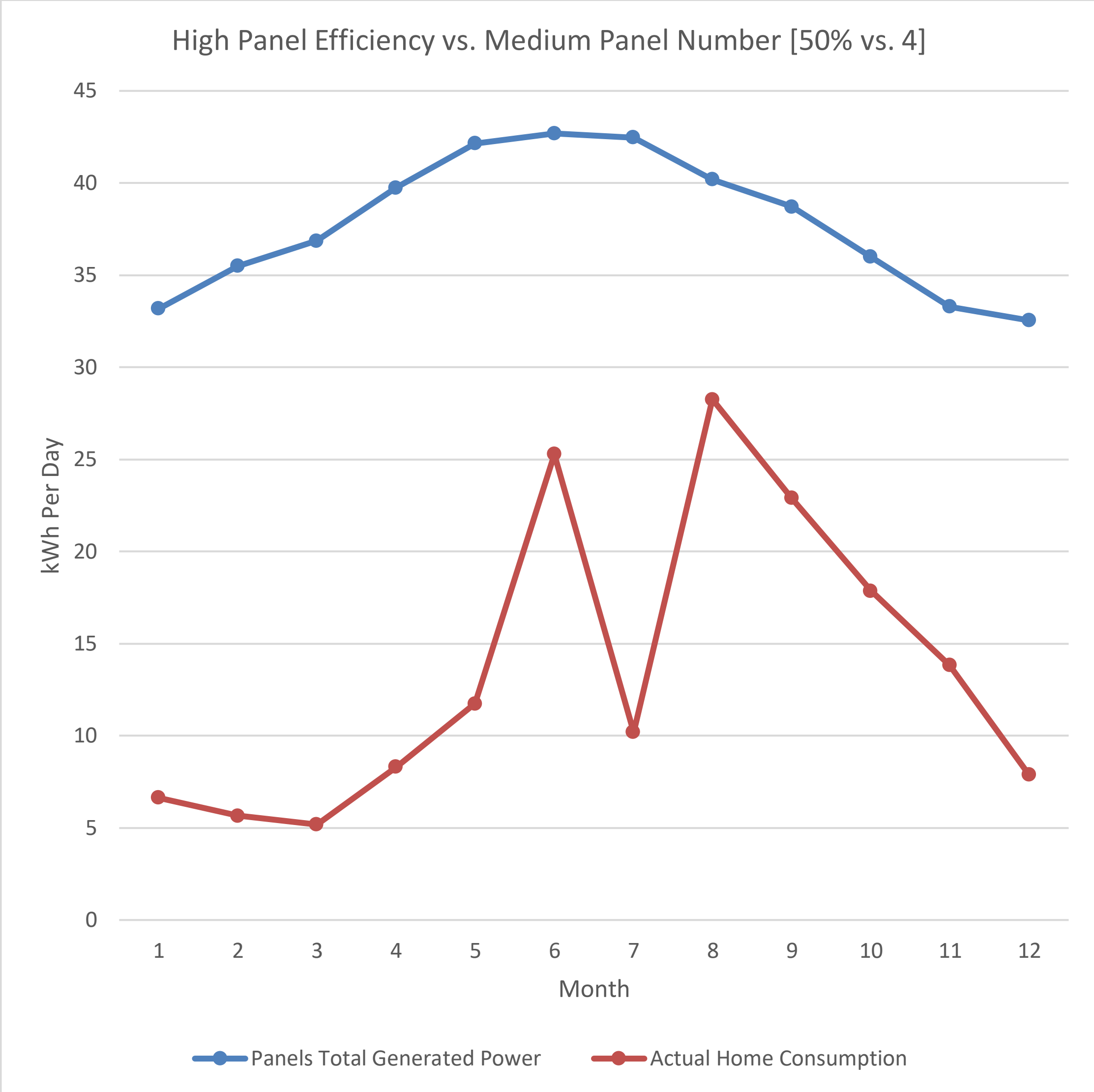


Figure 4.10: HPE vs. MPN

Source: Author

4.5.9. HPE vs. HPN (50% vs. 6 panels)

Figure 4.11 shows that this case is very good, whereby the home can depend on the generated energy from SPs around the year, with the possibility of having extra energy to supply it back to the main grid. Therefore, this scenario can be considered as a very good scenario for homeowners and energy companies.

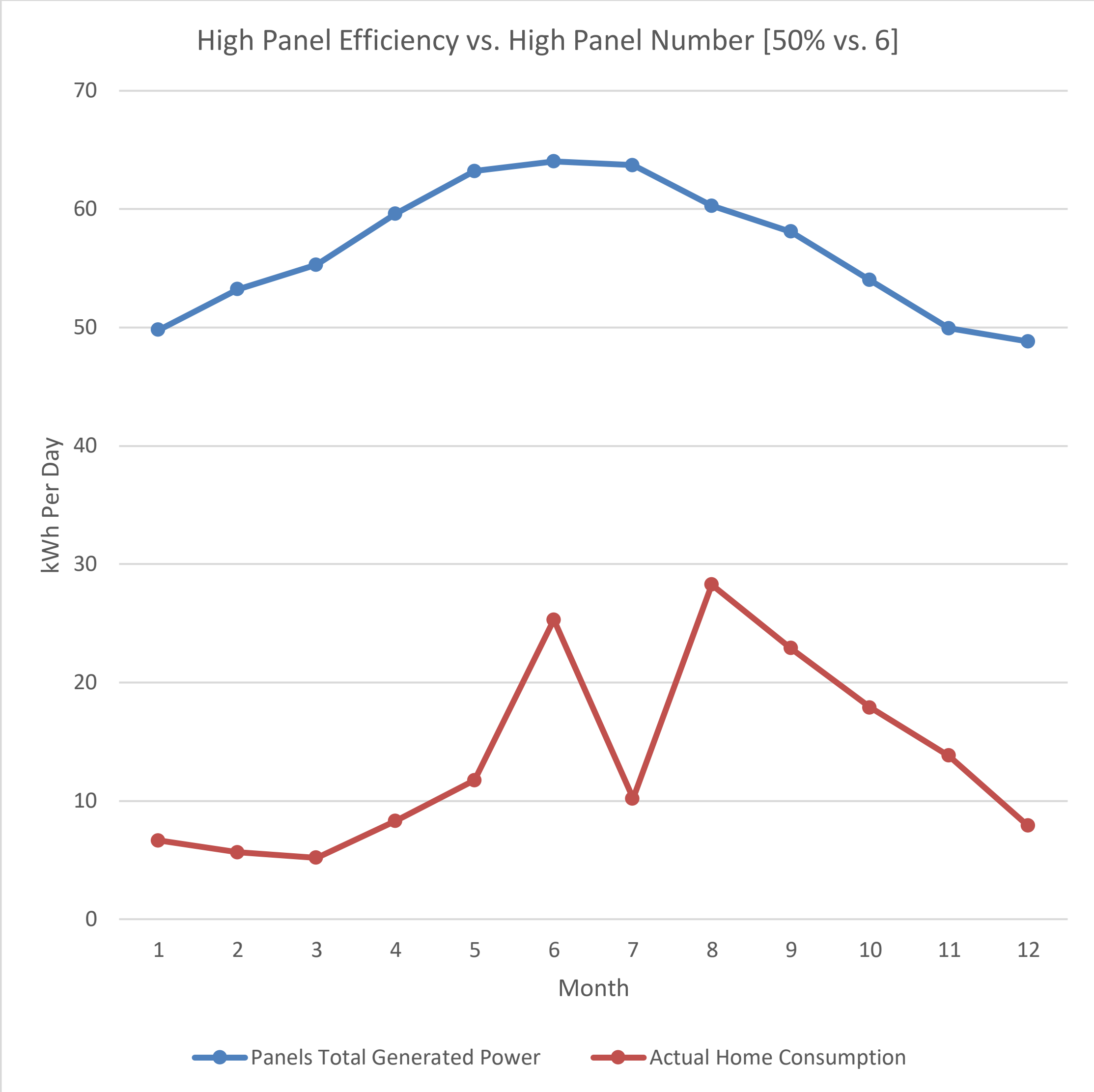


Figure 4.11: HPE vs. HPN

Source: Author

4.6. $\mathbf{G_{to}C}$ Use Cases

The following comparison of different installation ratios is based on the $\mathbf{G_{to}C}$ electrical energy ratio, which is given by:

$$G_{to}C = \left(\frac{G}{C}\right)100\% \tag{4.5}$$

where *G* is the total generated electrical energy from SPs in kWh, and *C* is the consumed electrical energy by the house in kWh.

4.6.1. Comparing different installation scenarios

When considering different installation scenarios for SPV panels in buildings, the main considerations are the available roof space, roof type, panel size, panel performance, and the amount of solar radiation arriving at the site (Fouad, Shihata and Morgan, 2017; Vidyanandan, 2017; Osma-Pinto and Ordóñez-Plata, 2019). Therefore, mathematical equations can be used to provide an assessment on the estimated generated energy from a SP system at particular property. On the other hand, comparing the generated energy with the consumed energy at a particular property gives a good indication of whether the property will be able to meet its own required energy demand at specific times, or whether it might require energy consumption from the main grid at certain times.

As shown in Table 4.3 and illustrated in Figure 4.12, the $\mathbf{G_{to}C}$ for each month around the year for the selected case study house. It clearly shows what settings are likely to provide better performance, highlighted in green, where the generated energy is much higher than consumed energy; amber, indicating that generated energy is equal or just higher that consumed energy; and red, indicating that generated energy is much less than consumed energy.

Table 4.3: $\mathbf{G_{to}C}$ to compare different installation scenarios

	Scenario								
	A	B	C	D	E	F	G	H	I
Jan	100.0271	200.0543	300.0814	200.0543	400.1085	600.1628	250.0678	500.1356	750.2035
Feb	125.3993	250.7986	376.1979	250.7986	501.5972	752.3958	313.4982	626.9965	940.4947
Mar	142.3046	284.6091	426.9137	284.6091	569.2183	853.8274	355.7614	711.5229	1067.284
Apr	95.67646	191.3529	287.0294	191.3529	382.7058	574.0587	239.1911	478.3823	717.5734
May	71.74668	143.4934	215.24	143.4934	286.9867	430.4801	179.3667	358.7334	538.1001
Jun	33.76681	67.53362	101.3004	67.53362	135.0672	202.6009	84.41702	168.834	253.2511
Jul	83.31175	166.6235	249.9353	166.6235	333.247	499.8705	208.2794	416.5588	624.8381
Aug	28.44344	56.88688	85.33031	56.88688	113.7738	170.6606	71.10859	142.2172	213.3258
Sep	33.82693	67.65387	101.4808	67.65387	135.3077	202.9616	84.56733	169.1347	253.702
Oct	40.2955	80.591	120.8865	80.591	161.182	241.773	100.7388	201.4775	302.2163
Nov	48.16905	96.33811	144.5072	96.33811	192.6762	289.0143	120.4226	240.8453	361.2679
Dec	82.55708	165.1142	247.6712	165.1142	330.2283	495.3425	206.3927	412.7854	619.1781
	LPE vs. LPN	LPE vs. MPN	LPE vs. HPN	MPE vs. LPN	MPE vs. MPN	MPE vs. HPN	HPE vs. LPN	HPE vs. MPN	HPE vs. HPN

Source: Author

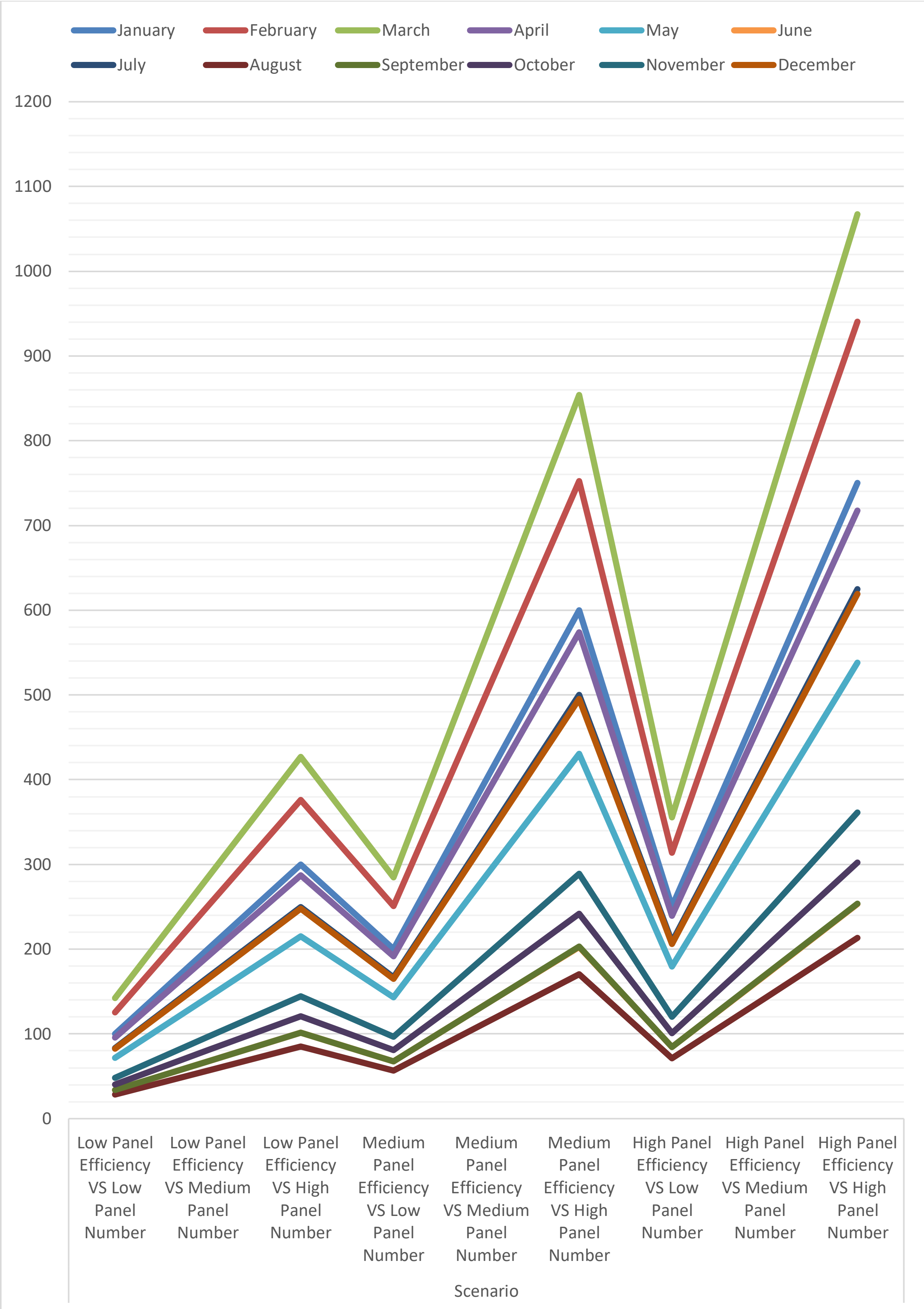


Figure 4.12: $G_{to}C$ electrical energy ratio (%)

Source: Author

4.6.2. New RE energy rating index

Energy Efficiency Index (EEI) is used as an indicator to monitor energy consumption performance (Bakar *et al*., 2015), in same manner with the energy-saving index. $\mathbf{G_{to}C}$ can be used as an index to provide indication in the capacity of property of generating energy from SP system to satisfy the property consumption. Table 4.4 explains the “Traffic Light Index” of red, amber, and green signals, where the colours indicate that generated energy is less than, greater than or equal to, or greater than the consumed energy (respectively), as mathematically described in the right-hand column. This Index can be a useful indicator for different stakeholders. For instance, potential homebuyers would be able to determine whether this property would be self-sufficient for expected energy consumption using the current solar system, which heavily affects property prices (Hoen *et al*., 2011). Moreover, $\mathbf{G_{to}C}$ can be also used to rank cities or countries in same manner as the World Energy Council‘s Energy Trilemma Index (Marti and Puertas, 2022), to evaluate general performance in attaining a sustainable combination between policies. The achieved grade reflects a state’s achievement, with “A” being the optimum assigned score. Such indices enable interactive monitoring of national energy policies’ sustainability.

Table 4.4: Traffic light index

Traffic Light	Representation	Mathematical Illustration
Red	Generated energy < consumed energy	$G_{to}C < 100\%$
Amber	Generated energy ≥ consumed energy	$150\% \leq G_{to}C \geq 100\%$
Green	Generated energy > consumed energy	$G_{to}C > 150\%$

Source: Author

4.6.3. $\mathbf{G_{to}C}$ as an investment index

RE investment by property owners or by companies seeking to enter the market of RE generation requires clear indicators to enable the sound decision making, including data that is trustworthy and which can be processed and communicated rapidly and concisely, particularly Energy Index, Weather Index, Energy Budget, and Weather Adjusted Energy Index indices (PV Magazine International, 2021). $\mathbf{G_{to}C}$ can be used to perform meaningful comparison between two or more settings. For example, for the given case shown in Figure 4.13, comparing the best two scenarios statistically using t-test (Siddikov *et al*., 2020) the t-value is 1.05571 and p-value is 0.151278; hence, the result is not significant at p < . 05. This clearly shows that there is no significant difference in the amount of the generated energy or the $\mathbf{G_{to}C}$ for two cases, but the cost of installation for the two systems is significantly different.

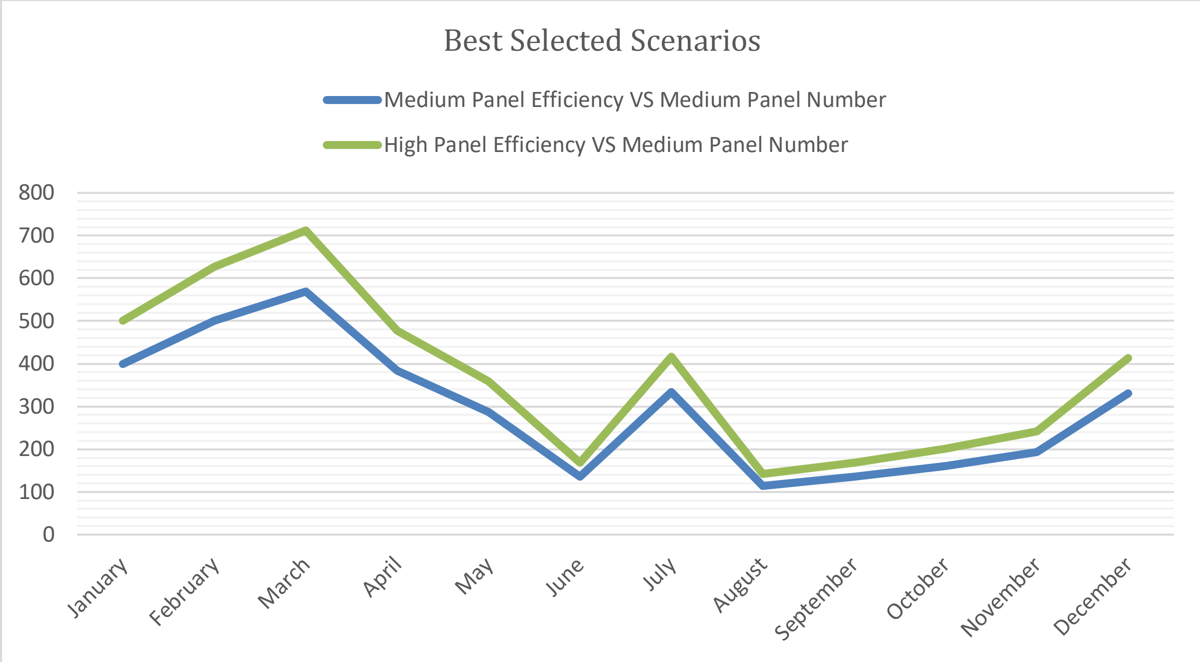


Figure 4.13: $\mathbf{G_{to}C}$ comparing two scenarios

Source: Author

Figure 4.14 compares the relative costs of SPs, assuming that the unit prices for medium and high efficiency panels are twice and thrice those of low efficiency panels, respectively. The configuration of "Medium Panel Number" with "Medium Panel Efficiency" yields an average cost, which agrees with the calculation driven from $\mathbf{G_{to}C}$, indicating a good compromise. Hence, having a smaller number of panels though the selection of this option can help achieving benefits such as lowering installation cost, best use of available roof space, best energy generation, safer, lesser material requirements (Pandey *et al.*, 2016). Most importantly, this enables much more effective cleaning and maintenance of panels in the harsh weather of Qatar (Alrawi *et al.*, 2022).

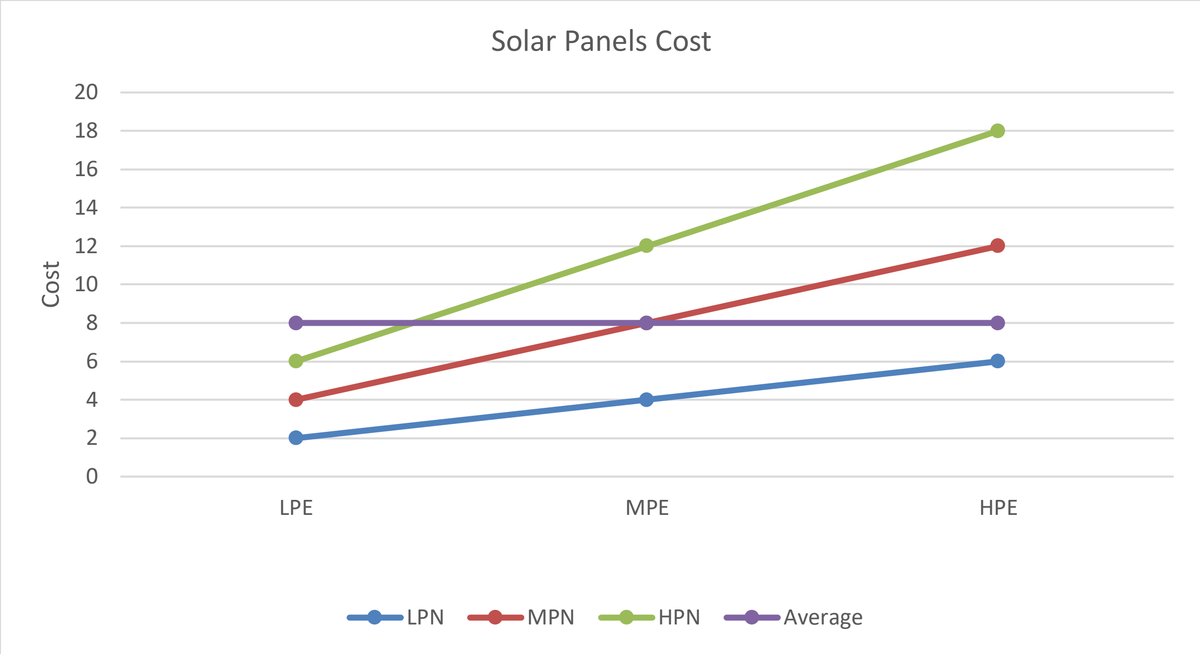


Figure 4.14: Comparing costs of different SPs

Source: Author

Nevertheless, going for more efficient panels means increasing the upfront cost of SP system (Bauner and Crago, 2015). Thus, having the right calculation which could offers average cost with good level of system efficiency are key for influencing factor (Fouad, Shihata and Morgan, 2017), which can encourage owners and policy makes to take real steps. This is particular apt given the pioneering nature of roof SP installation in Qatar, whereby a cautious and conservative approach might help drive the initial phase of deployment to achieve national millstones, forming a springboard to later expand and upgrade to top efficient panels, towards becoming clean energy exporter. Therefore, companies keen to sign contracts with householders or property owners will be able to assess the ROI based on the figures provided for $\mathbf{G_{to}C}$ and system upfront cost.

Moreover, another example for evaluating investment opportunities based on $\mathbf{G_{to}C}$ calculation, as presented in Table 4.3 and plotted in Figure 4.15, shows that for the period from December to April, when the temperature is clement in Qatar and demand for electricity for December to February is at its lowest (Alrawi *et al.*, 2018). This indicates a good opportunity to export energy, mainly from installation scenarios E, F, H and I with highest $\mathbf{G_{to}C}$ average for wintertime, when the demand for energy goes high in Europe (Darwish, Abdo and AlShuwaiee, 2018), which can support global efforts towards sustainable energy resources (Chakraborty, Li and Bhattacharya, 2021).

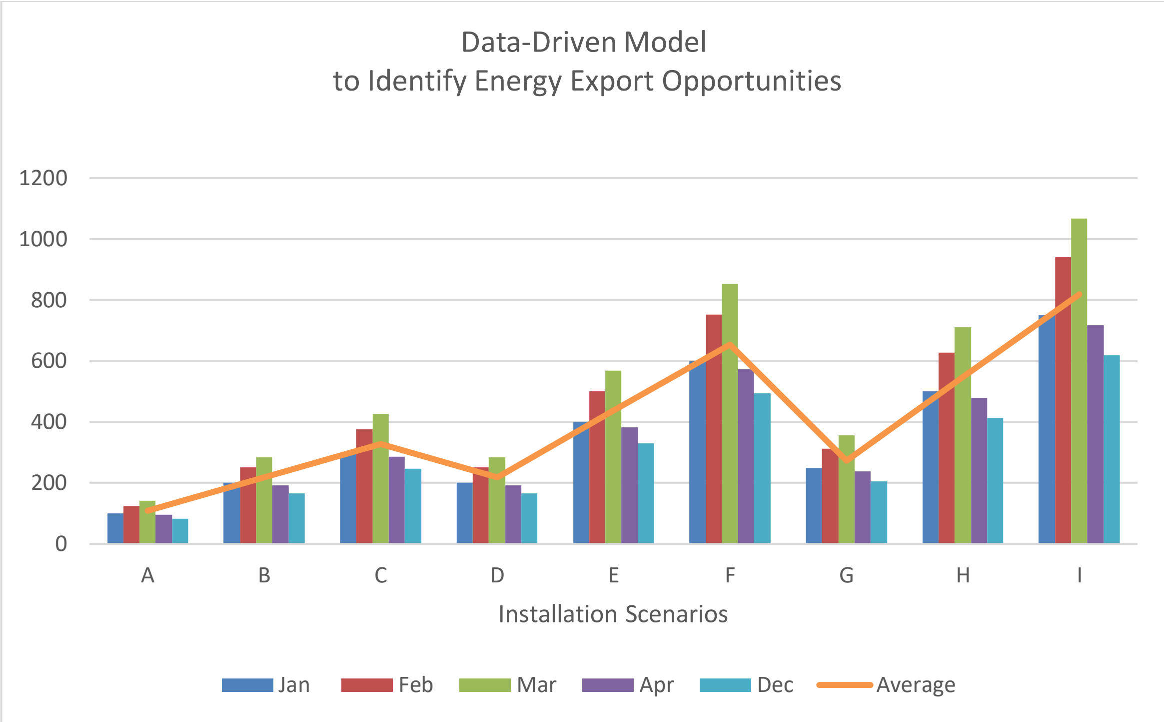


Figure 4.15: $\mathbf{G_{to}C}$ to identify energy export opportunities

Source: Author

4.6.4. Maintenance, upgrade, planning, and decision-making index

The long-term efficiency and sustainability of SPV systems themselves depends on periodic monitoring, maintenance, and potential upgrades, with regular evaluation of performance to sustain energy generation at required or optimum levels. Large $\mathbb{SP}$ plants use advanced systems including IoT and Intelligent Wireless Sensor Networks (IWSNs) for monitoring, but such costly technologies are unfeasible for smaller and localised private applications (Siddikov *et al*., 2020). For homes and businesses with a limited number of $\mathbb{SP}$s, there is a need for practical and affordable approach, such as $\mathbf{G_{to}C}$. Moreover, strategies and decision-making require enough data to enable making the right judgement (Provost and Fawcett, 2013). For example, if the government desired to establish national RE policies (Hafeznia *et al*., 2017), it may incentivise teams and consumers to install $\mathbb{SP}$ systems, or establish initiatives to support solar energy generation, requiring some indicators to enable them to make sound decisions.

$\mathbf{G_{to}C}$ can be very helpful to different stakeholders to establish good strategy and make informed decisions. On other hand, as dust, dirt, and ageing degrade PV systems and reduce their performance (Hafeznia *et al*., 2017). $\mathbf{G_{to}C}$ can be used as a good indicator to enable comparison with the previous reading when was the system at its best performance, to support planning, cleaning, or maintenance or replacement of parts or whole systems. This is especially important as Qatar is prone to high dust density during the months of May, June, and July (Bartlett, 2004). Figure 4.16 illustrates how not clearing SPs could degrade their performance, which can be identified from changes on $\mathbf{G_{to}C}$. This can be translated to order to perform clearing to restore the normal $\mathbf{G_{to}C}$.

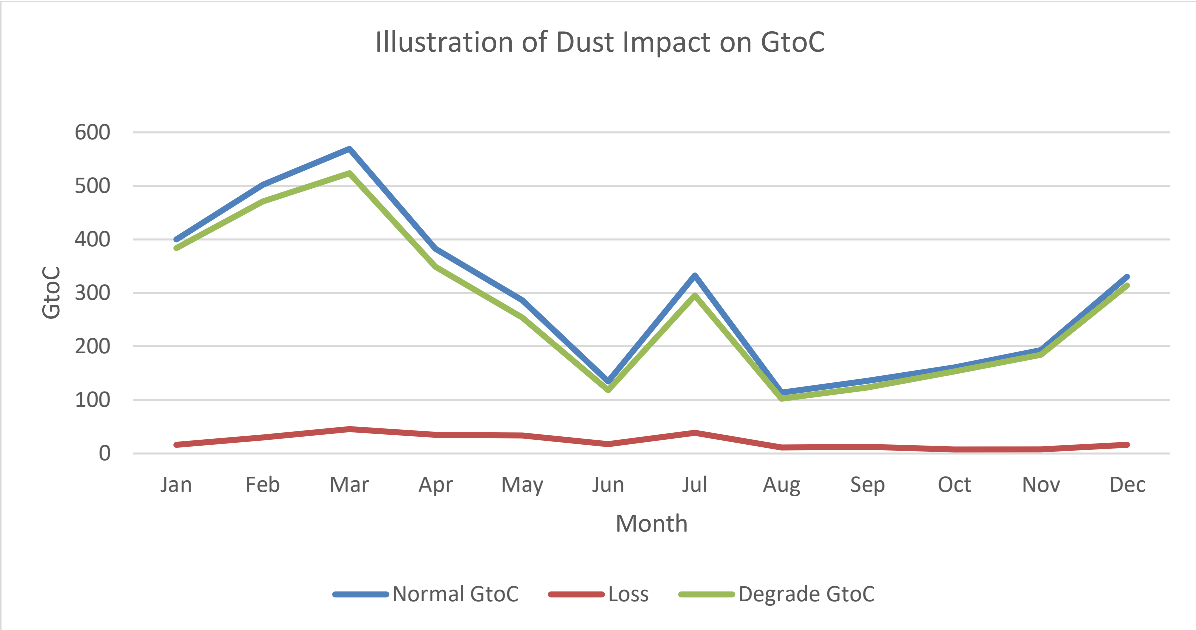


Figure 4.16: Illustration of dust impact on $\mathbf{G_{to}C}$

Source: Author

4.7. Summary

This chapter presented detailed analysis of various configuration scenarios to establish the feasibility for deploying SPs in Qatari houses and businesses roofs. The comparison between estimated generated energy from different settings of SPs of varying efficiency, total panel size, and sun exposure per day in each month clearly reveals the great potential for some settings that can enable properties to generate sufficient clean energy that can satisfy their own consumption, and even produce a surplus.

Some settings with medium to high panel efficiency and good panel size can provide very good investment potential, generating extra energy that can be sold back to grid or internationally, especially during the winter period when Qatar maintains relatively high solar exposure but electricity demand is lower due to less requirement for active cooling (which are coincidentally the times of peak energy demand in temperate and colder countries, which could be potential export markets for Qatar's solar power generation).

This study also indicates that $\mathbf{G_{to}C}$ is a reliable indicator for simple comparison. In addition, it can be used in a wider scale to establish DDM to support energy management and decision making. Since this study has been phased on analytical solutions, it would be useful to correlate these results with some other results obtained from real-life SP installation scenarios, in order to fully establish the performance under various operational scenarios.

CHAPTER 5
ASSESSING THE POTENTIAL OF QATARI HOUSE ROOFS FOR SP INSTALLATIONS: A FEASIBILITY SURVEY

5.1. Introduction

Qatar's ambitious Vision 2030 includes a major shift towards clean energy, and residential SPV installation can be an obvious option, given its abundant sunlight and high power for residential cooling. Despite significant SP farm investment, there has been limited progress in deploying SPs 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 SP installation across Qatar, considering space availability, currently utilised space, remaining space, shading, and roof type. It also provided indication on potential obstacles and shading that might affect panel sunlight exposure. The results showed that there is significant potential for installing SPs on Qatari houses, 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 provide insights for policymakers and stakeholders to develop strategies to affirm and actualise Vision 2030, and tangibly move towards clean energy in Qatar.

5.2. Chapter Methodology

To evaluate the feasibility of installing SPs on homes in Qatar, a survey was conducted using manual approach with a structured interview sheet with closed-ended questions as the data collection method (as shown in Appendix 2), based on previous literature (as explained in Table 5.1). The reason for opting for manual surveying instead of remote sensing methods, such as the use of satellite images (Starková, 2020), is primarily due to cost, accessibility, and issues related to legal and ethical approvals. Additionally, the use of drones has been considered; however, drone surveying is not currently authorised in Qatar except in exceptional cases (AL-Dosari, Hunaiti and Balachandran, 2023).

The survey aimed to gather data on the availability of space for SP installation, currently utilised space, remaining space, shading, and roof type. The use of a structured interview sheet with closed-ended questions provided a standardised approach to data collection and made the process more efficient. Closed-ended questions were used to collect quantitative data, which could be easily analysed statistically to identify patterns and relationships in the data (Fink, 2019). As shown in Figure 5.1, the research design for this chapter consisted of four stages. 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 5.1.

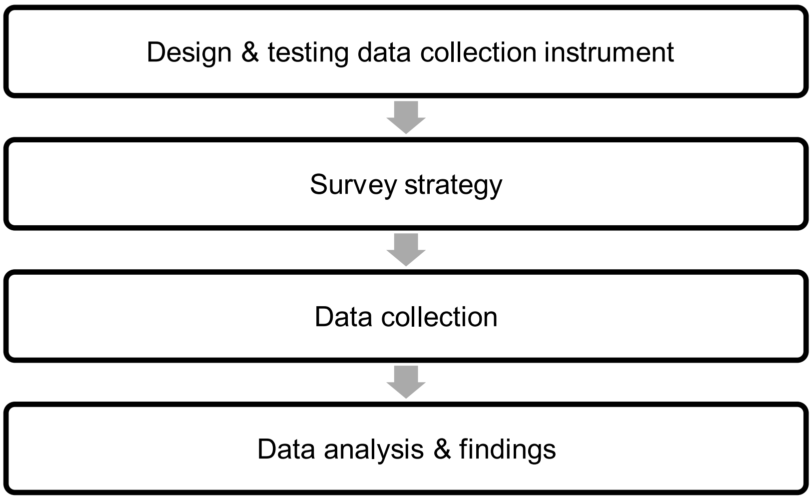


Figure 5.1: Research design

Source: Author

Table 5.1: Collected data and justification

Interview question	Rationale
House location	The location of a house in the field survey is essential to obtain accurate geographical representation (Torcellini and Crawley, 2006; Dikgole, 2018).
Number of similar houses in the street or compound	Understanding the number of similar houses in the same street or compound can help in achieving wider sample and representative sample for the study (Dillman, Smyth and Christian, 2014). Moreover, it can provide valuable insight when considering the installation of SPs. This information can be used to determine the potential for a community solar installation, whereby multiple households can share the cost and benefits of a single SP array. By pooling resources and collectively generating RE, these households can reduce their carbon footprint and save money on their energy bills. Additionally, a community solar installation can help build a sense of community and promote sustainable living practices (Dikgole, 2018; International Renewable Energy Agency, 2024).
Number of bedrooms in the house	The number of bedrooms in a house can provide valuable information when considering the installation of SPs. This information can be used to estimate the amount of energy consumed by the household and determine the optimal number of panels required to generate sufficient energy. Additionally, understanding households' energy usage patterns can help identify areas where energy conservation measures can be implemented, to further reduce energy consumption and increase the effectiveness of the SP installation (International Renewable Energy Agency, 2024).
Items on the roof	Before installing SPs on a roof, it is important to identify any existing objects that may interfere with the installation process or limit the amount of available space. These objects can include AC units, chimneys, skylights, and other structures. Evaluating the current use of these objects and their placement on the roof can help determine the best approach for SP installation (Torcellini and Crawley, 2006).
Approximate total roof size (m^2)	Determining the approximate size of a roof (in square metres) is essential when considering the installation of SPs. This information can be used to calculate the amount of viable free space available for SP installation (Torcellini and Crawley, 2006).
Average remaining empty space on roof	When considering the installation of SPs on a roof, it is important to evaluate the available space to determine the optimal configuration for energy generation. The average remaining empty space on the roof, such as areas not obstructed by vents, chimneys, or skylights, can be utilised to maximise the number of panels installed and the amount of energy generated. Additionally, proper planning and design can ensure that the panels are installed in a way that is aesthetically pleasing, which blends seamlessly (i.e., with minimal obtrusiveness) with the roof's architecture (Torcellini and Crawley, 2006).
Recreational use of roof	Before considering the installation of SPs on a roof being used for recreational purposes, it is important to evaluate the potential impact on those activities. Depending on the size and orientation of the panels, they may obstruct or limit the use of the roof for leisure activities (Torcellini and Crawley, 2006). However, with proper planning and design, SPs can also serve a dual purpose, providing shade and protection for recreational use while generating RE for the home (Dikgole, 2018).
Roof type	When considering the installation of SPs on a house, it is important to evaluate the type of roof and its condition, the roof orientation, and angle, to ensure the panels will receive adequate sunlight. A thorough assessment of the roof's suitability for solar installation can help maximise the benefits of RE for the home (Torcellini and Crawley, 2006).

Table 5.1: Collected data and justification

Interview question	Rationale
House height	To determine the feasibility of installing SPs on a particular house, it is important to consider the height of the building in relation to the surrounding structures. If neighbouring buildings are significantly taller and block direct solar radiation (i.e., being located to the east or west), it may be difficult to achieve optimal sun exposure for the panels (Torcellini and Crawley, 2006). Additionally, the angle and orientation of the roof must also be considered. Proper evaluation of these factors can help ensure that the installation of SPs will be effective and efficient, maximising the benefits of solar energy for the home (Dikgole, 2018).
Solar shading	Solar shading refers to the process of identifying whether nearby buildings, high trees, or other objects have the potential to obstruct the sun's rays from reaching a particular area, such as a rooftop or a SP installation. By understanding the potential for shading, effective measures can be taken to optimise the amount of sunlight that reaches the designated area, thereby maximising energy generation and reducing the need for additional energy sources (Torcellini and Crawley, 2006).

Source: Author

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 neighbourhoods 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 (2022) *Annual Statistics Report 2021*.

The third stage of the research design involved data collection. To facilitate this process, the interview questions were digitised into an electronic form that allowed for convenient and efficient data collection on the spot (Salgado, Segura, and León, 2017). 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 (Creswell and Creswell, 2018). 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 analyse and interpret the data.

The final stage of the research design involved data analysis and presentation of 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 (Khan, 2017). 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 (Hulland, 1999). Furthermore, the use of objective data in presenting research findings helps to draw meaningful conclusions.

5.3. Results

The sample size of the study is an important factor in determining its statistical significance and generalisability (Krejcie and Morgan, 1970). In this study, 11 homes were surveyed from 10 different areas in Doha, with an additional 1068 similar homes in the same street or compound (Table 5.2). Given the relative homogeneity of homes in Qatar (Scheller *et al*., 2021), this sample size is considered large enough to provide a statistically representative sample of the population. According to the rule of thumb, a sample size of at least 384 is needed for a population of 100,000 (Lin *et al*., 2018).

Table 5.2: Areas and number of houses surveyed

Surveyed house area	Number	Similar houses in street or compound
Abu Hamour	1	13
Ain Khaled	1	12
Al Sadd	1	20
Al Waab	3	260
AL-Hilal	1	10
Al-Kheesa	1	700
Lusail	1	8
Musheireb	1	20
The Pearl-Qatar	1	25
Total	11	1068

Source: Author

As seen in the Figure 5.2, the vast majority of homes are relatively large, with 40% being five-bedroom homes and 20% being four-bedroom homes. The remaining 40% are three- and two-bedroom homes.

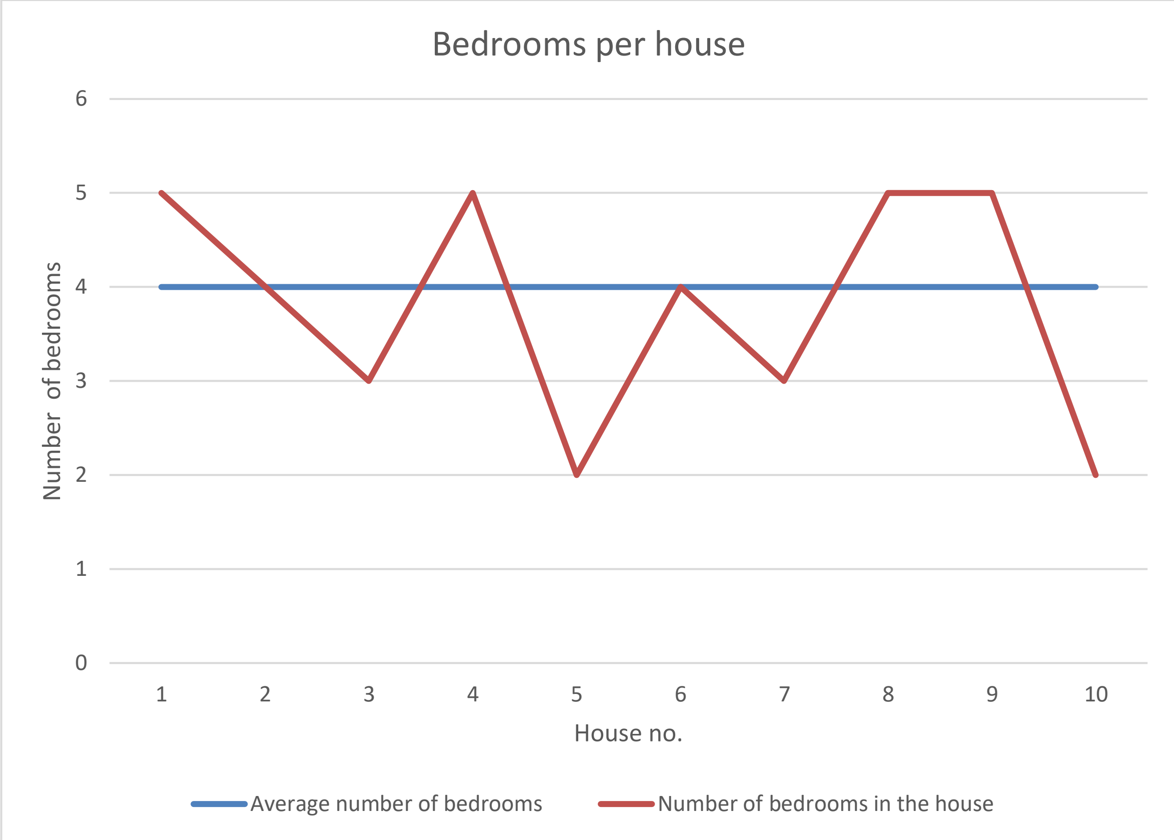


Figure 5.2: Bedrooms per house

Source: Author

The approximate total size in square metres varies between 150 and 500 m^2, with an average of 244 m^2, which is relatively large, as shown in the Figure 5.3.

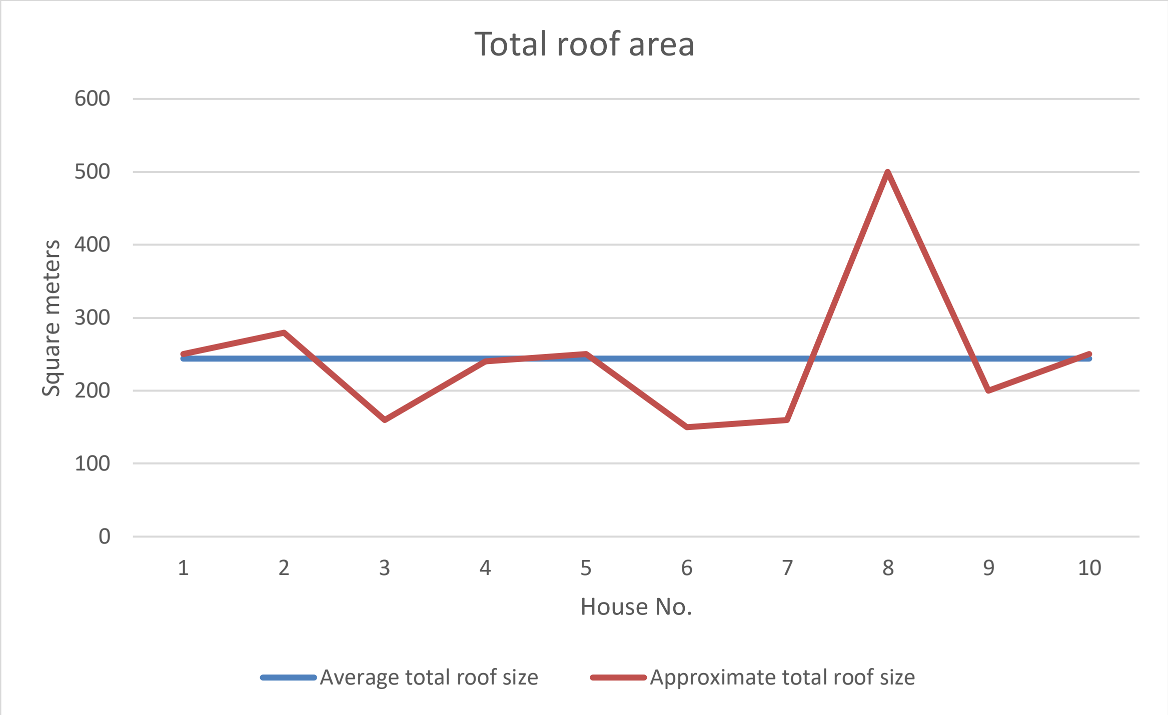


Figure 5.3: Total roof area

Source: Author

Figure 5.4 depicts items on the roof. It is evident that all houses have water tanks, and the vast majority (80%) have external AC units and satellite dishes installed on the roof. However, only 10% of houses have storage sheds, and 20% have SPs for water heating, indicating that these features are less common.

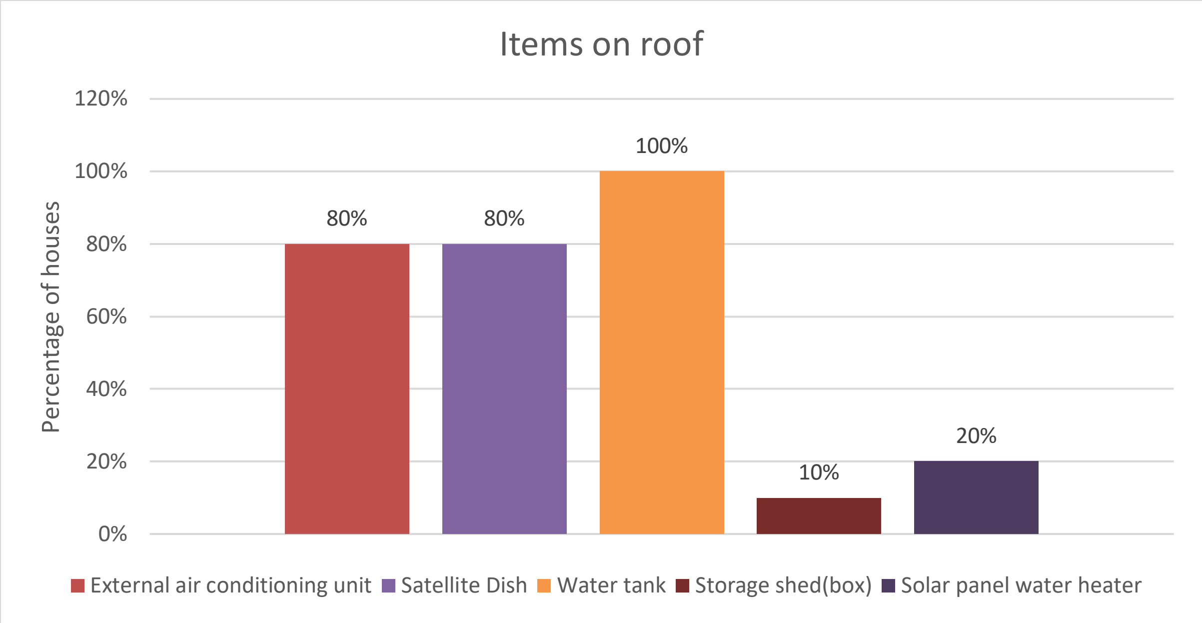


Figure 5.4: Items on roof

Source: Author

Figure 5.5 shows the average remaining empty space on the roof after considering the earlier mentioned items, revealing that 60% to 80% of the roof space is empty (with an average of 59%). This means that over 50% of houses with space can be considered for the installation of SPs.

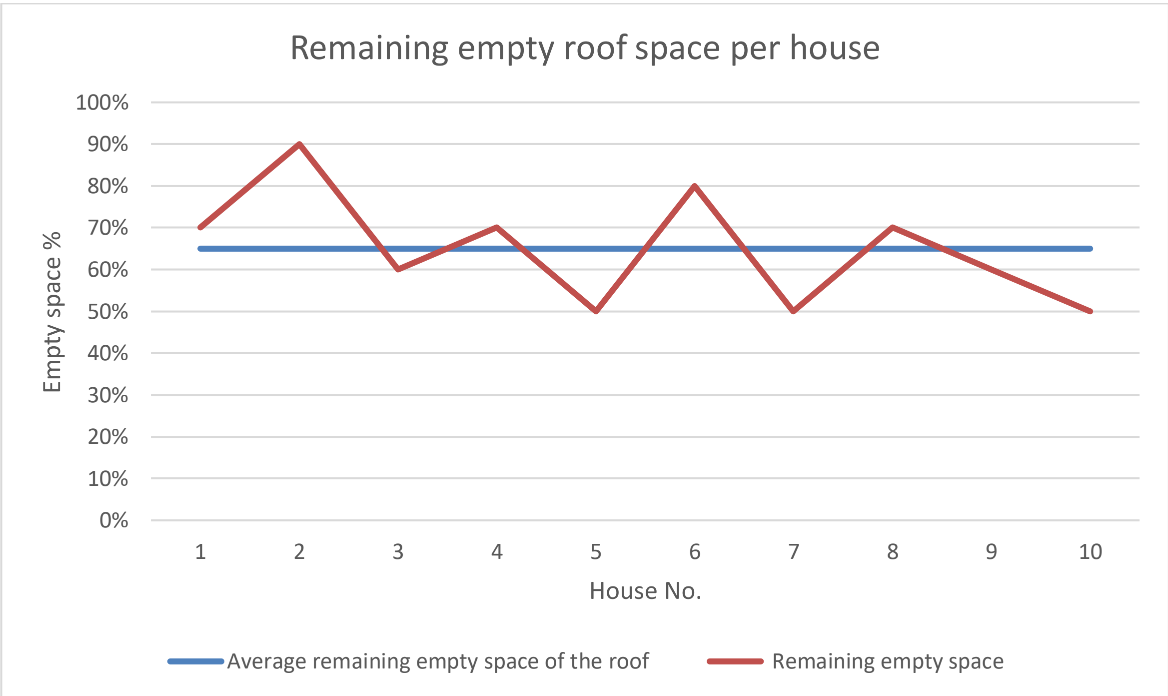


Figure 5.5: Empty roof space per house

Source: Author

Regarding the use of the roof for recreation, Figure 5.6 shows that 90% of respondents confirmed that their roofs were not being used for any other purposes, likely due to the hot climate in the country and modern indoor lifestyles. This means that if the roof were to be used for SP installation, it would not interfere with daily activities in the homes.

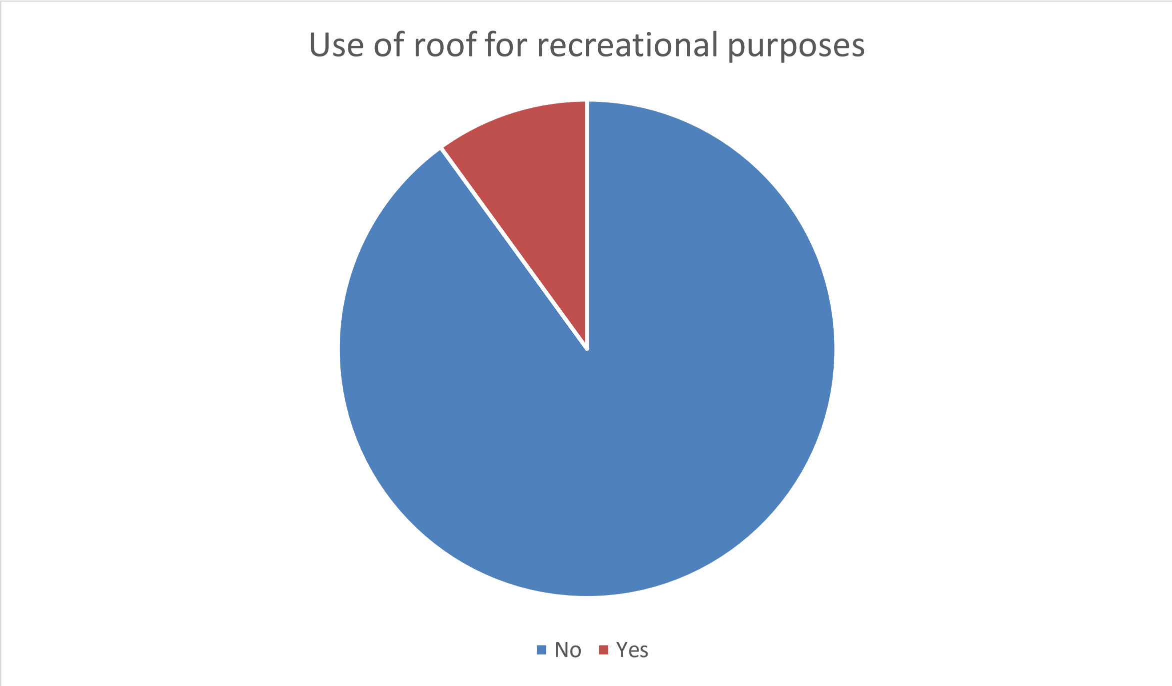


Figure 5.6: Roof use for recreational purposes

Source: Author

As seen in Figure 5.7, 100% of the roofs are flat, which means that they can be utilised to install SPs that can face the angle for maximum energy generation.

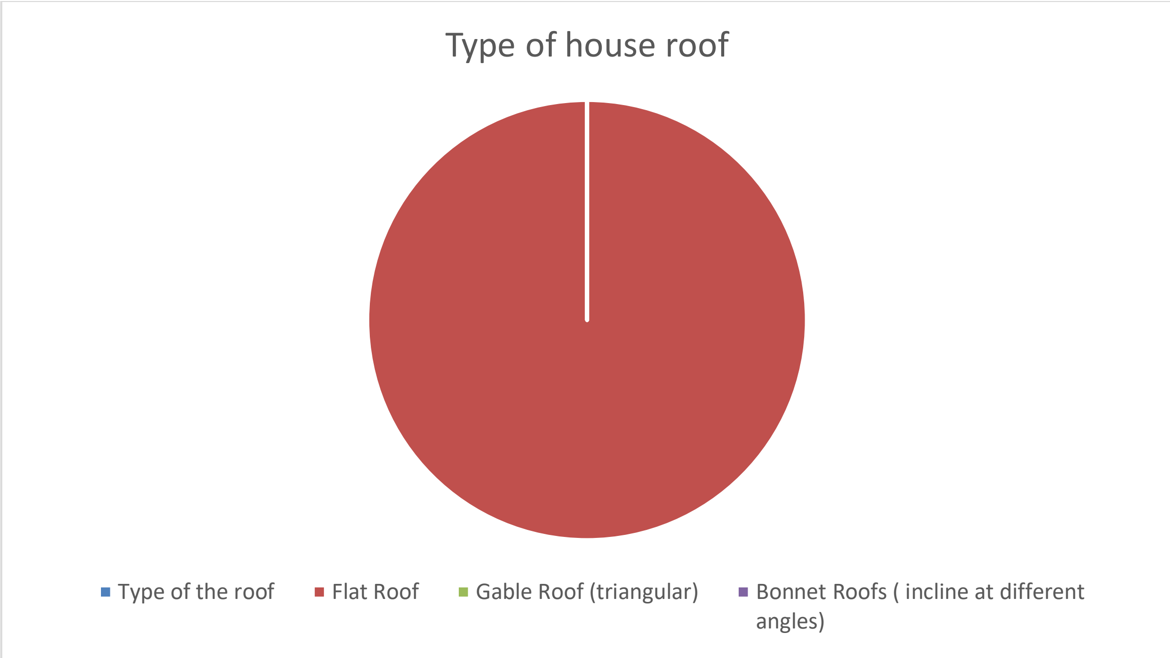


Figure 5.7: Type of house roof

Source: Author

As shown in Figure 5.8, the majority of houses have a height ranging from 7 to 10 metres, indicating that there is less likelihood of shading or obstructing sunlight.

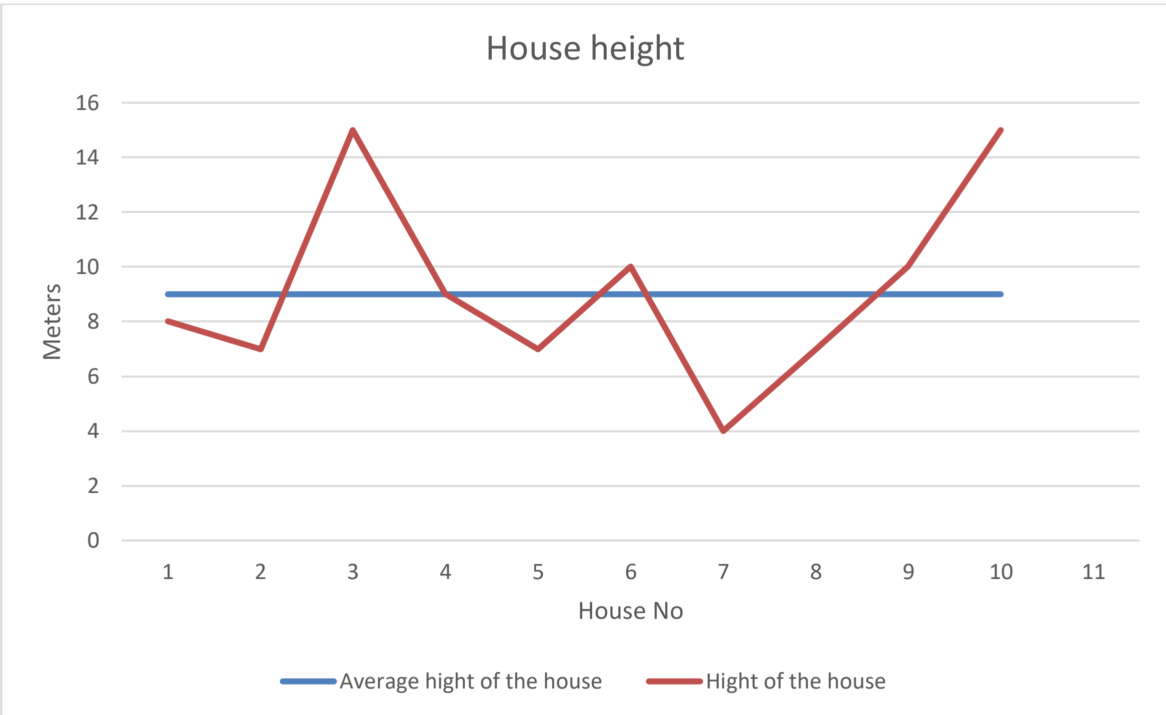


Figure 5.8: House height

Source: Author

Figure 5.9 shows the possibility of shading due to nearby buildings, trees, or other objects, revealing that 70% of surveyed houses do not have any objects that may cause shading, while 30% reported that shading may occur. Therefore, based on the area's results, it is clear that there is high potential for SPV installation to generate an optimal amount of clean energy.

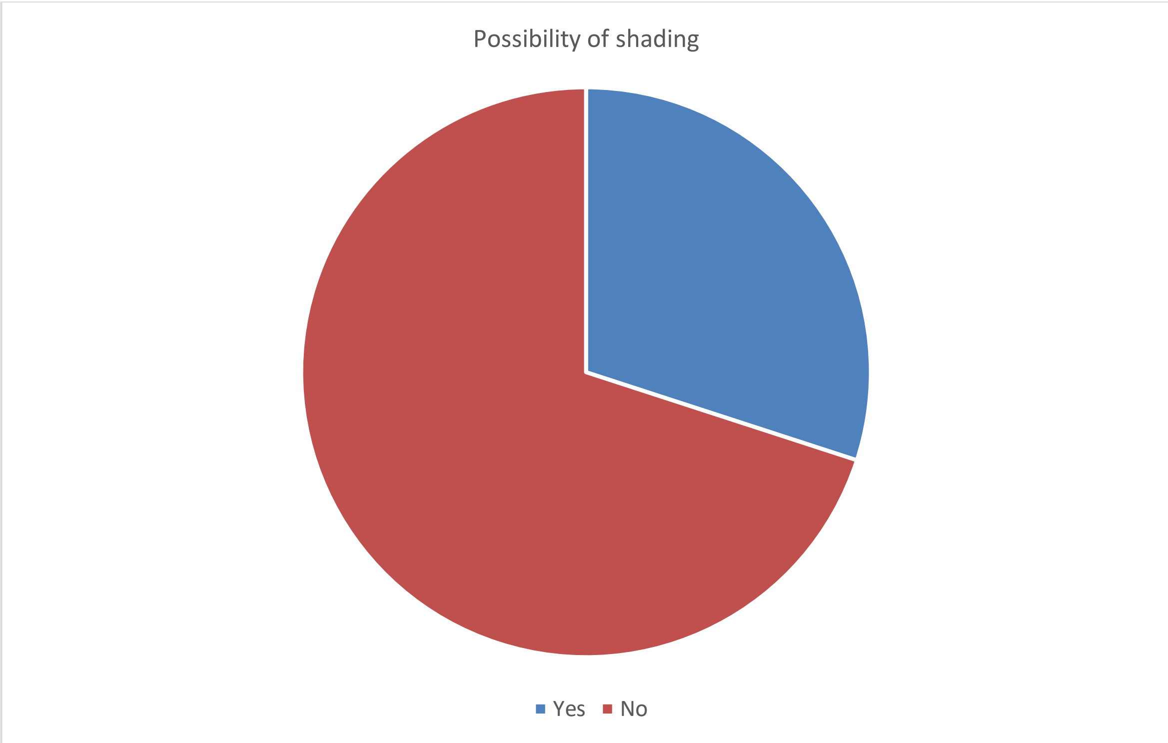


Figure 5.9: Possibility of shading

Source: Author

5.4. Discussion

The presented results indicate that Qatari houses are highly germane to the installation of SPs, due to their relatively large area and spaciousness. The study found that 50% or more of the roof space is available for SP installation without interfering with the daily activities of the homeowners. This is in line with a previous study, which reported that most Qatari houses have spacious rooftops with significant potential for SP installation (Al-Sulaiman and Zubair, 2019). Moreover, the study found that there are limited problems caused by shading (e.g., by trees or tall neighbouring structures etc.). This is because most Qatari houses are of similar height in wholly residential neighbourhoods, 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, SPs can be installed in locations that provide a minimum degree of shading and the best sun view. This is consistent with the findings of Al-Sulaiman and Zubair (2019), which indicated that shading can be minimised by choosing the best location for SP installation. Additionally, SPV 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.

Additionally, this study found that nearly all Qatari houses have flat roofs, providing several advantages for SP installation, as shown in Figure 5.10. Flat roofs are easily accessible, making it convenient for technicians to install SPs. Furthermore, SPs can be installed on stands to face the best orientation, maximising energy generation. The orientation of SPs can significantly affect their performance and energy generation, and flat roofs provide optimum flexibility in this regard (Ayoub and Al-Jibouri, 2021). Indeed, another advantage of flat roofs for SP installation is that they can be installed over an automatic platform, allowing for tracking of the sun for maximum energy generation (which is not possible to the same degree on angled roofs). Tracking systems can improve energy production by up to 25% compared to fixed systems (Gupta and Nayak, 2019). This is especially beneficial for regions with high solar irradiance, such as Qatar.

Figure 5.10: Example of surveyed home roof

Source: Author

Furthermore, the high similarities between homes in Qatar (Scheller *et al.*, 2021) as shown in Figure 5.11, enables 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 SPs, 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 standardisation in building design for RE adoption. For example, Murshed, Shafie and Saidur (2018) found that the standardisation of building design can facilitate the integration of RE systems, particularly in residential buildings, reducing costs by streamlining the installation process.

Figure 5.11: Example of structural homogeneity of Qatari houses

Source: Author

The findings of this study support the potential for SP installation in Qatari houses. With their spaciousness, limited shading, and flat roofs, Qatari houses are ideally suited for SP installation. This is in line with the Qatari government's ambitious goal of generating 200 MW of solar energy by 2022 (Al-Naimi, 2024). By encouraging and facilitating the installation of SPs in homes, Qatar can move towards a more sustainable future.

5.5. Summary

This chapter has successfully achieved its primary objective of assessing the suitability of Qatari houses for SP installation. The obtained results are highly promising and offer significant value to various stakeholders involved in decision-making regarding the deployment of SPs in residential areas. Furthermore, these findings hold invaluable importance for the parties responsible for the deployment, as they can utilise them to develop a comprehensive national strategy for replicating the deployment plan in different regions, considering the high similarities observed among homes in Qatar.

However, to draw a definitive conclusion, it is recommended to conduct real pilot projects involving the installation of SPs in actual homes and gather additional information on their performance *in situ*. Such initiatives could provide crucial insights into potential challenges that may arise during installation and usage, allowing for 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 SP installation in Qatari houses. 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.

CHAPTER 6
SOLAR SYSTEM PERFORMANCE DATA-DRIVEN MODEL: ASSESSING THE IMPACT OF DUST ACCUMULATION AND PANEL EFFICIENCY DEGRADATION OVER TIME

6.1. Introduction

The deployment of $\mathbb{SP}$s plays a vital role in generating clean energy and fulfilling countries' targets for carbon reduction. However, to sustain the energy output of $\mathbb{SP}$s, regular monitoring and maintenance are crucial. This is particularly significant in countries with harsh environments, such as Qatar, where dust poses a significant challenge to $\mathbb{SP}$ performance, leading to substantial energy degradation, as explained below. In response to this challenge, this chapter proposes a DDM that facilitates cost-effective monitoring of homes $\mathbb{SP}$s and enables decision-makers to make informed decisions by leveraging $\mathbf{G_{to}C}$ data. The model seeks to address the impact of dust accumulation on $\mathbb{SP}$s and panels' efficiency degradation over time and support the efficient management of the $\mathbb{SP}$ system.

6.2. Data Driven Model for SP Systems

Regular monitoring, maintenance, and upgrades are crucial for the long-term sustainability and efficiency of SPV systems (Olorunfemi, Ogbolumani and Nwulu, 2022). While advanced monitoring technologies, such as IoT and IWSNs, are utilised in large $\mathbb{SP}$ plants for performance evaluation (Siddikov *et al.*, 2020), such technologies are too costly for smaller and localised private applications. Therefore, there is a need for a practical and affordable approach like the $\mathbf{G_{to}C}$ ratio for homes and businesses with a limited number of $\mathbb{SP}$s. Additionally, having enough data is essential for making the right decisions and establishing strategies. For instance, $\mathbf{G_{to}C}$ can be used as an indicator to support decision-making when the government desires to establish national RE policies, to incentivise teams and consumers to install $\mathbb{SP}$ systems or support solar energy generation.

The implementation of $\mathbf{G_{to}C}$ within a data-driven decision support system can assist various stakeholders in developing effective strategies and making informed decisions (Power, 2008). Moreover, $\mathbf{G_{to}C}$ can be used as an indicator to compare the current reading with the previous reading, when the system was at its peak performance, to support planning, cleaning, maintenance, or replacement of parts or whole systems. This is crucial as dust, dirt, and ageing can reduce the performance of PV systems, particularly in Qatar, where high dust density occurs during specific months of the year (Touati *et al*., 2017). For example, if the $\mathbf{G_{to}C}$ changes, it could indicate a decline in panel performance, which can be restored by performing cleaning to restore the normal $\mathbf{G_{to}C}$. Figure 6.1 illustrates how dust can affect $\mathbf{G_{to}C}$ data.

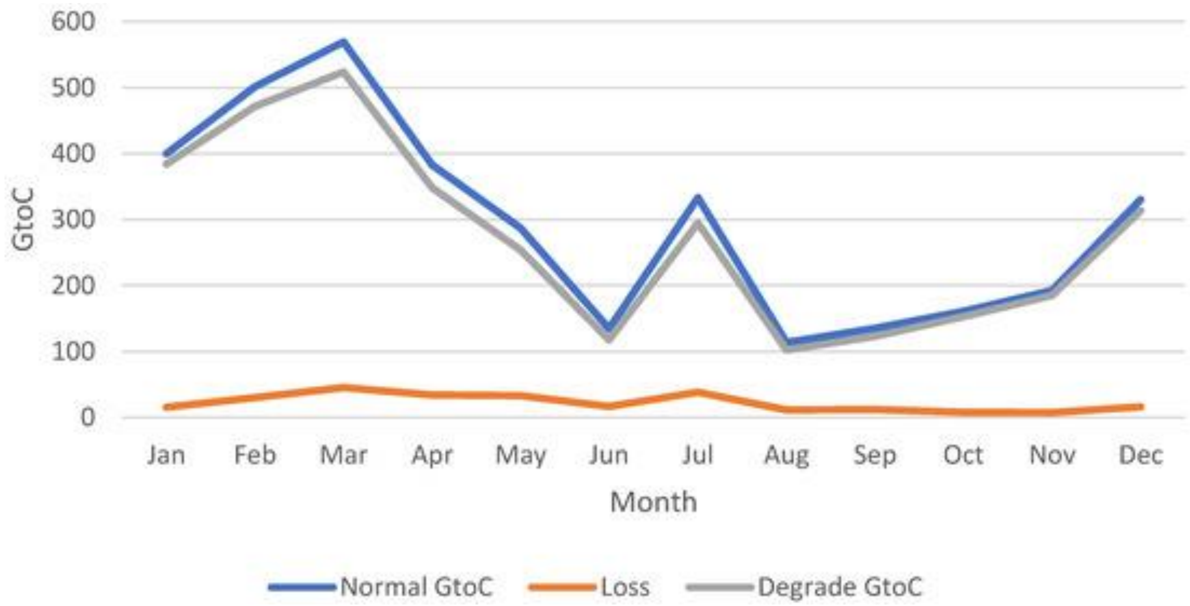


Figure 6.1: Illustration of dust impact on $\mathbf{G_{to}C}$

Source: Author

6.3. Methodology

6.3.1. Overview

As the objective is to introduce a data-driven system as a new mechanism to improve decision-making for solar roof panels, this analysis adopted the well-known Plan–Do–Study–Act (PDSA) methodology, which has been widely used within healthcare and other industries to improve processes and achieve desired outcomes (Figure 6.2) (Langley *et al*., 2009; Taylor *et al*., 2014). PDSA is used in this study to establish the DDM's effectiveness relative to the purposes of this research project. The PDSA cycle is a four-step iterative process that involves planning, executing, evaluating, and refining a change (Langley *et al*., 2009). It begins with the Plan phase, where a problem is identified, and a plan is developed to address it. In the Do phase, the plan is implemented, and data is collected. The Study phase involves analysing the data collected in the previous step, to determine if the plan was successful in addressing the identified problem. Finally, in the Act phase, the findings from the Study phase are used to refine and improve the plan, which is then implemented again in the next PDSA cycle.

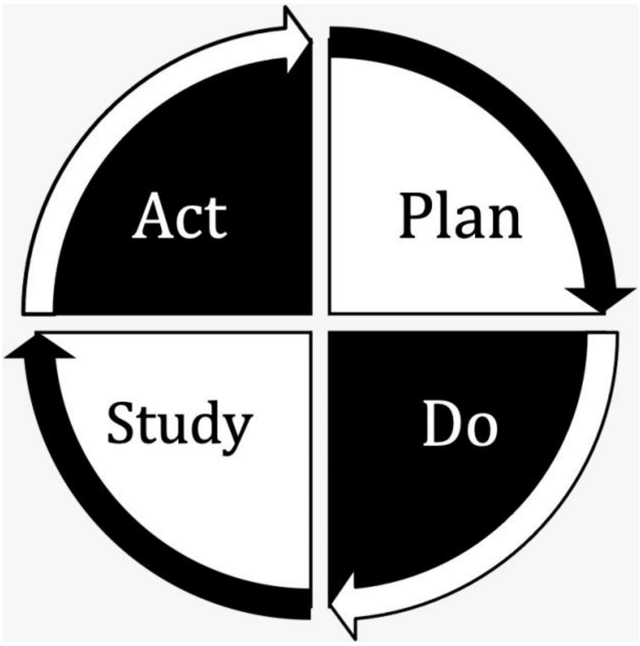


Figure 6.2: PDSA cycle

Source: Langley *et al*. (2009)

Adopting PDSA as a methodology for establishing a data-driven decision support system for SP roofs can be effective because it allows for continuous improvement of the system over time.

- The Plan phase can involve identifying areas where data can be collected, and developing a plan for collecting and analysing that data.
- In the Do phase, the plan can be implemented, and data can be collected from $\mathbf{G_{to}C}$.
- In the Study phase, the data can be analysed to identify patterns or trends, and to determine if the system is meeting its intended goals.
- Finally, in the Act phase, the findings can be used to refine the system and improve its performance in subsequent PDSA cycles.

6.3.2. Method for creating DDM

As can be seen in Figure 6.3, the process of creating a DDM (Davis, 2022), involves several key stages, as supported by Smith, Johnson and Anderson (2020). It begins by defining the mission or problem at hand and then proceeds to identify the relevant data sources. Once the data is collected, it undergoes a thorough cleaning and organising process to ensure its quality and suitability for analysis (Adams, 2019). The next stage involves performing statistical analyses on the cleaned and organised data, utilising appropriate methods and techniques

(Jones and Williams, 2017; Brown, 2021). This step aims to extract meaningful insights, identify patterns, and derive conclusions based on the information derived from the data and statistical analysis (Jones and Williams, 2017).

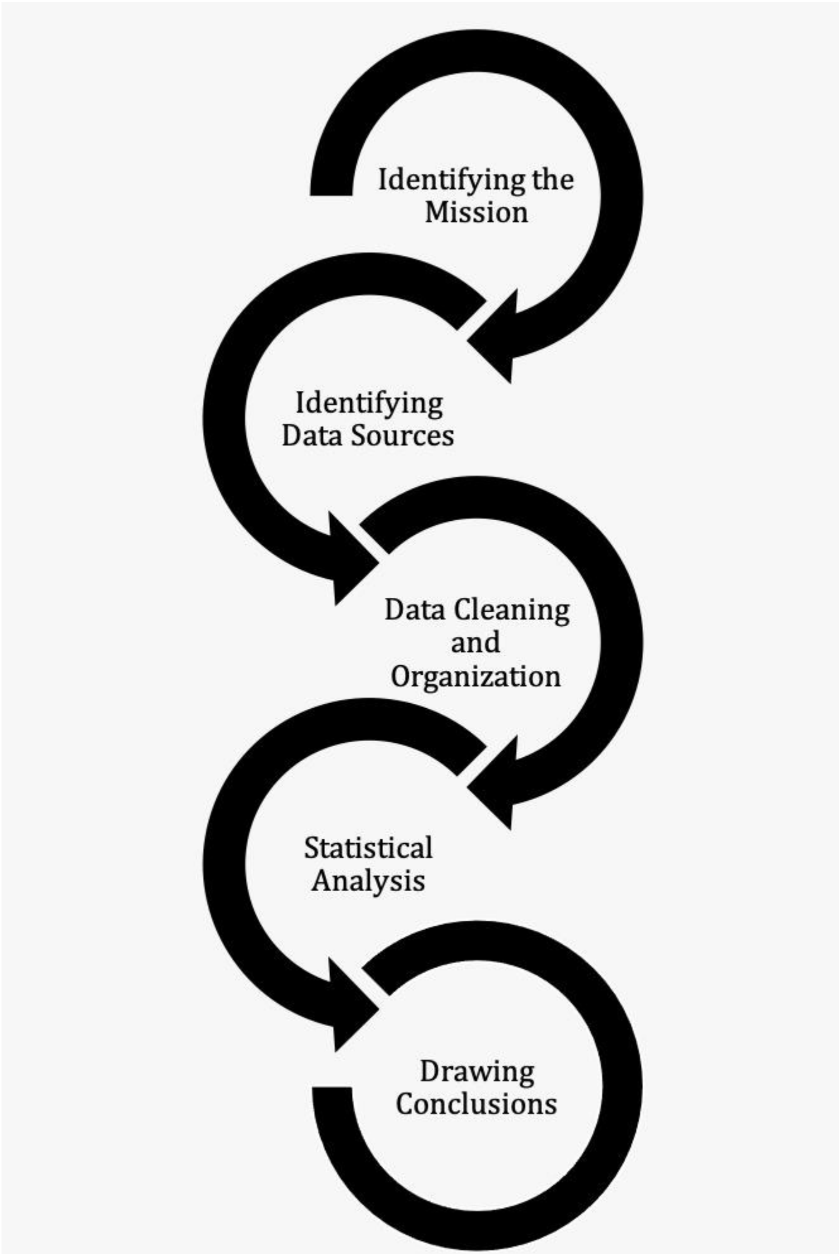


Figure 6.3: Process of creating a DDM model

Source: Davis (2022)

MATLAB toolboxes (Sherfey *et al*., 2018), can be used to perform modelling due to their strong capabilities and specialisations, especially the "Fuzzy Logic Toolbox" and "Neural Network Toolbox", which are well-suited for handling small data sets (as pertinent to this research). This study adopted the neuro-fuzzy approach, specifically using an adaptive neuro-fuzzy inference system (ANFIS), due to its capability to combine the learning power of neural networks with the interpretability and generalisation strengths of fuzzy logic.

This hybrid methodology is particularly advantageous when working with limited data, as it allows for effective generalisation and the incorporation of uncertainty into the model, leading to more reliable predictions. MATLAB's extensive optimisation tools were utilised to fine-tune the parameters of the neuro-fuzzy system, maximising the extraction of valuable information from the small data set. Furthermore, MATLAB's pre-built functions and powerful data visualisation capabilities streamlined the implementation process in this research, enabling efficient exploration and validation of the model.

6.4. Proposed DDM

Countries like Qatar are prone to sandstorms, which can lead to the accumulation of sand on SPs and degrade the amount of energy generated (Guo *et al*., 2015; Javed *et al*., 2017). The proposed DDM, as depicted in the Figure 6.4, aims to contribute to the monitoring of changes in the performance of SP systems. By comparing the amount of $\mathbf{G_{to}C}$ under ideal working conditions with the amount of $\mathbf{G_{to}C}$ after dust accumulation, statistical analysis can determine if the impact of dust significantly degrades the amount of energy generated. This analysis can be conducted for a single home, a specific region with multiple homes, homes distributed across a city, or the total number of homes in a country. Based on these findings, informed decisions can be made to address the impact of dust accumulation on SP performance.

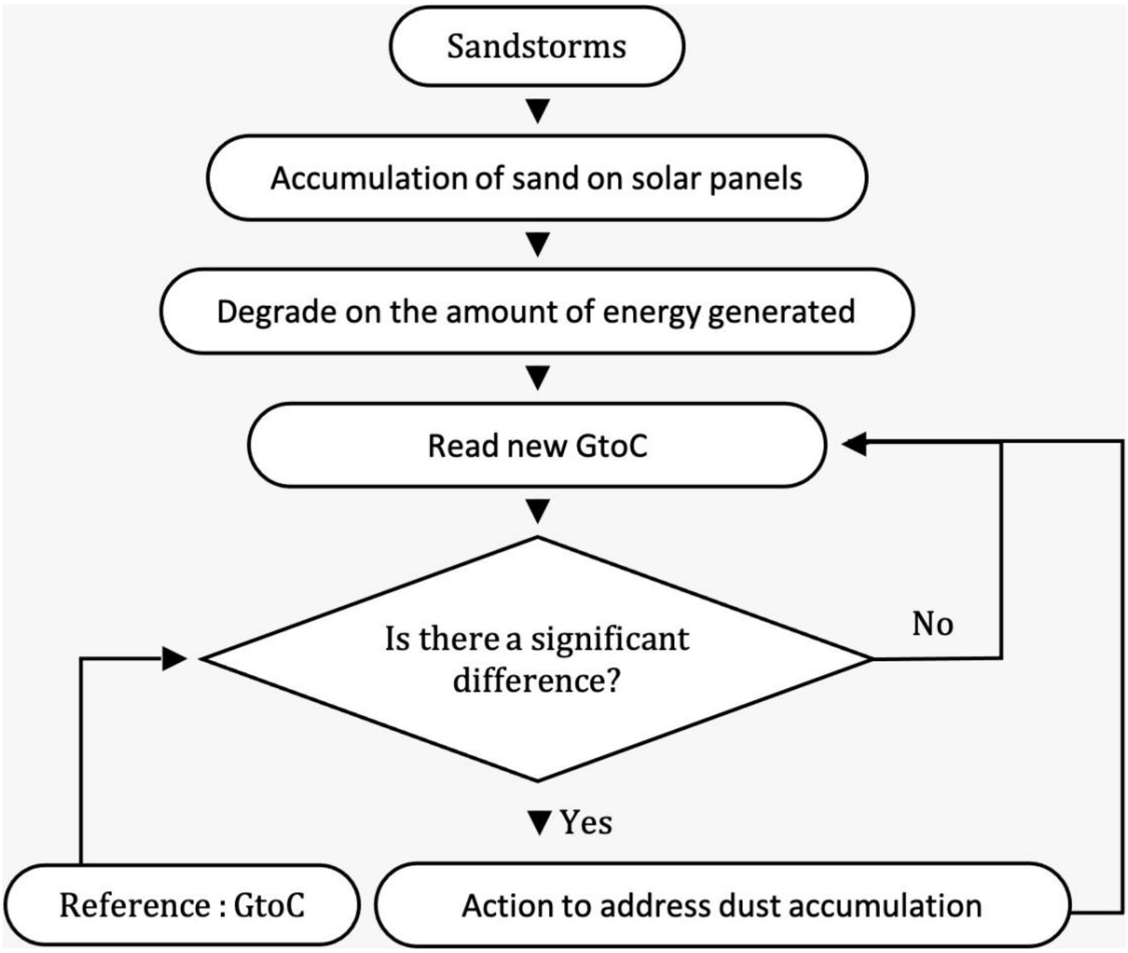


Figure 6.4: DDM Flowchart

Source: Author

6.4.1. Identifying mission/problem

SPs may experience degradation in the amount of generated energy due to aging, lack of maintenance, and other reasons (Kaldellis and Zafirakis, 2011). It is important to monitor the extent of this degradation in order to determine the necessary course of action. With multiple SPs installed on home roofs, a reactive approach is often taken, waiting until the system completely stops or experiences a significant drop in energy generation before conducting checks. However, a proactive approach is more advantageous for sustaining clean energy generation (Makrides, Schubert and Georghiou, 2017). Therefore, the objective of this study is to establish a mechanism that can effectively identify degradation in the amount of energy generated by home SPs, providing stakeholders with valuable information to make informed decisions.

6.4.2. Identifying data sources

Identifying the right data sources is a critical factor in enabling the proposed approach to function as intended. In the related research conducted, it was found that the "generated to consumed energy" indicator can serve as a simple and useful data source (Smith, Johnson and Anderson, 2020). The $\mathbf{G_{to}C}$ indicator can be extracted from a single home, a specific region, or even the entire country, depending on the analyses needs to be made. By utilising this data, valuable insights into energy generation and consumption patterns, which can inform decision-making processes by different stakeholders and support the development of sustainable energy strategies. As previously established in Chapter 4, $\mathbf{G_{to}C}$ data provides a wealth of information that can be used to supply DDMs with the necessary data to make informed decisions. $\mathbf{G_{to}C}$ data can be generated based on the equations expounded in section 4.4 (i.e., Eq. 4.1-4.4) for estimated daily SP generation, $\mathbf{G_{to}C}$, average $\mathbf{G_{to}C}$ for number of homes in city, and national $\mathbf{G_{to}C}$ (respectively).

6.4.3. Cleaning and organising data

Cleaning and organising the data in DDMs is crucial to ensure accurate and reliable results. It is important to note that only 20% of the data is used for analysis, in order to make informed decisions, and organising the flow of the data is essential to ensure a meaningful approach that captures relevant information (Johnson *et al*., 2019). In this research, the implementation of the tree-topology approach is considered the most appropriate, as it enables a better flow and collection of data for subsequent statistical analysis. This approach offers several advantages, including improved data handling, efficient data processing, and enhanced data integrity (Johnson *et al*., 2019). By utilising this approach, the collected data can be managed and analysed, effectively; leading to more accurate and reliable research outcomes. Figure 6.5 illustrates the tree topology, which facilitates the collection of $\mathbf{G_{to}C}$ data across three tiers: home, city, and national levels. This hierarchical structure allows for statistical analysis to be conducted at different levels, enabling informed decision-making based on the data obtained from each tier.

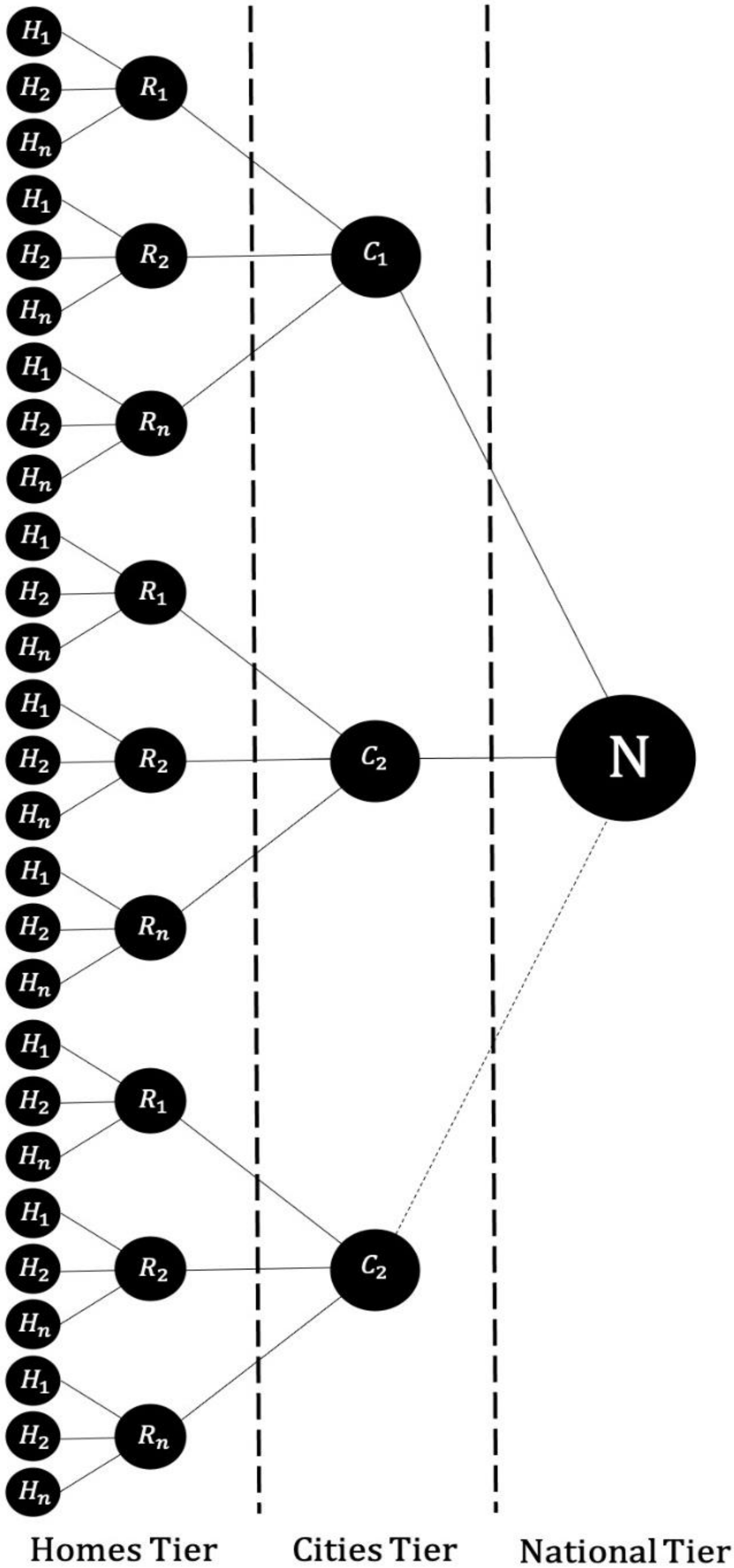


Figure 6.5: Tree DDM topology

Source: Author

In order to establish a DDM to support decision-making regarding the impact of dust accumulation on $\mathbf{SP}$ performance and energy generation, an assumption was made based on a study of 100 homes. The $\mathbf{G_{to}C}$ data was calculated using information from YES Energy Solutions (2024), as reported in Chapter 4, representing the ideal operational scenario. Subsequently, the data was degraded at different levels, including -5%, -10%, and -20%, as shown in the Table 6.1. This degraded data was then utilised to feed the model and perform the subsequent stage of statistical analysis, transforming the data into meaningful information that can be understood by various stakeholders.

Table 6.1: Used $\mathbf{G_{to}C}$ data

Month	Degradation Situation				
	0%	-5%	-10%	-15%	-20%
January	39.8208	37.82976	35.83872	33.84768	31.85664
February	42.5856	40.45632	38.32704	36.19776	34.06848
March	44.2368	42.02496	39.81312	37.60128	35.38944
April	47.6928	45.30816	42.92352	40.53888	38.15424
May	50.5728	48.04416	45.51552	42.98688	40.45824
June	51.2256	48.66432	46.10304	43.54176	40.98048
July	50.9568	48.40896	45.86112	43.31328	40.76544
August	48.2304	45.81888	43.40736	40.99584	38.58432
September	46.464	44.1408	41.8176	39.4944	37.1712
October	43.2	41.04	38.88	36.72	34.56
November	39.936	37.9392	35.9424	33.9456	31.9488
December	39.0528	37.10016	35.14752	33.19488	31.24224
Av. $\mathbf{G_{to}C}$	**45.3312**	**43.06464**	**40.79808**	**38.53152**	**36.26496**

Source: Author

6.4.4. Statistical analysis

Statistical analysis is a powerful tool used to uncover patterns, trends, and relationships within data. It involves collecting, organising, analysing, interpreting, and presenting data to make informed decisions or draw conclusions. By employing various statistical techniques, such as descriptive statistics, inferential statistics, regression analysis, and hypothesis testing, statisticians can extract valuable insights from datasets of varying sizes and complexities. Statistical analysis plays a crucial role across numerous fields, including science, business, economics, healthcare, and social sciences, helping researchers, analysts, and decision-makers make evidence-based decisions and predictions.

6.4.4.1. Descriptive analysis

Descriptive analysis allows for the representation of data and provides a general overview of its behaviour. This analysis, such as calculating means, is extracted from the data presented in Table 6.1. The radar plot in Figure 6.6 illustrates the different degradation scenarios, enabling a comparison of each degradation level with the ideal scenario. Additionally, comparing the $\mathbf{G_{to}C}$ average for each degradation case with the average of the ideal scenario, as depicted in the Figure 6.7, offers another method of assessing the different levels of degradation. However, it is important to note that descriptive analysis alone does not provide a meaningful comparison to determine if the changes are significantly different from the ideal scenario. To contextualise these findings and gain further insights, a comparative analysis should be incorporated. By combining descriptive and comparative analyses, the situational implications of the data can be better understood (Freund and Wilson, 2003).

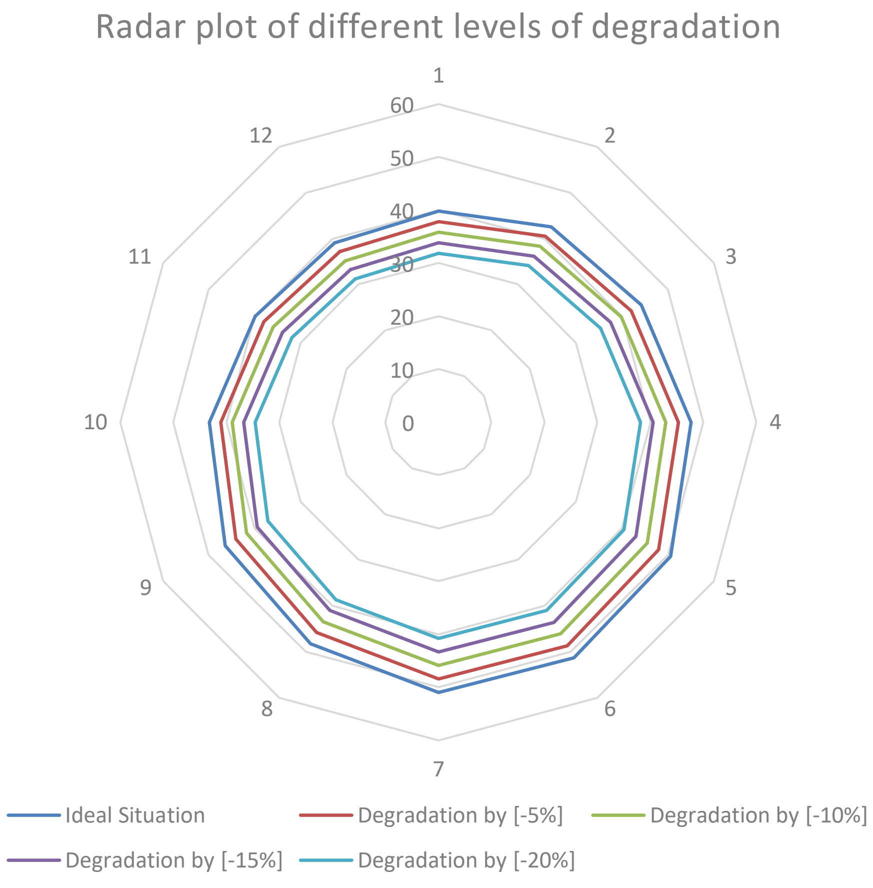


Figure 6.6: Radar plot of different levels of degradation

Source: Author

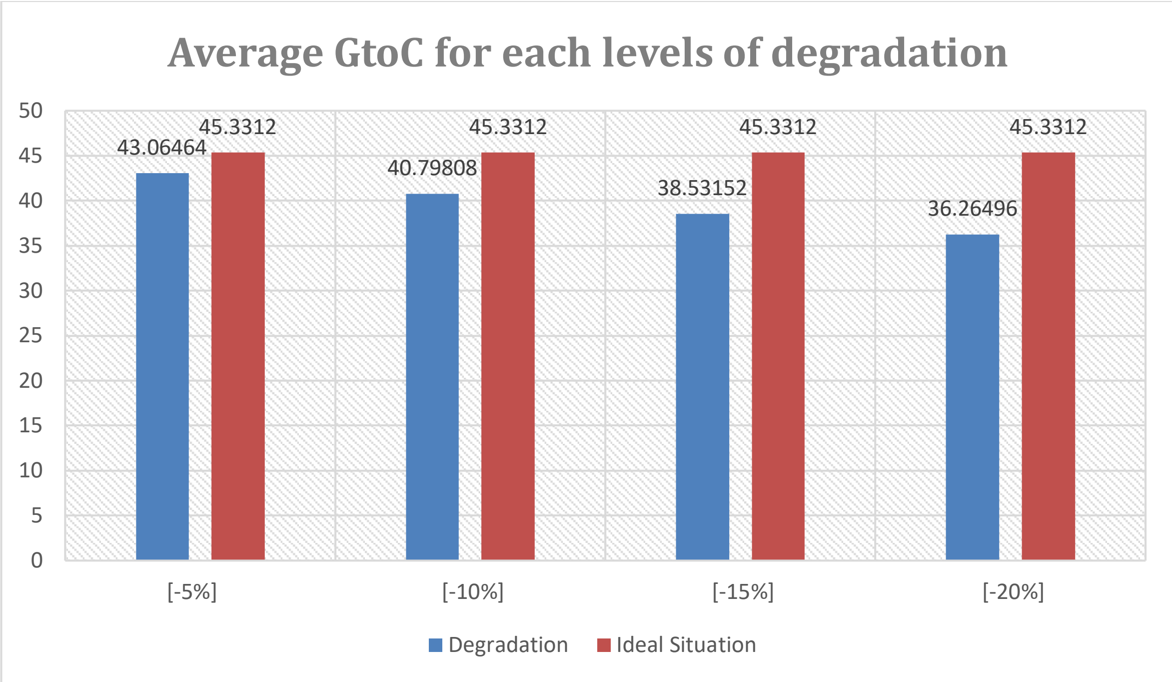


Figure 6.7: Average $G_{to}C$ for each levels of degradation

Source: Author

6.4.4.2. Comparative analysis

Comparative analysis is a valuable approach for making meaningful comparisons between the degradation situation and the ideal situation. Since the comparison involves two distinct groups, conducting statistical tests becomes essential. One well-known test for such comparisons is the t-test, which examines the means of each group and determines if there is a significant difference. In cases where the level of degradation is high, the statistical test will reveal a significant difference (Freund and Wilson, 2003).

Table 6.2 displays the results of various tests conducted to compare the different levels of degradation with the ideal situation. These tests involve calculating the t-value and p-value to establish the level of significance. The t-value reflects the extent of degradation, with higher values indicating greater degradation. The p-value is crucial for determining whether the observed degradation is statistically significant or not.

Table 6.2: Summary of t-test statistical analysis data

Degradation	Calculated t-Value	Calculated *p* Value	Result Significance [Yes/No]
-5%	1.26911	0.108832	No
-10%	2.60228	0.008132	Yes
-15%	4.00133.	0.000301	Yes
-20%	4.16806.	0.000289	Yes

Source: Author

6.4.5. Visual representation of t-value vs degradation value

Figure 6.8 illustrates the relationship between the t-value and degradation provides decision-makers with a visual representation that facilitates the understanding of the statistical findings presented earlier. Such illustrations offer decision-makers an intuitive way to interpret the data and make informed decisions based on the observed changes in the line's position. The graph includes a horizontal line marked at 0%, representing the ideal situation. When there is minimal degradation, as seen in the case of a 5% degradation, the line closely aligns with the horizontal line; however, as the value of t increases with greater degradation, the line deviates towards the vertical axis. By observing these changes, decision-makers can determine the appropriate course of action. For example, when the degradation is at 5%, it can be concluded that the situation falls within the normal range. In cases where the degradation reaches 10%, it is recommended to implement a plan for SP cleaning. When the degradation exceeds 15%, it becomes crucial to conduct cleaning to address the significant degradation.

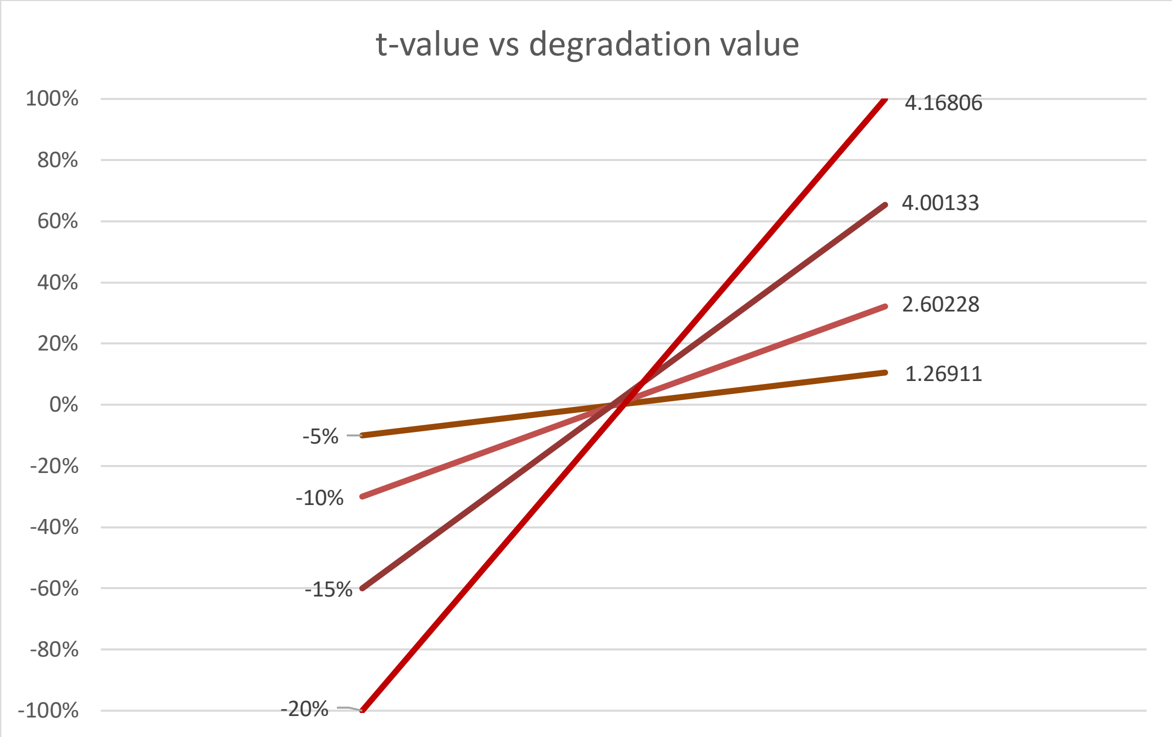


Figure 6.8: Visual representation of t-value vs degradation value

Source: Author

6.5. Integrating Panels' Efficiency Degradation Over Time

Integrating panels' efficiency degradation due to age is a critical consideration in comprehensive modelling for solar energy systems. PV panels experience a decrease in efficiency over time, directly undermining the overall energy output of the system. To accurately depict the long-term performance of such systems, it is imperative to incorporate this degradation factor into the modelling process. In this context, it is observed that the panel efficiency diminishes progressively over the years. The established model incorporates a degradation rate of 2% for the initial year, followed by a subsequent decrease of 7% in each subsequent year (Smith, Johnson and Davis, 2018). This degradation pattern significantly influences the amount of energy generated by the system. By integrating this dynamic efficiency degradation into the model, a more holistic understanding of the system's behaviour emerges, allowing for informed decision-making processes, particularly in matters concerning system upgrades or maintenance (Johnson and Brown, 2020).

To illustrate the application of this degradation model, Figure 6.9 depicts a flowchart exemplifying the programming function used for the calculation. Furthermore, Figure 6.10 offers a 3D visual representation based on the data sourced from Table 6.1. The provided flowchart serves as a comprehensive guide, detailing the step-by-step process for calculating the efficiency for each year, thereby enhancing the clarity surrounding the evolution of efficiency over time. While the degradation pattern may not strictly adhere to a linear trajectory, the figure encapsulates the fundamental concept of efficiency reduction in panels for each successive year. Additionally, it affords valuable insights into the efficiency fluctuations throughout each month, extrapolated from the initial energy generation data established during the system's setup phase. It's noteworthy that this dataset signifies the system's pinnacle performance during its initial installation (Jones and White, 2019).

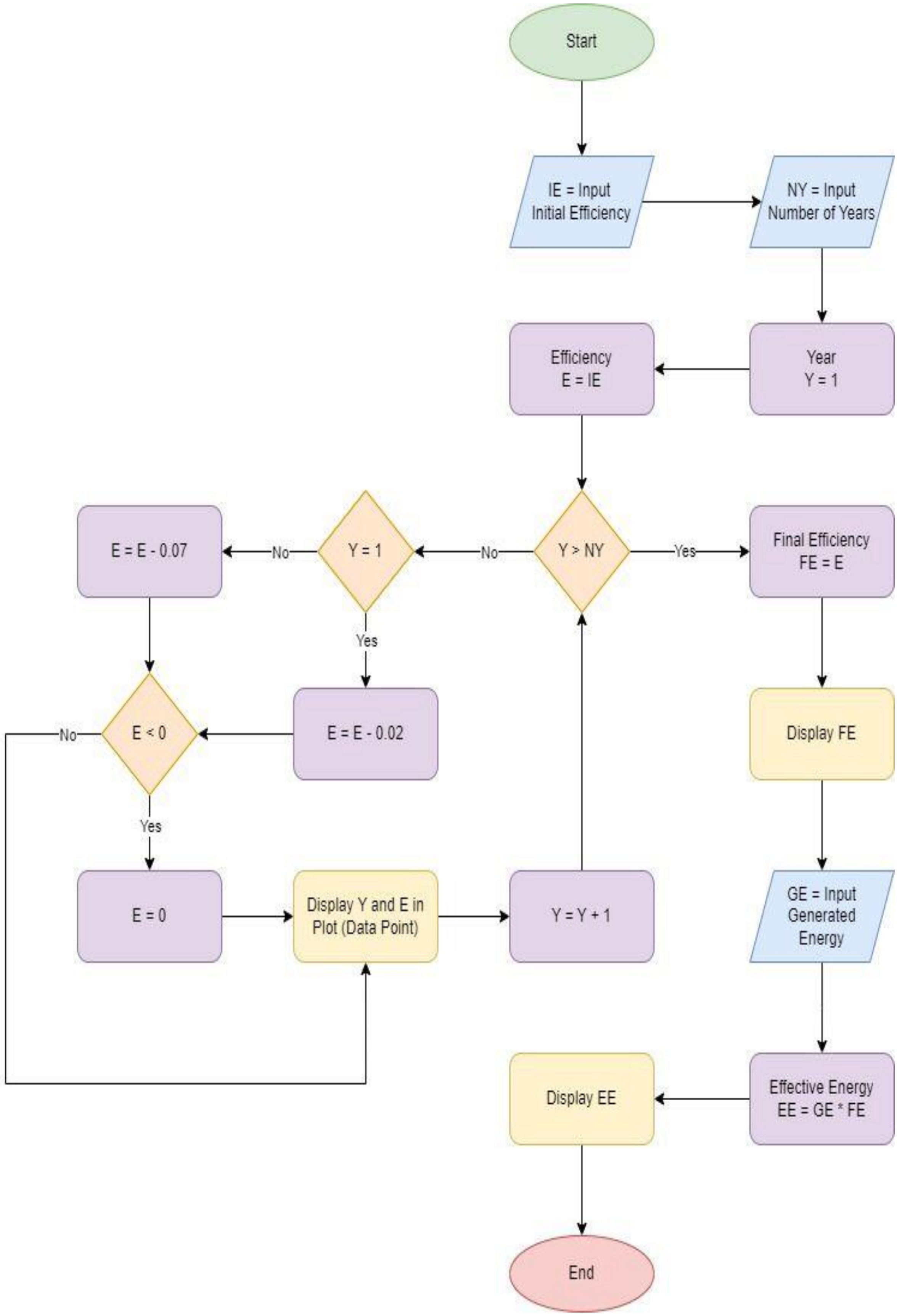


Figure 6.9: Programming function flowchart of panel efficiency degradation over time

Source: Author

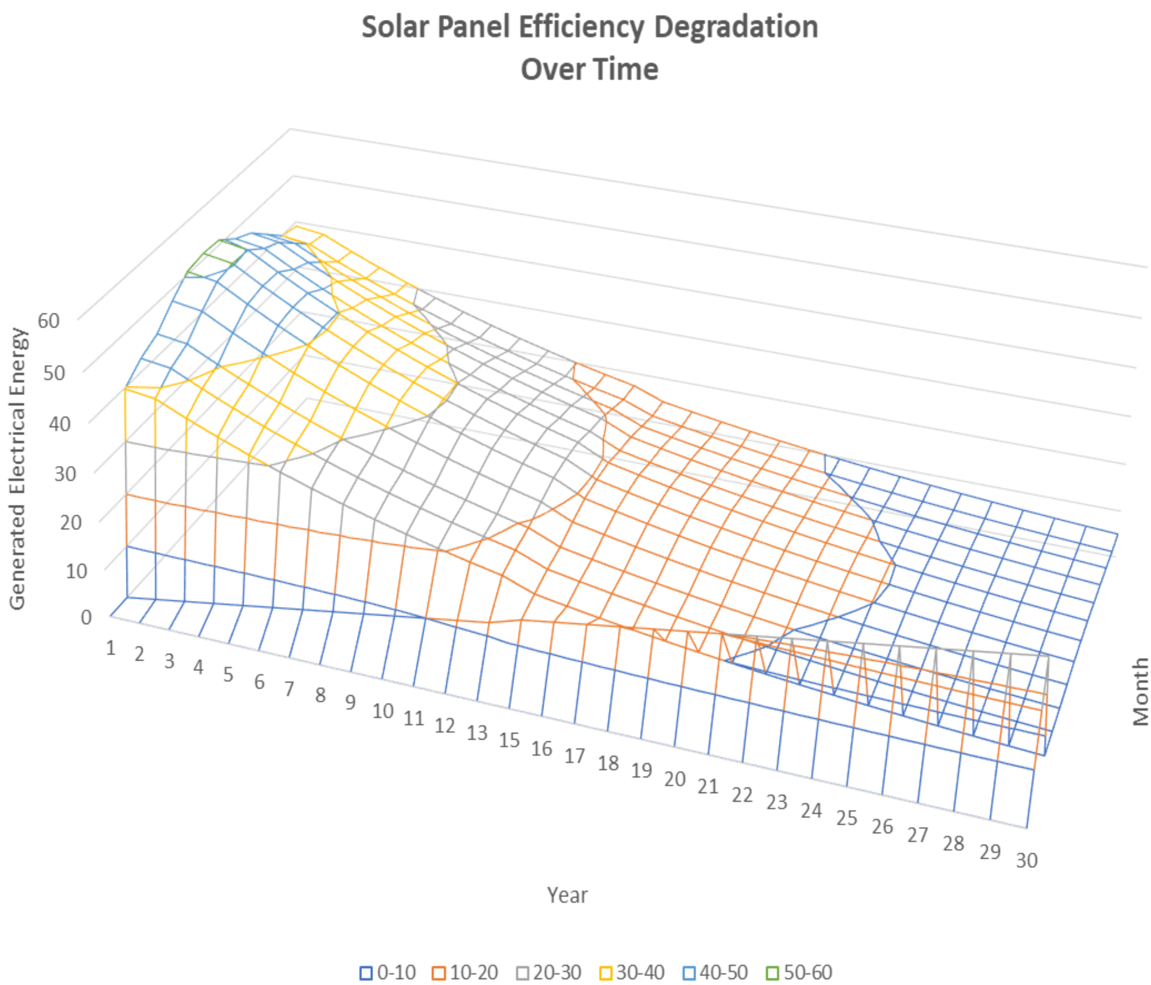


Figure 6.10: 3D visualisation of a linear panels' efficiency degradation over time

Note: Illustrates how the amount of energy generated by a solar panel is highest during its early years and gradually decreases over time due to degradation, eventually reaching a point where the panel becomes old and produces significantly less energy.

Source: Author

6.6. MATLAB Modelling

Accuracy was compared using the mean squared error (MSE), which measures the average of the squares of the errors—specifically, the difference between the observed and predicted values. Lower MSE values indicate that a model more accurately fits the data. To compare the results and determine which MATLAB modelling toolbox achieves the best accuracy, three methods were used, with the following model parameters:

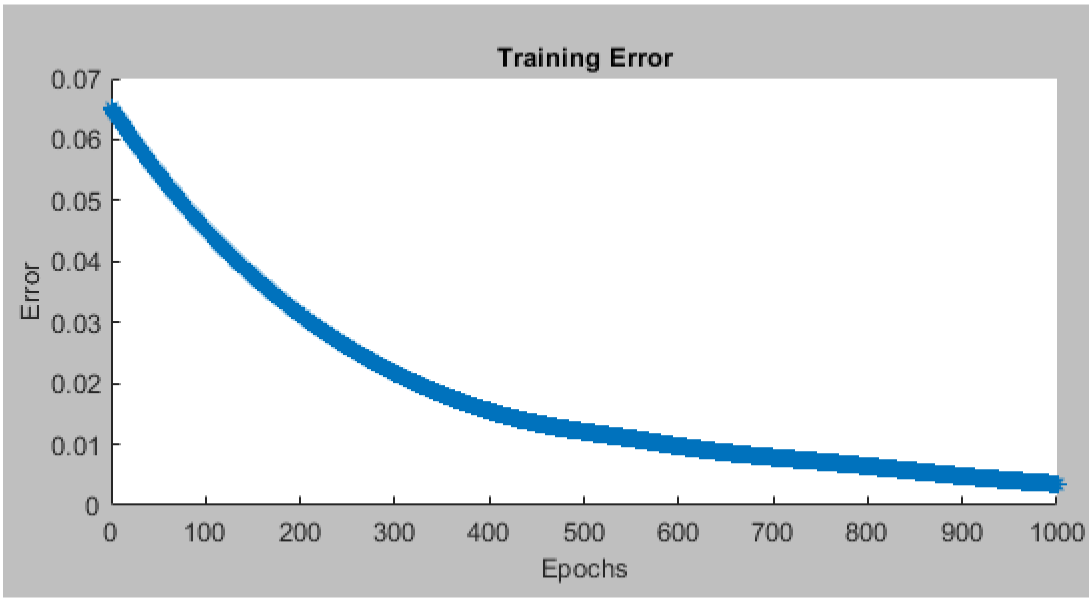
- Regression: second order equation

- Neuro-Fuzzy: (a) membership function: Gaussian; (b) number of membership functions: four per variable; (c) cost function: MSE
- Neural Networks: (a) feedforward NN; (b) activation function: TanSig; (c) topology: single hidden layer, with 10 neurons; (d) cost function: MSE

The following illustrations pertain to "Linear model Poly22":

- val(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2
- Coefficients (with 95% confidence bounds):
- p00 = 7.34 (-1.945, 16.63)
- p10 = 0.8461 (0.4355, 1.257)
- p01 = -1.376 (-1.46, -1.293)
- p20 = -1.025e-12 (-0.004525, 0.004525)
- p11 = -0.02789 (-0.02961, -0.02618)
- p02 = 0.0444 (0.04345, 0.04535)

The Neuro-Fuzzy Model, as shown in Figure 6.11, captures a detailed relationship whereby energy decreases with increasing time and radiation, suggesting that the interaction between these variables is complex and not purely linear. The Regression Model in Figure 6.12 shows a straightforward, linear decrease in energy as time and radiation increase, offering a simple and easily interpretable trend. In contrast, Figure 6.13 presents the surface of the training data using the ANN Model, which captures a complex and smooth decline in energy, indicating a strong inverse relationship and effectively understanding the intricate interactions between the variables.



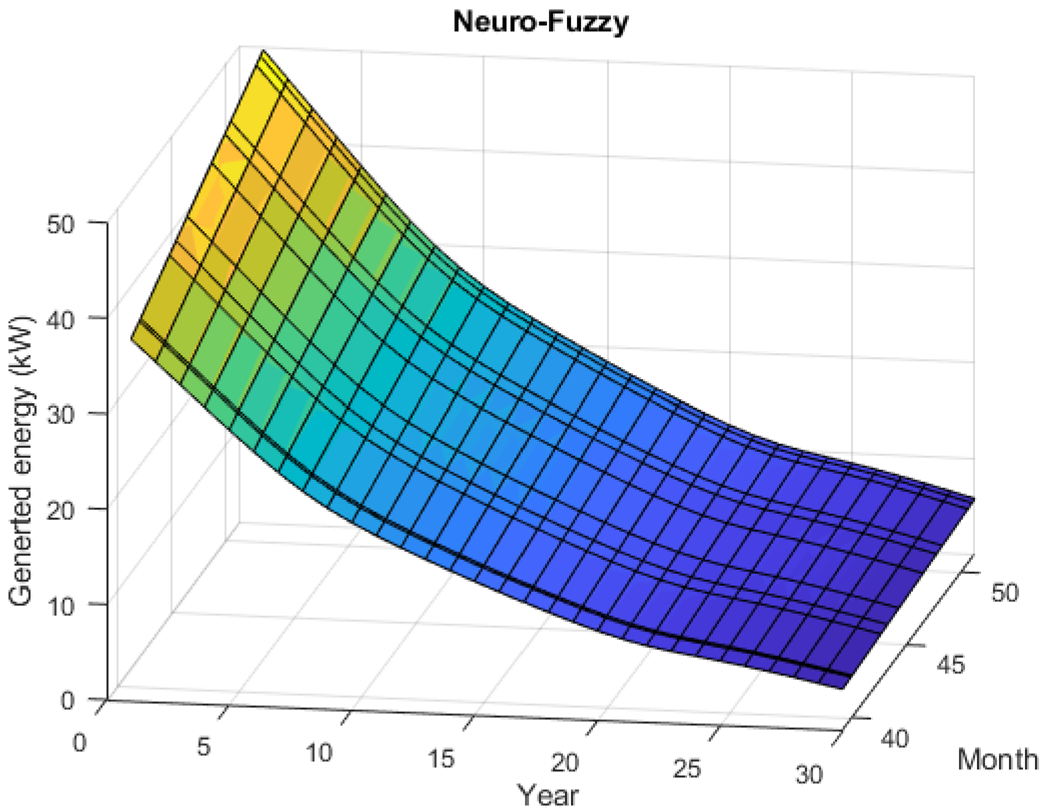


Figure 6.11: Neuro-fuzzy training error and generated energy

Source: Author

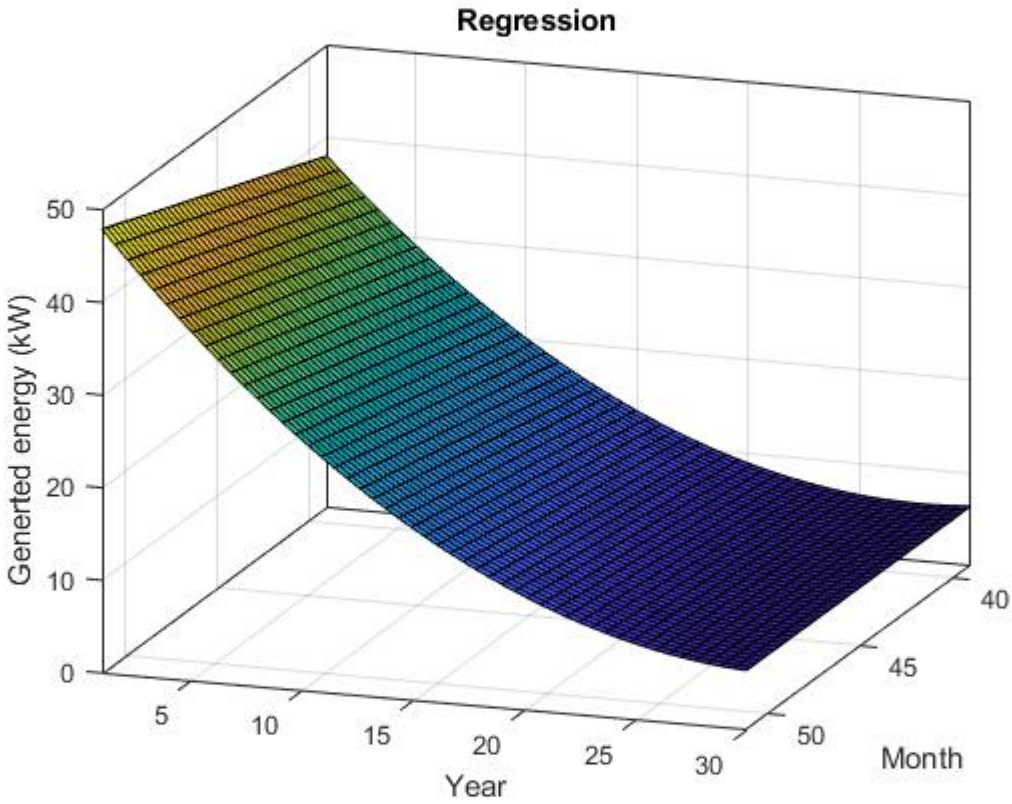


Figure 6.12: Regression

Source: Author

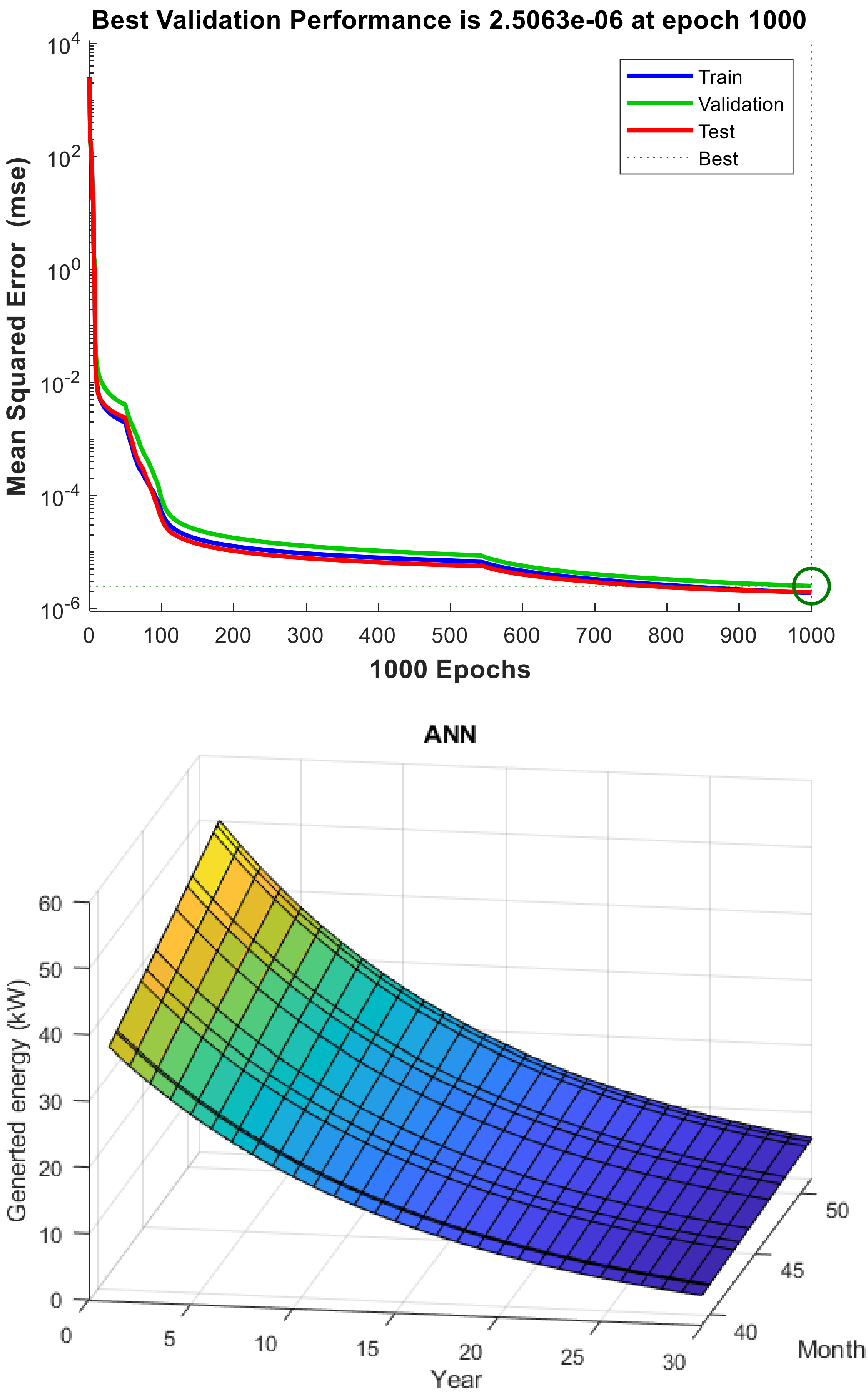


Figure 6.13: Neural Networks

Source: Author

When comparing the performance of the three proposed models according to the MSE, it can be observed that the ANN Model has an MSE of 2.5063×10^{-6}, suggesting that it predicts the data points with an extremely low error rate, indicating a highly accurate model on the training data. The Neuro-Fuzzy Model has an MSE of 0.0035274, which is also very low, demonstrating a high level of accuracy. In contrast, the regression Model has a higher MSE of 0.4, indicating that it is the least accurate of the three models when fitting the data. This is likely due to its over-simplicity, which limits its ability to capture the complexity of the data compared to the other models.

6.7. Discussion

The adaptation of continuous improvement approaches for effective decision-making within SP systems is essential, to sustain the generation of clean energy and minimise reliance on non-renewable sources of energy. Failing to do so can have consequences, including increased costs and a failure to meet national sustainability targets. In this case, the use of a DDM proved to be effective in supporting decision-makers in monitoring SP degradation caused by dust accumulation. By leveraging G2C data as a valuable source of information, decision-makers can gain insights through descriptive analysis and complement it with comparative analysis, as demonstrated in the examples presented. This approach equips decision-makers with comprehensive information to make informed decisions and take necessary actions.

Moreover, the integration of panels' efficiency degradation due to age in modelling solar energy systems is paramount for a comprehensive and accurate representation of their long-term performance. By accounting for the diminishing efficiency over time, the model offers a detailed insight into energy output patterns, enabling well-informed decisions for system management and potential enhancements. The visual representation aids in grasping the intricacies of efficiency reduction, further contributing to a thorough understanding of system dynamics.

When comparing the MATLAB simulation outcomes, the performance of the three proposed models using MSE evidences that the ANN Model predicts the data points with an exceptionally low error rate, indicating a highly accurate fit to the training data. The Neuro-Fuzzy Model also demonstrates a high level of accuracy with a low error rate. In contrast, the Regression Model shows the least accuracy, likely due to its simplicity, which limits its ability to capture the complexity of the data compared to the other models

Notably, this data-driven approach is cost-effective and can be easily expanded to provide daily-based comparisons or similar analyses, as exemplified in the presented analysis. By adopting this method, decision-makers can gather rich information and drive informed decision-making processes. Overall, the continuous improvement of decision-making approaches, particularly through the use of DDMs, plays a crucial role in ensuring the effectiveness and sustainability of $\mathbb{SP}$ systems.

6.8. Summary

This chapter introduced a DDM for decision-making within the context of $\mathbb{SP}$ systems. The model leverages $\mathbf{G_{to}C}$ data to perform statistical analysis and translate it into actionable information for stakeholders. The proposed DDM offers a cost-effective approach with clear and understandable statistical methodologies, making it accessible to a wide range of stakeholders. The DDM utilises descriptive and comparative analysis, including the t-test, to provide insights into the performance of $\mathbb{SP}$s.

It is worth noting that additional tests and comparisons can be incorporated into the model to further enhance its effectiveness. Furthermore, the model can be extended to enable daily-based comparisons instead of monthly assessments, particularly if prompt action is required to address degradation issues in a timely manner. Overall, the DDM presented in this chapter serves as a valuable tool for decision-makers in the $\mathbb{SP}$ industry. By utilising modelling as presented in this chapter, with descriptive and comparative analyses, stakeholders can make better-informed decisions to optimise the performance and maintenance of $\mathbb{SP}$ systems.

CHAPTER 7
"DRIVE" FRAMEWORK FOR FOSTERING SP DEPLOYMENT ON QATARI HOUSE ROOFS

7.1. Introduction

Building upon the earlier-presented studies in the previous chapters, it is imperative to develop a framework that can serve as a roadmap for overcoming early presented challenges and efficient strategy for facilitating optimal options for the deployment of SP systems within Qatari houses. Additionally, the framework should enable effective post-installation management, ensuring the sustainability of the clean energy generation target. This involves continuous monitoring for accumulated dust, cleaning procedures, maintenance operations, and plans for system upgrades.

7.2. Chapter Methodology

7.2.1. Overview:

The methodology employed for establishing the framework was based on the theory of change, dating back to the 1930s (Coryn *et al*., 2011). This theory delineates how activities lead to a series of outcomes contributing to intended impacts. Consequently, it has found extensive application in interventions, policies, events, strategies, and programs, aiding in the formulation of concrete plans through accurate identification of objectives and activities. This allows various stakeholders to make informed decisions and address emerging issues. The theory of change, also known as "logframe" (Rogers, 2014), is characterised by its process-level analysis, encompassing inputs, outputs, outcomes, and impacts.

Utilising the theory of change as a methodology for constructing the framework could support the future development of SPs in Qatari houses by identifying a sequence of processes that effectively contribute to the success of both the deployment and post-installation management phases. A thorough analysis of causal relationships between stakeholder engagement in the planning process and the identification and attainment of long-term goals can reveal potential challenges in achieving those goals (Clark and Taplin, 2012). Furthermore, employing the theory of change to develop a framework based on causal relationships can simplify complex issues, facilitating change as the deployment of solar energy for homes necessitates collaboration among diverse stakeholders from various organisations (James, 2011).

Before constructing the logframe, as shown in Figure 7.1, it was crucial to ascertain the fundamental objective of the framework. This objective was identified as establishing a framework that fosters the deployment and efficient management of home solar systems in Qatar, easily comprehensible to different stakeholders. The purpose is to support the future deployment of SPs in Qatari houses by overcoming challenges and providing mechanisms for sustaining solar energy through data-driven approaches. This process could also enable Qatar to engage homes in working towards achieving milestones outlined in the low-carbon strategy for Vision 2030.

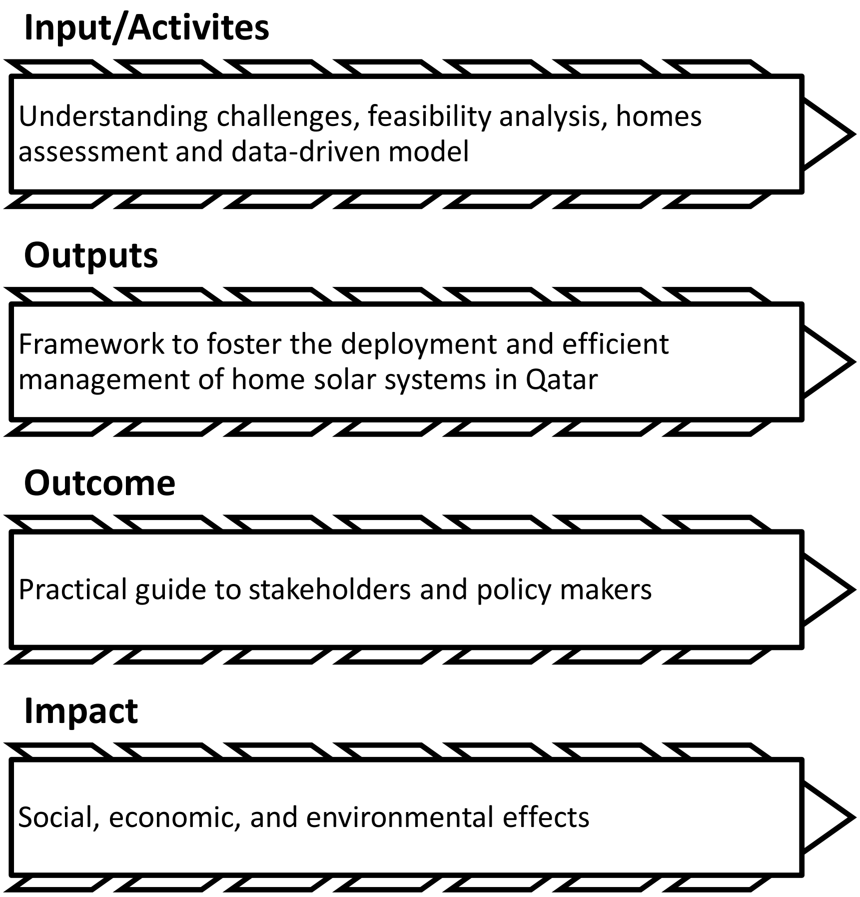


Figure 7.1: Logframe

Source: Author

7.2.2. Framework development method

Systematic mapping is a recognised and robust technique employed in the framework development process to pinpoint essential elements. It serves as a transparent and effective method for identifying and extracting pertinent information relevant to a specific research question. This approach is particularly beneficial for gathering literature, showcasing both the quantity and quality of available evidence. It is crucial to emphasise that, in contrast to systematic reviews, the primary objective of systematic maps is not to amalgamate the compiled evidence; instead, their focus is on presenting a comprehensive overview of the existing literature landscape (Petersen *et al*., 2015). This systematic and thorough approach guarantees the extraction of key elements crucial for developing a well-informed framework.

7.2.3. Framework evaluation method

For the evaluation of the proposed framework by key lead engineers from the energy sector, the TAM was employed (Marangunić and Granić, 2013), as illustrated in Figure 7.2. TAM elucidates the factors influencing individuals' acceptance of information systems (Davis, 1993); it is widely acknowledged as a versatile and applicable framework for various end-user computing technologies and user populations. The fundamental components of TAM comprise "perceived usefulness" (PU), reflecting a user's belief that a proposed approach will enhance their job performance, and "perceived ease-of-use" (PEoU), gauging a user's perception of the ease or difficulty in using a technology. These concepts are intricately connected, with PEoU exerting an indirect impact on user acceptance of technology based on the influence of PU.

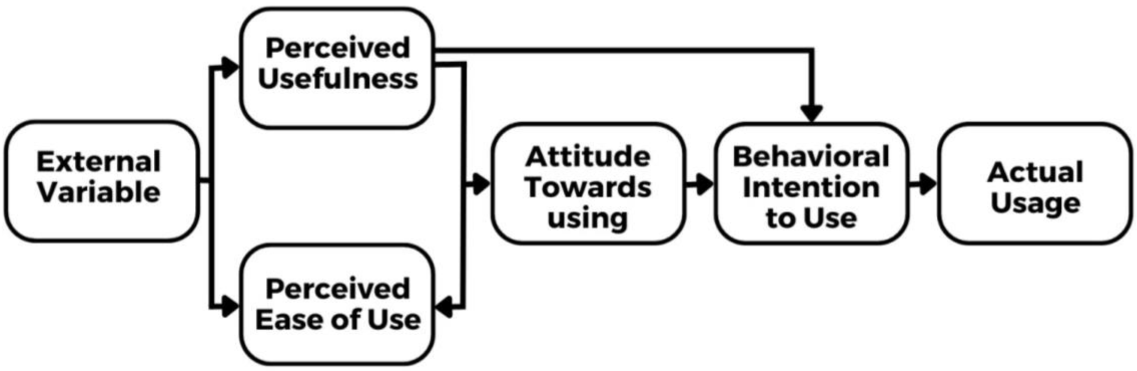


Figure 7.2: Technology acceptance model

Source: Davis (1993)

To establish a correlation between the two approaches and ensure comprehensive evaluation outcomes, the TAM evaluation incorporated testing across four domains: PU, PEoU, "behavioural intention to use" (BI2U), and *actual* "usage", using construct items outlined in Table 7.1. Subsequent analyses were conducted based on the aligned model, following the decision support system evaluation methodology (Rigopoulos, Psarras and Askounis, 2008). The refined TAM model (depicted in Figure 7,3), initially introduced by Money and Turner (2004) and later extended by subsequent research (Rigopoulos, Psarras and Askounis, 2008), assesses users' attitudes towards adopting decision support systems to enhance the decision-making process. The primary goal is to investigate end-users' attitudes towards the utilisation of the proposed framework, examining identified study hypotheses as detailed in Table 7.2, based on reviewed literature and the empirical findings reported in the preceding chapters (Hajjar, 2018). This examination aims to unveil the relationships between PU, PEoU, BI2U, and actual usage of the new system.

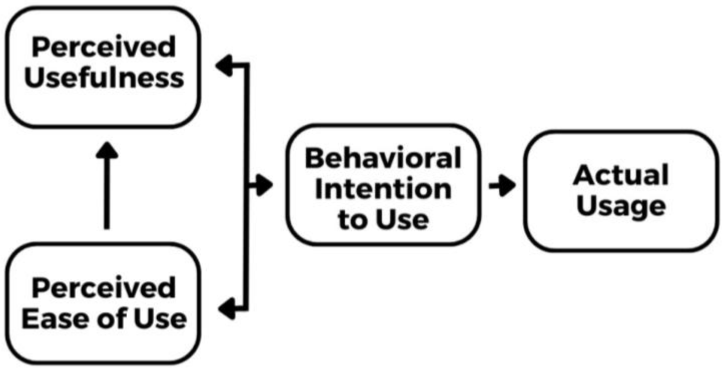


Figure 7.3: Adopted research model

Source: Money and Turner (2004)

Table 7.1: Construct items

Perceived usefulness (PU)	1. With DRIVE decisions are easier
	2. With DRIVE decisions are more accurate
	3. With DRIVE decisions are faster
Perceived ease of use (PEoU)	1. DRIVE is easy to use
	2. DRIVE and its methodology is easy to understand
Behavioural intention to use (BI2U)	1. I think that using DRIVE is a good idea
	2. I think that using DRIVE is beneficial
	3. I have positive perceptions about using DRIVE
Usage	1. I intend to use DRIVE
	2. I intend to use DRIVE instead of the traditional procedure

Source: Author

Table 7.2: Adopted hypotheses

No.	Hypothesis
H1	PU positively affects BI2U
H2	PEoU has a strong indirect positive relationship to BI2U
H3	PEoU has a less strong direct positive relationship to BI2U
H4	BI2U has a strong positive impact on system usage
H5	PU and PEoU have a strong positive impact on BI2U

Source: Rigopoulos, Psarras and Askounis (2008)

7.2.4. Data collection and data analysis methods

In evaluating a framework using the TAM approach, closed-ended interview questionnaires were selected for data collection due to a number of reasons. Closed-ended questionnaires facilitate the quantitative data collection, which guaranteeing an objective measurement of users' perceptions and attitudes toward the technology integrated into the framework. Moreover, the structured nature of closed-ended questions indorses efficiency, consistency, and easy analysis, that enables a systematic evaluation of key TAM constructs such as PU and PEoU. This method also enables focused inquiries, in line with the theoretical foundations of TAM (Vogelsang, Steinhüser and Hoppe, 2013). Furthermore, the standardised data collected through these questionnaires enables the use of SPSS (v. 20) as a data analysis tool. The compatibility with SPSS facilitated the statistical analysis process, allowing a more concrete and better exploration of the collected data and support the comprehensive understanding of the framework's effectiveness (Arkkelin, 2014).

7.3. Proposed DDM, Regulation, Incentive, Volume, Economical (DRIVE) Framework

7.3.1. Overview

To identify the main elements for constructing the framework, systematic mapping was conducted on previous studies (Petersen *et al*., 2015). These studies encompassed the outcomes, including key challenges, related to the installation of SPs in Qatari houses. The analysis considered the results of an analytical feasibility study to ascertain the potential deployment of SPs in Qatari houses. Additionally, insights from a field survey were examined to support the feasibility of deploying SPs on Qatari houses. Furthermore, the study explored the potential for establishing a DDM for SP systems, which could be utilised for strategic planning of deployment and post-planning monitoring to ensure effective and sustainable clean energy generation. Following this comprehensive analysis, elements of the framework were identified in alignment with each finding from the previous studies, as illustrated in Figure 7.4. The proposed DRIVE framework for this particular research context is shown in Appendix 3, and its components (translated into graphical representation) are as shown in Figure 7.5 and described below.

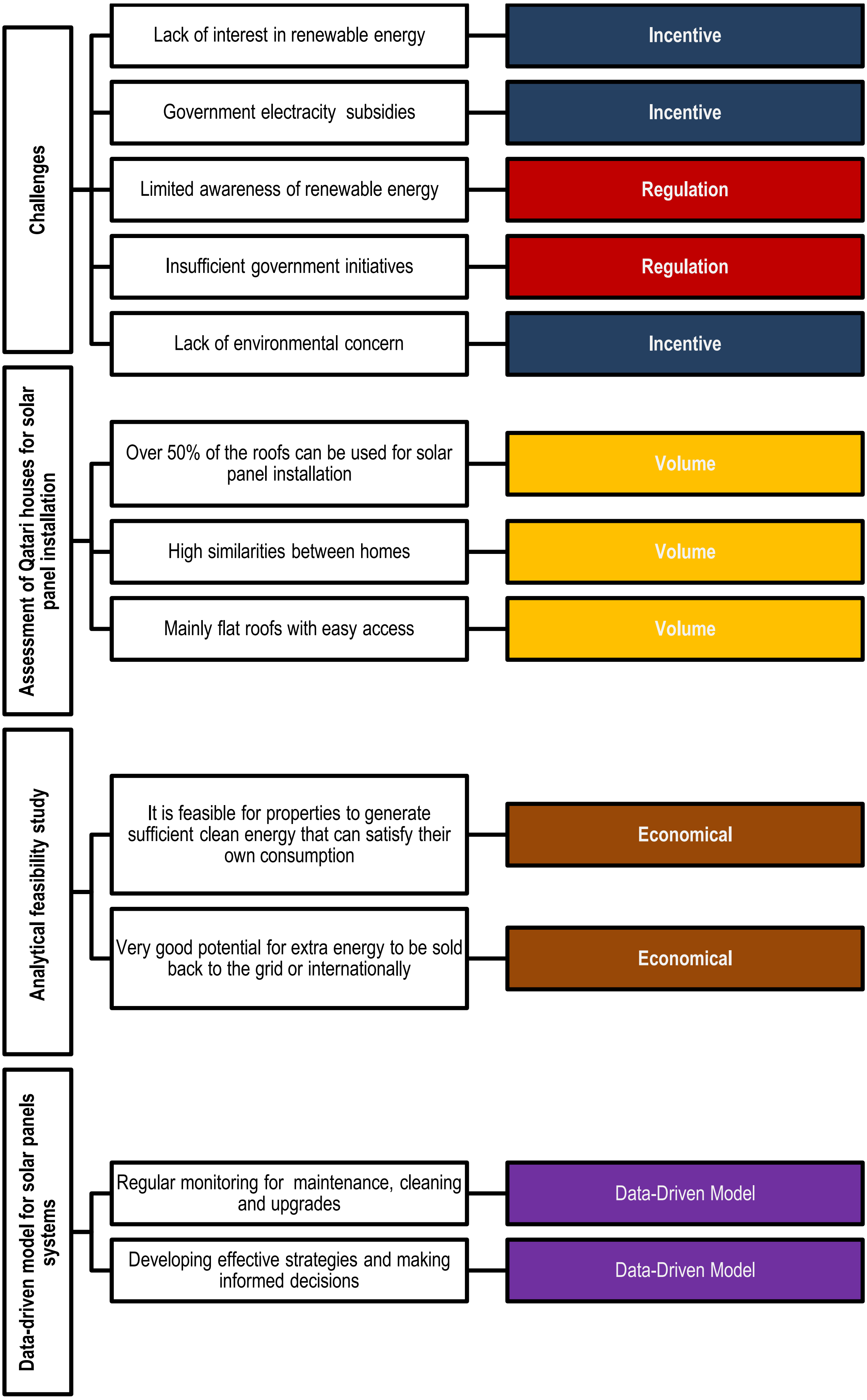


Figure 7.4: Systematic mapping for framework elements identifications

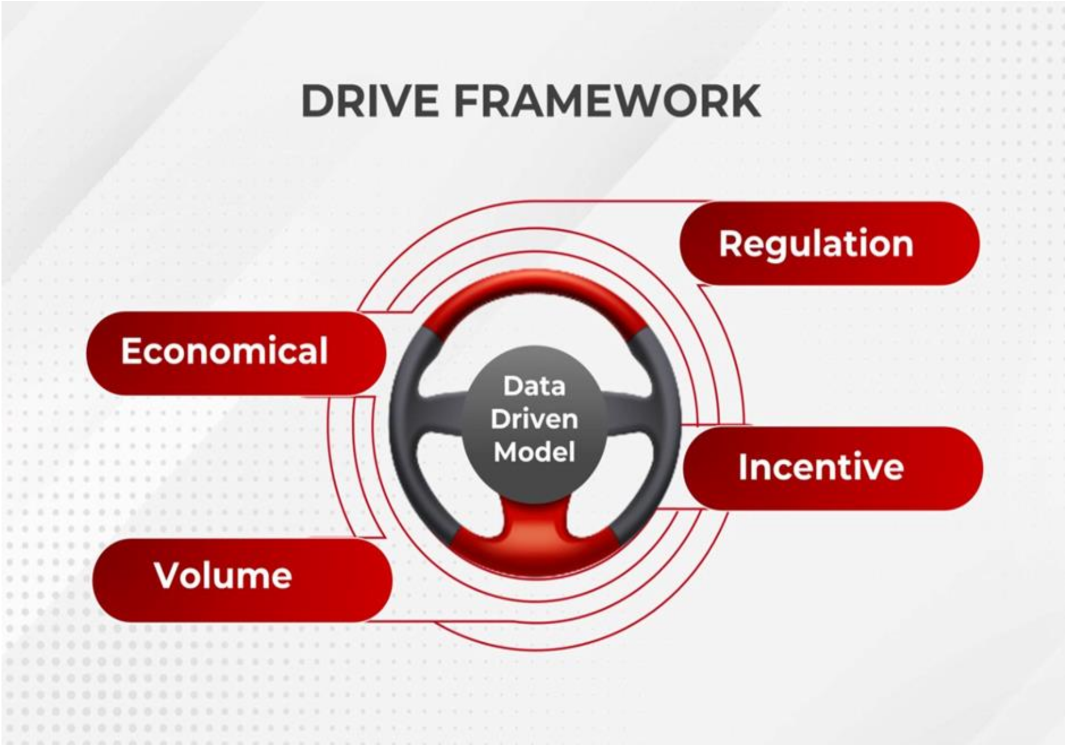


Figure 7.5: Proposed DRIVE framework dimensions

Source: Author

7.3.2. Data-Driven Model

Implementing a DDM as central part of the framework entails the collection and analysis of pertinent information related to solar energy potential, consumption patterns, and economic benefits. This approach facilitates informed decision-making concerning the installation of SPs, addressing aspects such as optimal locations, system sizes, and anticipated energy savings. Furthermore, it plays a crucial role post-deployment by sustaining continuous and effective clean energy generation through monitoring for accumulated dust, cleaning, maintenance, and plans for upgrades. This system functions as a decision-making support system, providing ongoing support for strategic decisions in the maintenance and enhancement of SP systems (Hamed *et al*., 2018).

7.3.2.1. Regulation

Regulation refers to the development and enforcement of policies and guidelines that support the adoption of SPs in residential properties. This includes simplifying permitting processes, establishing safety standards, and ensuring compliance with building codes. Clear and supportive regulations can remove barriers and streamline the approval process for solar installations (Daszkiewicz, 2020).

7.3.2.2. Incentive

Providing incentives is a crucial aspect of encouraging homeowners to adopt and invest in SPs. These incentives can take various forms, such as financial incentives (e.g., tax credits and rebates), net metering policies, or FITs. By offering attractive incentives, the government or utilities can make SP installations more financially appealing to homeowners (Schelly, 2014).

7.3.2.3. Volume

Achieving a significant volume of SP installations is vital for making a substantial impact on the country's clean energy goals. This part of the framework focuses on scaling-up adoption by encouraging a large number of homes to install SPs. Strategies may include bulk procurement programs, community initiatives, or partnerships with housing developers to include solar as a standard feature (Hernandez *et al*., 2014).

7.3.2.4. Economical

Any successful framework aimed at fostering SP adoption should include economic feasibility as a fundamental pillar. This necessitates the assessment of initial costs like equipment and installation expenses against long-term savings. By highlighting the financial benefits, such as reduced dependence on grid electricity and monthly utility bill savings, frameworks can encourage wider adoption. Additionally, homeowners and government can also explore income-generating opportunities, like selling excess energy locally or internationally. Integrating economic feasibility into these frameworks promotes financial sustainability and contributes to a cleaner, more sustainable energy future (de Oliveira Azevêdo *et al*., 2020).

7.4. Evaluation

The data were collected from 37 engineers using a digital closed-end questionnaire. These key stakeholders were selected as they are the key stakeholders with direct experience in RE issues in Qatar. Subsequently, this collected dataset was exported to SPSS (v. 20) to conduct the statistical analysis. This method ensures a rigorous examination of the collected information, enhancing the reliability and accuracy of the statistical findings from the frameworks expected end-users' evaluation (Arkkelin, 2014). To ensure the stability of the study tool, Cronbach's alpha coefficients were calculated for each construct, as shown in the Table 7.3, and all values were higher than 0.7, which indicates that the study tool is valid for research purposes (Hajjar, 2018).

Table 7.3: Cronbach's alpha coefficients

Construct	Cronbach alpha
Perceived usefulness	0.92
Perceived ease-of-use	0.88
Behavioural intention to use	0.95
Usage	0.84

Source: Author

To test the hypotheses of the study, find the Pearson correlation coefficients as shown in Table 7.4. Figure 7.6 also shows the results and the values of significance levels based on the study model. Table 7.5 summarises the result of each of the five hypotheses of the study, indicating that all five hypotheses were supported.

Table 7.4: Correlation of constructs

Construct	1	2	3	4
1	**1**	.906**	.846**	.834**
2	.906**	**1**	.882**	.834**
3	.846**	.882**	**1**	.836**
4	.832**	.834**	.836**	**1**

Key: 1: Perceived usefulness, 2: Perceived ease-of-use, 3: Behavioural intention to use, 4: Usage

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

Source: Author

Table 7.5: Hypotheses testing results

No.	Hypothesis	Support
H1	PU positively affects BI2U	Yes
H2	PEoU has a strong indirect positive relationship to BI2U	Yes
H3	PEoU has a less strong direct positive relationship to BI2U	Yes
H4	BI2U has a strong positive impact on system usage	Yes
H5	PU and PEoU have a strong positive impact on BI2U	Yes

Source: Author

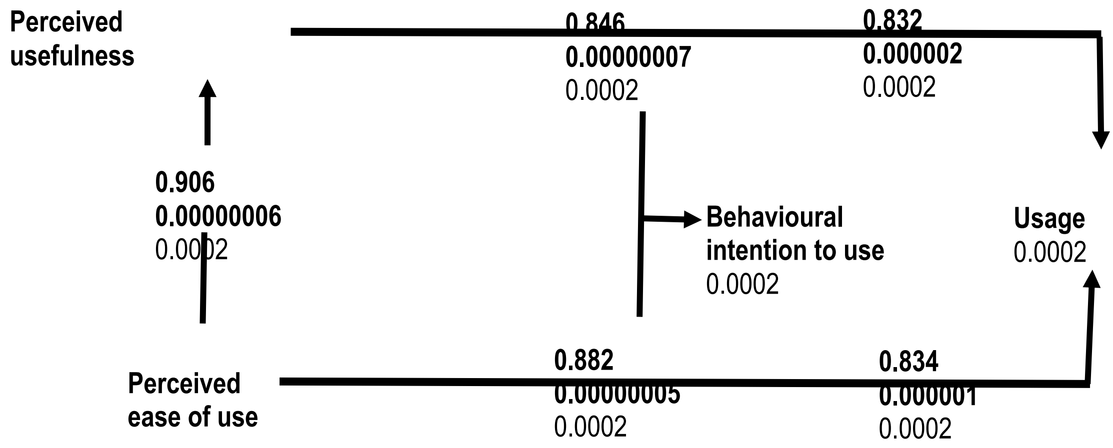


Figure 7.6: Research model with correlations

Source: Author

7.5. Summary

The presented "DRIVE" framework has been established based on systematic mapping from previous findings from this research project. Its key objective is to address early barriers to SP deployment in Qatari houses and create an efficient strategy for facilitating optimal possibilities for deploying SP systems within Qatari houses. Furthermore, the framework is designed to enable effective post-installation management, ensuring the sustainability of clean energy generation targets. This includes provisions for continuous monitoring of accumulated dust, cleaning procedures, maintenance operations, and plans for system upgrades. Since the framework has been evaluated by experienced engineers in the field of electric power, their invaluable feedback has been instrumental in refining and supporting its development. Hence, it is anticipated to serve as a comprehensive roadmap, empowering key stakeholders to navigate the complexities of SP deployment in Qatari houses.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

The principal aim of this research endeavour was to conduct a thorough examination aimed at identifying the obstacles associated with implementing residential SP systems in Qatar. Additionally, the study intended to perform a detailed feasibility analysis to determine the viability of deploying such systems. This involved conducting on-site assessments of household rooftops to evaluate their suitability for SP installation, in order to develop a DDM to aid decision-making regarding the operation and maintenance of SP setups. Integration of this model into a proposed framework was envisioned to streamline the process of SP deployment on residential properties in Qatar, thus contributing to the transition towards sustainable energy sources. Following the accomplishment of this project, the following drivers for roof SP adoption in Qatar and other outcomes have been identified.

Qatar has made progress in large-scale solar farm investments, but residential SP deployment is still lagging behind where it needs to be in order to achieve the national clean energy goals of Vision 2030 (Al-Hababi, 2023). By considering the six drivers for promoting SP adoption, namely potential, awareness, net-zero pathway, energy efficiency, lowering subsidies, and sustainability, stakeholders can develop effective strategies to encourage the installation of SPs and achieve the vision of a sustainable future (Figure 8.1).

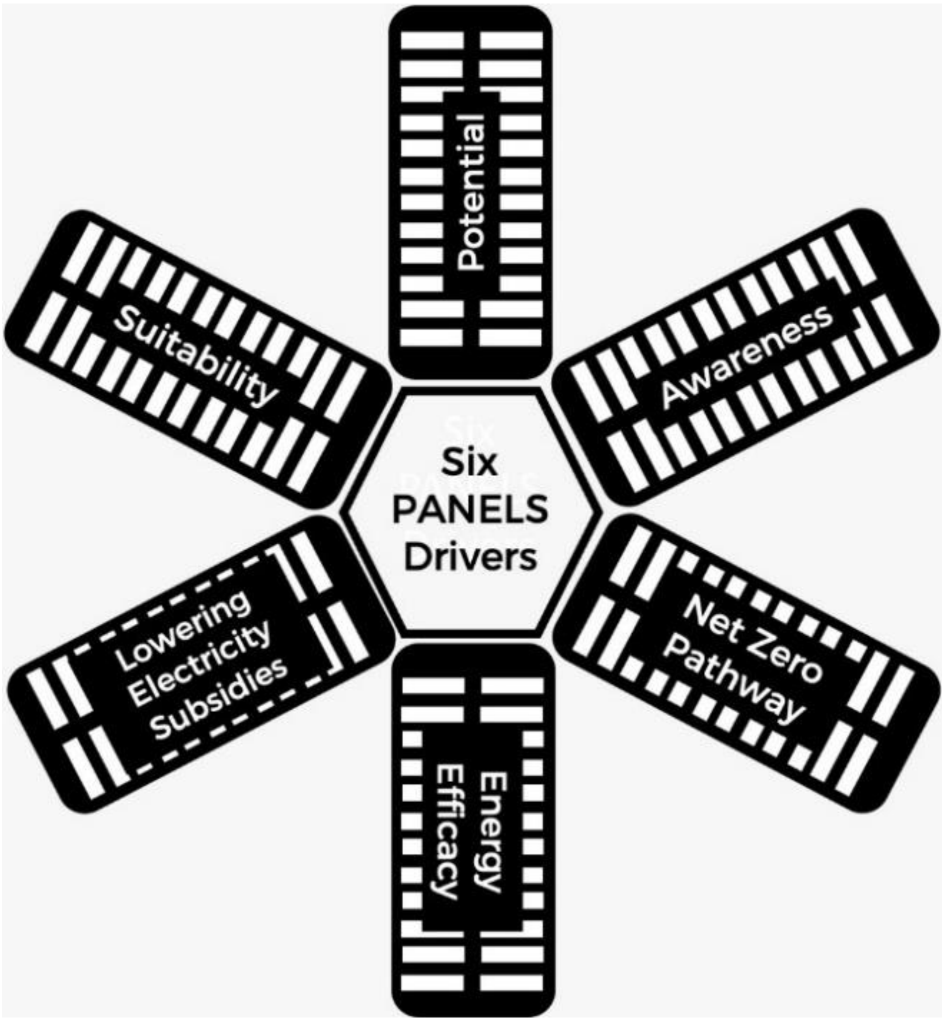


Figure 8.1: Six PANELS drivers

Source: Author

8.1.1. Potential

Qatar has vast potential for solar energy investment, and it can position 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 (Darwish, Abdo and AlShuwaiee, 2018). With an average of 3,600 hours of direct solar radiation annually, Qatar is well-suited for solar energy investments (World Data, 2024). The country is committed to reducing its carbon footprint and aims to generate 20% of its energy from renewable by 2030, with solar energy playing a significant role (Bayram and Koç, 2017).

The conducted feasibility study part of this research project (as presented in Chapter 4) explored various scenarios of SP deployment in Qatar's residential and commercial buildings, considering panel sizes, efficiency, and daily sun exposure. The results revealed substantial potential for rooftop SPs, 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.

Qatar's extensive experience in the energy market, particularly in the O&G industries, can be leveraged to develop the solar energy sector and gain a competitive advantage in the global clean energy market (Buckley and Trivedi, 2021). The country's financial capacity and resources enable large-scale solar energy investments (Obaideen *et al.*, 2021). Notably, Qatar has already invested in significant solar energy projects, including the Al-Kharsaah Solar Power Plant, one of the world's largest (Al-Ammari and Romanowski, 2016). 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 (Bergman and Eyre, 2011). Its high sun hours, market experience, and financial capacity make it an ideal destination for solar energy investment.

8.1.2. Awareness

Awareness plays a vital role in promoting the adoption of RE resources, and a lack of awareness has been identified as a significant challenge hindering the deployment of RE in Qatar, and it was one of the key challenges identified by this research project. To address this challenge, the government should implement projects that allow households to actively participate and experience the benefits of installing SPs. This can effectively raise national public awareness (Almulhim, 2022). Given Qatar's socially connected society, visible SPs on homes would initiate conversations and spark interest in RE, leading to a snowball effect of adoption (Voss and Musall, 2012). The installation of SPs serves as a strategic tool to raise awareness and drive the transition toward clean energy use (Hussain *et al.*, 2022).

In addition to potentially offering tangible benefits like reduced energy bills, solar also visually demonstrates the commitment of individuals, businesses, and nations to reducing carbon emissions and contributing to global climate change mitigation efforts (Almulhim, 2022). This visual representation can generate public interest and awareness of RE, inspiring more individuals and businesses to embrace clean energy sources, particularly in the context of corporate social responsibility (CSR) initiatives, which in the case of SPV adoption can serve the dual purpose of generating ROI in addition to signalling a commitment to environmental and social responsibility (Mohammed *et al.*, 2022).

Moreover, increasing public awareness about RE can garner support for policies and initiatives aimed at promoting clean energy adoption (Tsalikis and Martinopoulos, 2015). This creates a favourable environment for RE investment and deployment in Qatar, encouraging businesses to invest in RE projects. Therefore, enhancing public understanding of the nature and significance of clean RES options is a crucial step in establishing them as a normative and primary component of the national energy mix. In Qatar, the installation of SPs on homes acts as a catalyst for raising awareness and driving the transition to clean energy. By generating public interest and support for RE, Qatar can contribute to global climate change mitigation efforts and foster a more sustainable future for all.

8.1.3. 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 (Cao, Dai and Liu, 2016). Currently, homes in Qatar heavily rely on external energy sources, but the installation of SPs on rooftops can pave the way towards net-zero buildings (Jaber and Saidur, 2020). By incorporating SPs, homes in Qatar can reduce their dependence on conventional energy sources and promote the use of RE. The region's abundant sunshine makes solar energy an ideal solution for meeting residential energy needs (Bohra and Shah, 2020). Local energy production allows homes to decrease their reliance on grid-supplied electricity, which is often costly and contributes to carbon emissions. 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 (International Renewable Energy Agency, 2024).

This introduces a new revenue stream and helps offset the upfront costs of SP installation. 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 (Torres and Herold, 2019). Therefore, installing SPs on homes in Qatar serves as a strategic step towards achieving net-zero buildings. Through localised energy production, homeowners can decrease their reliance on conventional energy sources, lower energy expenses, and contribute to global climate change mitigation (Jaber and Saidur, 2020). Thus, implementing a net-zero strategy is essential for creating a more sustainable and energy-efficient built environment in Qatar.

8.1.4. 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 (AL-Dosari, Hunaiti and Balachandran, 2023). By installing SPs and implementing a net-zero strategy, homeowners are expected to shift towards using energy-efficient appliances and monitoring their energy usage (Fink, 2019). SP installation on Qatar's homes can transform how 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 (Fink, 2019).

Furthermore, a net-zero strategy incentivises energy efficiency through a feedback loop between production and consumption (Fink, 2019). 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 SP installation and a net-zero approach, homeowners can enhance awareness, invest in efficient technologies, and contribute to a sustainable built environment (Khan *et al*., 2017). Energy efficiency is essential for achieving a sustainable and energy-efficient future in Qatar.

8.2. Recommendations

8.2.1. Lowering electricity subsidies

Qatar can transition to a sustainable energy future by deploying SPs on homes. However, this research has corroborated previous studies' findings that public energy subsidies pose a challenge, as the government provides free energy to citizens, hindering SP installation. However, the government can support panel installation to reduce non-clean energy use and subsidies (Bohra and Shah, 2020; Obaideen *et al*., 2021). For example, financial support of various kinds, including fiscal relief, can empower homeowners and business owners to generate their own energy, reducing reliance on non-clean sources and latent subsidies (International Renewable Energy Agency, 2024). Shifting the energy production burden from the government to individuals would lower the financial burden of subsidies and massive waste (Obaideen *et al*., 2021). Homeowners can contribute to the grid and export excess energy, generating personal revenue for owners, and potential export revenue from foreign markets. Government support for SPs demonstrates commitment to sustainability and emission reduction, fostering environmental consciousness and encouraging investment in sustainable energy (Seyfang and Haxeltine, 2012; International Renewable Energy Agency, 2024).

8.2.2. Suitability

The deployment of SPs 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 in having a new source of energy and sustaining the other available sources for future generations (Obaideen *et al*., 2021). 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 (Oxford Analytica, 2022). Moreover, solar energy can benefit society by minimising pollution, particularly carbon emissions. The use of SPs 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 (Omer, 2008). By reducing the generation of CO_2 from clean sources of energy, SPs 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 (Scharfenort, 2012).

In order to effectively facilitate the implementation of the six drivers for SP deployment in Qatar, it was essential to carry out a field survey to evaluate the viability of installing SPs on different types of residential buildings. This survey provided valuable insights for homeowners and decision-makers, enabling them to develop suitable scenarios for the installation and effective utilisation of SPs on domestic roofs in Qatar (Ayoub and Al-Jibouri, 2021). Moreover, to ensure sustainable energy generation from SPs installed on home roofs in Qatar, it is essential to establish a practical mechanism for regularly monitoring the system's performance. This mechanism should address issues such as degradation due to dust accumulation and aging of the SPs. The proposed data-driven approach, which is a core part of this research, demonstrates an efficient method for providing dynamic data that can facilitate effective decision-making in various aspects, including system management, performance monitoring, maintenance scheduling, system upgrades, and related decisions.

Ultimately, as home rooftop SP deployment is still in its early stages in Qatar, various stakeholders need to adopt a cohesive strategic approach to foster its widespread adoption. The proposed DRIVE framework expounded in Chapter 7 this research can serve as a roadmap, guiding efforts towards this goal. It has the potential to play a significant role in achieving the national strategy aimed at transitioning homes towards clean energy and aligning with global efforts to meet environmental targets.

8.2.3. Further research

One of the key outcomes of this research project is to pave the way for further research agendas related to the state of Qatar or the field of home SP systems. Building on the outcomes of this research, and addressing its limitations, the following suggestions are offered for further work:

- Since analytical feasibility has been assessed through mathematical means, it would be beneficial to establish prototype installations for some homes. This would enable the testing of different scenarios and allow for a comparison between calculated and actual generated energy, providing concrete evidence for each scenario.
- Due to the limited size of the data collected and used in modeling the DDM, while the ANN Model shows perfect accuracy on the training data, it’s essential to evaluate its performance on a validation or test dataset to ensure it generalises well. If overfitting is a concern, the Neuro-Fuzzy Model might offer a good balance between accuracy and generalisation.
- The proposed DRIVE framework has been tested with a number of specialised stakeholders. Therefore, it would be useful to put this into practice and conduct further evaluation to ensure any necessary alignments or to confirm its suitability after the deployment of residential rooftop SPs.
- Finally, the outcomes of this research project can be beneficial for other countries, particularly within analogous climate zones such as the GCC region. Thus, conducting further research in other countries would contribute to and expand the impact of this research. It would also enable those countries to achieve their targets for transitioning to cleaner energy sources.

References

Abul Kashem, S. B., Chowdhury, M. E. H., Tabassum, M., Molla, M. E., Ashraf, A. and Swinburne, J. A. (2020) ‘Feasibility study of solar power systems in residential area’, *International Journal of Innovation in Computational Science and Engineering*, 1(1), pp. 10-17.

Adams, A. (2019) ‘Data cleaning and preparation for analysis’, *Journal of Data Science*, 15(2), pp. 123-145.

Ahmad, T., Madonski, R., Zhang, D., Huang, C. and Mujeeb, A. (2022) ‘Data-driven probabilistic machine learning in sustainable smart energy/smart energy systems: key developments, challenges, and future research opportunities in the context of smart grid paradigm’, *Renewable and Sustainable Energy Reviews*, 160, p. 112128. Available at: http://dx.doi.org/10.1016/j.rser.2022.112128.

Al Shehhi, A., Al Hazza, M., Alnahhal, M., Sakhrieh, A. and Al Zarooni, M. (2021) ‘Challenges and barriers for renewable energy implementation in the United Arab Emirates: empirical study’, *International Journal of Energy Economics and Policy*, 11(1), pp. 158-164. Available at: https://doi.org/10.32479/ijeep.10585.

Al Touma, A. and Ouahrani, D. (2017) ‘Enhanced thermal performance of mosques in Qatar’, *IOP Conference Series: Earth and Environmental Science*, 104(1), p. 012012. Available at: http://dx.doi.org/10.1088/1755-1315/104/1/012012.

Al Zohbi, G. and AlAmri, F. G. (2020) ‘Current situation of renewable energy in Saudi Arabia: Opportunities and challenges’, *Journal of Sustainable Development*, 13(2), pp. 98-119. Available at: http://dx.doi.org/10.5539/jsd.v13n2p98.

Al-Ammari, B. and Romanowski, M. H. (2016) ‘The impact of globalisation on society and culture in Qatar’, *Pertanika Journal of Social Sciences and Humanities*, 24, pp. 1535-1556.

AL-Dosari, K., Hunaiti, Z. and Balachandran, W. (2023) ‘Civilian UAV deployment framework in Qatar’, *Drones*, 7, p. 46. Available at: https://doi.org/10.3390/drones7010046.

Al-Hababi, R. (2023) ‘The evolvement of Qatar’s environmental sustainability policy: the strategies, regulations, and institutions’, in L. Cochrane and R. Al-Hababi (eds.) *Sustainable Qatar: social, political and environmental perspectives*. Singapore: Springer Nature, pp. 17-35.

Al-Mohannadi, S. A. (2023) *Using solar energy in electrification: a case of an office building in Qatar*. Master's thesis, Qatar University. Available at: https://qspace.qu.edu.qa/bitstream/handle/10576/40573/Shaikha%20Al-Mohannadi_%20OGS%20Approved%20Project.pdf?sequence=1&isAllowed=y (Accessed: 11 May 2024).

Almulhim, A. I. (2022) 'Understanding public awareness and attitudes toward renewable energy resources in Saudi Arabia', *Renewable Energy*, 192, pp. 572-582.

Al-Naimi, N. (2024) *Morphology of urban Qatari homes*. Available at: https://sites.northwestern.edu/buildingdoha/morphology-of-urba (Accessed: 11 May 2024).

Al-Nuaimi, H., Abu-Serdaneh, A., Kablan, H., Al-Darmaki, G. and Abdrabou, A. (2018) 'A low-cost online performance monitoring system for home photovoltaic generators', in *2018 Advances in Science and Engineering Technology International Conferences (ASET)*, New York, NY: IEEE, pp. 1-5. Available at: https://doi.org/10.1109/ICASET.2018.8376795.

Alqahtani, N. and Balta-Ozkan, N. (2021) 'Assessment of rooftop solar power generation to meet residential loads in the city of neom, Saudi Arabia. *Energies*, 14(13), p. 3805. Available at: https://doi.org/10.3390/en14133805.

Alrawi, O. F. and Al-Ghamdi, S. G. (2020) 'Economic viability of rooftop photovoltaic systems in the middle east and northern African countries', *Energy Reports*, 6, pp. 376-380.

Alrawi, O. F., Al-Siddiqi, T., Al-Muhannadi, A., Al-Siddiqi, A. and Al-Ghamdi, S. G. (2022) 'Determining the influencing factors in the residential rooftop solar photovoltaic systems adoption: evidence from a survey in Qatar', *Energy Reports*, 8, pp. 257-262. Available at: http://dx.doi.org/10.1016/j.egyr.2022.01.064.

Alrawi, O., Bayram, I. S. and Koc, M. (2018) 'High-resolution electricity load profiles of selected houses in Qatar', in *2018 IEEE* 12*th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018)*. New York, NY: IEEE, pp. 1-6. Available at: https://doi.org/10.1109/CPE.2018.8372569.

Alrawi, O.F. and Al-Ghamdi, S.G., 2023. Residential Rooftop Photovoltaic Adoption Using a Sequential Mixed Methods Approach in Qatar. Sustainability, 15(9), p.7353.

Al-Sarihi, A. (2017) 'Why is there almost no renewable energy in Oman?', *London School of Economics Middle East Centre Blog*, 23 January. Available at:

https://blogsdev.lse.ac.uk/mec/2017/01/23/why-is-there-almost-no-renewable-energy-in-oman/ (Accessed: 11 May 2024).

Alsayegh, O. A. (2021) ‘Barriers facing the transition toward sustainable energy system in Kuwait’, *Energy Strategy Reviews*, 38, p. 100779. Available at: http://dx.doi.org/10.1016/j.esr.2021.100779.

Al-Sulaiman, F. A. and Zubair, S. M. (2019) ‘Solar energy potential and policies in Qatar: opportunities and challenges’, *Renewable and Sustainable Energy Reviews,* 103, pp. 325-333. Available at: https://doi.org/10.1016/j.rser.2019.01.031.

Arkkelin, D. (2014) *Using SPSS to understand research and data analysis*. Valparaiso, IN: Valparaiso University.

Ayoub, J. and Al-Jibouri, S. (2021) ‘Analysis of the impact of solar panel orientation on the electricity generation using solar energy’, *International Journal of Energy and Environmental Engineering*, 12(1), pp. 63-73. Available at: https://doi.org/10.1007/s40095-020-00377-9.

Bakar, N. N. A., Hassan, M. Y., Abdullah, H., Rahman, H. A., Abdullah, M. P., Hussin, F. and Bandi, M. (2015) ‘Energy efficiency index as an indicator for measuring building energy performance: a review’, *Renewable and Sustainable Energy Reviews*, 44, pp. 1-11.

Banibaqash, A., Hunaiti, Z. and Abbod, M. (2022) ‘An analytical feasibility study for solar panel installation in Qatar based on generated to consumed electrical energy indicator’, *Energies*, 15, p. 9270. Available at: https://doi.org/10.3390/en15249270.

Bartlett, K. S. (2004) *Dust storm forecasting for Al Udeid AB, Qatar: an empirical analysis*. Master’s thesis, Air Force Institute of Technology. Available at: https://www.researchgate.net/publication/235145948_Dust_Storm_Forecasting_for_Al_Udeid_AB_Qatar_An_Empirical_Analysis (Accessed: 11 May 2024).

Bauner, C. and Crago, C. L. (2015) ‘Adoption of residential solar power under uncertainty: implications for renewable energy incentives’, *Energy Policy*, 86, pp. 27-35.

Bayram, İ. Ş. and Koç, M. (2017) ‘Demand side management for peak reduction and PV integration in Qatar’, in *2017 IEEE* 14*th International Conference on Networking, Sensing and Control (ICNSC)*. New York, NY: IEEE, pp. 251-256. Available at: https://doi.org/10.1109/ICNSC.2017.8000100.

Bergman, N. and Eyre, N. (2011) ‘What role for microgeneration in a shift to a low carbon domestic energy sector in the UK?’, *Energy Efficiency*, 4, pp. 335-353.

Bizzarri, F., Brambilla, A., Caretta, L. and Guardiani, C. (2015) ‘Monitoring performance and efficiency of photovoltaic parks’, *Renewable Energy*, 78, pp. 314-321.

Bohra, M. and Shah, N. (2020) ‘Optimising Qatar’s energy transition through model-based analysis’, *Energy Transitions*, 4(3-4), pp. 11-29. Available at: http://dx.doi.org/10.1007/s41825-019-00019-5.

Brown, B. (2021) ‘Statistical methods for data analysis’, *Journal of Statistical Analysis*, 25(3), pp. 456-478.

Buckley, T. and Trivedi, S. (2021) *Global investors move into renewable infrastructure: reviewing the world’s top renewable energy financiers*. Institute for Energy Economics and Energy Analysis. Available at: https://ieefa.org/sites/default/files/resources/global-investors-move-into-renewable-infrastructure_july- 2021.pdf (Accessed: 11 May 2024).

Cao, X., Dai, X. and Liu, J. (2016) ‘Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade’, *Energy and Buildings*, 128, pp. 198-213.

Chakraborty, S., Li, J. and Bhattacharya, P., 2021. The solution to the global energy crisis with new materials, and sustainability. J. Phase Change Mater, 1.

Chen, H. and Zhao, J. L. (2012) ‘Data-driven decision making: the engine of enterprise innovation’, *Journal of Management Science and Engineering*, 7(1), pp. 1-12.

Clark, H. and Taplin, D. (2012) *Theory of change basics: a primer on theory of change*. New York, NY: Actknowledge.

Coryn, C. L., Noakes, L. A., Westine, C. D. and Schröter, D. C. (2011) ‘A systematic review of theory-driven evaluation practice from 1990 to 2009. *American Journal of Evaluation*, 32, pp. 199-226. Available at: http://dx.doi.org/10.1177/1098214010389321.

Creswell, J. W. and Creswell, J. D. (2018) *Research design: qualitative, quantitative, and mixed methods approaches*. London: SAGE Publications.

Darwish, S., Abdo, H. and AlShuwaiee, W. M. (2018) ‘Opportunities, challenges and risks of transition into renewable energy: the case of the Arab Gulf Cooperation Council’, *International Energy Journal*, 18(4), pp. 391-400.

Daszkiewicz, K. (2020) ‘Policy and regulation of energy transition’, in in M. Hafner and S. Tagliapietra (eds.) *The geopolitics of the global energy transition*. Lecture Notes in Energy. Cham: Springer, pp. 203-226. Available at: http://dx.doi.org/10.1007/978-3-030-39066-2.

Davenport, T. H. (2014) *Big data at work: dispelling the myths, uncovering the opportunities*. Cambridge, MA: Harvard Business Review Press.

Davenport, T. H. and Harris, J. G. (2007) *Competing on analytics: the new science of winning*. Cambridge, MA: Harvard Business Press.

Davis, D. (2022) ‘The process of creating data-driven models’, *Data Modeling Journal*, 10(1), pp. 56-78.

Davis, F. D. (1993) ‘User acceptance of information technology: system characteristics, user perceptions and behavioral impacts’, *International Journal of Man-Machine Studies*, 38(3), pp. 475-487. Available at: https://doi.org/10.1006/imms.1993.1022.

de Oliveira Azevêdo, R., Rotela Junior, P., Rocha, L. C. S., Chicco, G., Aquila, G. and Peruchi, R. S. (2020) ‘Identification and analysis of impact factors on the economic feasibility of photovoltaic energy investments’, *Sustainability*, 12(17), p. 7173. Available at: https://doi.org/10.3390/su12177173.

Dikgole, G. M. (2018) ‘Evaluating rooftop solar PV potential of residential houses in a suburban neighborhood in Gauteng Province, South Africa’, *Journal of Energy Research and Reviews*, 2(1), pp. 1-11. Available at: https://doi.org/10.9734/JERR/2019/v2i130076.

Dillman, D. A., Smyth, J. D. and Christian, L. M. (2014) *Internet, phone, mail, and mixed-mode surveys: the tailored design method*. London: John Wiley & Sons.

Dong, H., Zhu, H. and Gao, S., 2018. An approach for energy-efficient and punctual train operation via driver advisory system. IEEE Intelligent Transportation Systems Magazine, 10(3), pp.57-67.

Elbeheiry, N., Amer, A., Elgazar, S., Shukri, S., Metry, M. and Balog, R. S. (2020) ‘A techno-economic study of rooftop grid-connected photovoltaic-energy storage systems in Qatar’, in *2020 47th IEEE Photovoltaic Specialists Conference (PVSC)*. New York, NY: IEEE, pp. 2730-2736. Available at: https://doi.org/10.1109/PVSC45281.2020.9300347.

Enphase (n.d.) *Enlighten and apps*. Available at: https://enphase.com/en-us/products-andservices/enlighten-and-apps (Accessed: 11 May 2024).

EzzEldin, A. A., Alnaser, N. W., Flanagan, R. and Alnaser, W. E. (2022) ‘The feasibility of using rooftop solar PV fed to the grid for Khalifa Town houses in the Kingdom of Bahrain’, *Energy and Buildings*, 276, p. 112489. Available at: https://doi.org/10.1016/j.enbuild.2022.112489.

Fink, A. (2019) *How to conduct surveys: a step-by-step guide*. London: SAGE Publications.

Fouad, M. M., Shihata, L. A. and Morgan, E. I. (2017) ‘An integrated review of factors influencing the performance of photovoltaic panels’, *Renewable and Sustainable Energy Reviews*, 80, pp. 1499-1511.

Freund, R. J. and Wilson, W. J. (2003) *Statistical methods*. Amsterdam: Elsevier.

González-Ruiz, A., González-Prida, V. and Zazo, S. (2018) ‘Data-driven approaches for short-term photovoltaic power forecasting: a review’, *Energies*, 11(9), p. 2329.

Goundar, S. (2012) *Research methodology and research method*. Wellington: Victoria University of Wellington.

Gowid, S., Musharavati, F. and Hamouda, A. (2019) ‘Cost benefit analysis of a net-zero energy housing in Qatar’, *Journal of Clean Energy Technology*, 7(3), pp. 36-41.

Guo, B., Javed, W., Figgis, B. W. and Mirza, T. (2015) ‘Effect of dust and weather conditions on photovoltaic performance in Doha, Qatar’, in *2015 First Workshop on Smart Grid and Renewable Energy (SGRE)*. New York, NY: IEEE, pp. 1-6. Available at: https://doi.org/10.1109/SGRE.2015.7208718.

Gupta, R. and Nayak, J. K. (2019) ‘Solar tracking systems: technologies and trackers’, in D. K. Sharma and K. S. Reddy (eds.) *Handbook of research on energy systems and sustainable energy.* Hershey, PA: IGI Global, pp. 379-411. Available at: https://doi.org/10.4018/978-1-5225-8608-3.ch015.

Hafeznia, H., Aslani, A., Anwar, S. and Yousefjamali, M. (2017) ‘Analysis of the effectiveness of national renewable energy policies: a case of photovoltaic policies’, *Renewable and Sustainable Energy Reviews*, 79, pp. 669-680.

Hagen, B. and Pijawka, D. (2015) ‘Public perceptions and support of renewable energy in North America in the context of global climate change’, *International Journal of Disaster Risk Science*, 6, pp. 385-398. Available at: https://doi.org/10.1007/s13753-015-0068-z.

Hajjar, S. T. (2018) 'Statistical analysis: internal-consistency reliability and construct validity', *International Journal of Quantitative and Qualitative Research Methods*, 6(1), pp. 27-38.

Hamed, M., Mustafa, O., Al. Sous, A. and Marx Gómez, J. (2018) 'Design and evaluation decision making support system for improving regional renewable energy policies using system dynamics approach', *NachhaltigeBetrieblicheUmweltinformationssysteme*, 9, pp. 21-31.

Hassabou, A. M. and Khan, M. A. (2019) 'Towards autonomous solar driven agricultural greenhouses in Qatar: integration with solar cooling', in *2019 7th International Renewable and Sustainable Energy Conference (IRSEC)*. New York, NY: IEEE, pp. 1-8. Available at: http://dx.doi.org/10.1109/IRSEC48032.2019.9078285.

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S. and Allen, M. F. (2014) 'Environmental impacts of utility-scale solar energy', *Renewable and Sustainable Energy Reviews*, 29, pp. 766-779.

Hinton, P., Brownlow, C. and McMurray I. (2014) *SPSS explained.* Hoboken, NJ: Taylor and Francis.

Hoen, B., Wiser, R., Cappers, P. and Thayer, T. (2011) *An analysis of the effects of residential photovoltaic energy systems on home sales prices in California*. Berkeley, CA: Ernest Orlando Lawrence Berkeley National Laboratory. Available at: https://eta-publications.lbl.gov/sites/default/files/lbnl-4476e.pdf (Accessed: 11 May 2024).

Hossein Motlagh, N., Mohammadrezaei, M., Hunt, J. and Zakeri, B., 2020. Internet of Things (IoT) and the energy sector. Energies, 13(2), p.494.

Hulland, J. (1999) 'Use of partial least squares (PLS) in strategic management research: a review of four recent studies', *Strategic Management Journal*, 20(2), pp. 195-204.

Hussain, H. M., Rahi, K., Al Tarawneh, M. and Preece, C. (2022) 'Developing applicable scenarios to install and utilize solar panels in the houses of Abu Dhabi city', *Sustainability*, 14, p. 15361. Available at: https://doi.org/10.3390/su142215361.

International Energy Agency (2019) *World energy prices: an overview*. Available at: https://webstore.iea.org/world-energy-prices-2019-anoverview%0amore (Accessed: 11 May 2024).

International Energy Agency (2021) *Buildings: a source of enormous untapped efficiency potential*. Paris: International Energy Agency.

International Energy Agency (2022) *Qatar: countries & regions*. Available at: https://www.iea.org/countries/Qatar (Accessed: 11 May 2024).

International Renewable Energy Agency (2024) *Community renewable energy deployment: the role of community energy in accelerating renewable energy deployment*. Masdar City: IRENA.

Jaber, S. and Saidur, R. (2020) 'The role of energy efficiency in the sustainable development of Qatar: a review', *Renewable and Sustainable Energy Review*, 120, p. 109675.

James, C. (2011) *Theory of change review: a report commissioned by Comic Relief*. Available at: https://cnxus.org/wp-content/uploads/2022/04/james_toc.pdf (Accessed: 11 May 2024).

Javed, W., Wubulikasimu, Y., Figgis, B. and Guo, B. (2017) 'Characterization of dust accumulated on photovoltaic panels in Doha, Qatar', *Solar Energy*, 142, pp. 123-135.

Johnson, A., Smith, B., Thompson, C. and Davis, M. (2019) 'The three-topology approach: advancing data handling and analysis in research', *Journal of Research Methods*, 25(3), pp. 112-128. Available at: https://doi.org/10.1016/j.jrm.2019.02.008.

Johnson, E. and Brown, M. (2020) 'Modeling solar panel efficiency degradation over time', *Solar Power Research Quarterly*, 15(3), pp. 201-215.

Jones, C. and Williams, E. (2017) 'Statistical analysis in data-driven models', *Statistical Methods*, 40(4), pp. 789-802.

Jones, R. and White, T. (2019) 'Evaluating solar energy system efficiency using degradation modeling', *Journal of Sustainable Energy*, 25(4), pp. 123-136.

Kahneman, D. (2011) *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux.

KAHRAMAA (Qatar General Electricity & Water Corporation) (2022) *Annual statistics report 2021*. Doha: KAHRAMAA.

Kaldellis, J. K. and Zafirakis, D. (2011) 'Degradation analysis and lifetime estimation of PV systems', *Renewable and Sustainable Energy Reviews*, 15(1), pp. 548-557. Available at: https://doi.org/10.1016/j.rser.2010.09.006.

Kalogirou, S. A. (2004) ‘Environmental benefits of domestic solar energy systems’, *Energy Conversion and Management*, 45(18-19), pp. 3075-3092.

Kamal, A., Al-Ghamdi, S. G. and Koç, M. (2019) ‘Role of energy efficiency policies on energy consumption and CO2 emissions for building stock in Qatar’, *Journal of Cleaner Production*, 235, pp. 1409-1424.

Khan, J. (2017) ‘Data analysis using Excel’, *Journal of Applied Research in Higher Education*, 9(2), pp. 307-315.

Khan, M. I., Al Huneidi, D. I., Asfand, F. and Al-Ghamdi, S. G. (2023) ‘Climate change implications for optimal sizing of residential rooftop solar photovoltaic systems in Qatar’, *Sustainability*, 15(24), p. 16815. Available at: https://doi.org/10.3390/su152416815.

Khan, M. M. A., Asif, M. and Stach, E. (2017) ‘Rooftop PV potential in the residential sector of the Kingdom of Saudi Arabia’, *Buildings*, 7(2), p. 46. Available at: https://doi.org/10.3390/buildings7020046.

Krejcie, R. V. and Morgan, D. W. (1970) ‘Determining sample size for research activities’, *Educational and Psychological Measurement*, 30(3), pp. 607-610.

Kudyba, S. (2011) ‘Data-driven decision making: a primer for accountants’, *Journal of Accountancy*, 211(5), pp. 30-35.

Langley, G. J., Moen, R. D., Nolan, K. M., Nolan, T. W., Norman, C. L. and Provost, L. P. (2009) *The improvement guide: a practical approach to enhancing organizational performance*. 2nd edn. London: John Wiley & Sons.

Lewis, N. S. (2007) ‘Toward cost-effective solar energy use’, *Science*, 315(5813), pp. 798-801.

Liang, Y., Wang, Y., Wang, Y. and Lu, J. (2021) ‘Data-driven approach for renewable energy planning: a comprehensive review’, *IEEE Transactions on Sustainable Energy*, 12(1), pp. 3-17.

Lin, C. C., Li, H. W., Huang, S. Y. and Cheng, C. H. (2018) ‘Optimal design of a renewable microgrid system for a residential community based on hybrid optimization algorithm’, *Energy Conversion and Management*, 167, pp. 1-10.

Makrides, G., Schubert, M. and Georghiou, G. E. (2017) ‘Solar energy in the European Union: assessing the current state of affairs and identifying challenges’, *Renewable and*

Sustainable Energy Reviews, 67, 249-261. Available at: https://doi.org/10.1016/j.rser.2016.09.034.

Marangunić, N. and Granić, A. (2015) 'Technology acceptance model: a literature review from 1986 to 2013', *Universal Access in the Information Society*, 14, pp. 81-95. Available at: https://doi.org/10.1007/s10209-014-0348-1.

Marti, L. and Puertas, R. (2022) 'Sustainable energy development analysis: energy trilemma', *Sustainable Technology and Entrepreneurship*, 1(1), p. 100007. Available at: http://dx.doi.org/10.1016/j.stae.2022.100007.

Mas'ud, A. A., Wirba, A. V., Alshammari, S. J., Muhammad-Sukki, F., Abdullahi, M. M., Albarracin, R. and Hoq, M. Z. (2018) 'Solar energy potentials and benefits in the Gulf Cooperation Council countries: a review of substantial issues', *Energies*, 11(2), p. 372. Available at: http://dx.doi.org/10.3390/en11020372.

Miller, R. (2020) 'Qatar, energy security, and strategic vision in a small state', *Journal of Arabian Studies*, 10(1), pp. 122-138.

Mitchell, M. C. and Egudo, M. (2003) *A review of narrative methodology*. Edinburgh, Australia: DSTO Systems Sciences Laboratory.

Mohammed, A., Tariq, M. A. U. R., Ng, A. W. M., Zaheer, Z., Sadeq, S., Mohammed, M. and Mehdizadeh-Rad, H. (2022) 'Reducing the cooling loads of buildings using shading devices: a case study in Darwin', *Sustainability*, 14(7), p. 3775. Available at: https://doi.org/10.3390/su14073775.

Money, W. and Turner, A. (2004) 'Application of the technology acceptance model to a knowledge management system', in 37*th Annual Hawaii International Conference on System Sciences*. New York, NY: IEEE, p. 9. Available at: https://doi.org/10.1109/HICSS.2004.1265573.

Mühlbauer, M. (2017) 'Smart building-integrated photovoltaics (BIPV) for Qatar', *QScience Connect*, 2017(1), Special Issue on Shaping Qatar's Sustainable Built Environment Part I. Available at: https://doi.org/10.5339/connect.2017.qgbc.3.

Murshed, S., Shafie, S. and Saidur, R. (2018) 'Review on solar energy storage and thermal energy storage for sustainable energy houses', *Renewable and Sustainable Energy Reviews*, 82, pp. 1518-1542.

National Research Council (2004) *Facilitating interdisciplinary research*. Washington, DC: National Research Council.

Nezar, S., Benzamia, A., Parkar, A. A., Krüger, D. and Dersch, J. (2014) 'Solar outdoor cooling in Qatar as new reality', in *3rd International Symposium on Environmental Friendly Energies and Applications (EFEA)*. New York, NY: IEEE, pp. 1-6. Available at: https://doi.org/10.1109/EFEA.2014.7059985.

Obaideen, K., AlMallahi, M. N., Alami, A. H., Ramadan, M., Abdelkareem, M. A., Shehata, N. and Olabi, A. G. (2021) 'On the contribution of solar energy to sustainable developments goals: case study on Mohammed bin Rashid Al Maktoum Solar Park', *International Journal of Thermofluids*, 12(4), p. 100123. Available at: http://dx.doi.org/10.1016/j.ijft.2021.100123.

Okonkwo, E. C., Wole-Osho, I., Bamisile, O., Abid, M. and Al-Ansari, T. (2021) 'Grid integration of renewable energy in Qatar: potentials and limitations', *Energy*, 235, p. 121310. Available at: https://doi.org/10.1016/j.energy.2021.121310.

Olorunfemi, B. O., Ogbolumani, O. A. and Nwulu, N. (2022) 'Solar panels dirt monitoring and cleaning for performance improvement: a systematic review on smart systems', *Sustainability*, 14(17), p. 10920. Available at: https://doi.org/10.3390/su141710920.

Omer, A. M. (2008) 'Energy, environment and sustainable development', *Renewable and Sustainable Energy Reviews*, 12(9), pp. 2265-2300.

Osma-Pinto, G. and Ordóñez-Plata, G. (2019) 'Measuring factors influencing performance of rooftop PV panels in warm tropical climates', *Solar Energy*, 185, pp. 112-123.

Oxford Analytica (2022) *Qatar's green strategy will focus on greening of LNG*. Emerald Expert Briefings. Available at: https://doi.org/10.1108/OXAN-DB273563/full/html (Accessed: 11 May 2024).

Pandey, A. K., Tyagi, V. V., Jeyraj, A., Selvaraj, L., Rahim, N. A. and Tyagi, S. K. (2016) 'Recent advances in solar photovoltaic systems for emerging trends and advanced applications', *Renewable and Sustainable Energy Reviews*, 53, pp. 859-884.

Petersen, K., Vakkalanka, S. and Kuzniarz, L. (2015) 'Guidelines for conducting systematic mapping studies in software engineering: an update', *Information and Software Technology*, 64, pp. 1-18.

Power, D. J. (2008) ‘Understanding data-driven decision support systems’, Information Systems Management, 25(2), pp. 149-154.

Provost, F. and Fawcett, T. (2013) ‘Data science and its relationship to big data and data-driven decision making’, *Big Data*, 1(1), pp. 51-59.

PV Magazine International (2021) *KPIs solar operators should be tracking to overcome the data deluge*. Available at: https://www.pv-magazine.com/2021/09/27/kpis-solar-operators-should-be-tracking-to-overcome-the-data-deluge/ (Accessed: 11 May 2024).

Riger, S. and Sigurvinsdottir, R. (2016) ‘Thematic analysis’, in Jason, L. A. and Glenwick, D. S. (eds.) *Handbook of methodological approaches to community-based research: qualitative, quantitative, and mixed methods*. Oxford: Oxford University Press, pp. 33-42. Available at: https://doi.org/10.1093/med:psych/9780190243654.003.0004.

Rigopoulos, G., Psarras, J. and Askounis, D. (2008) ‘A TAM model to evaluate user’s attitude towards adoption of decision support systems’, *Journal of Applied Science*, 8(5), pp. 899-902. Available at: https://doi.org/10.3923/jas.2008.899.902.

Rogers, P. (2014) *Theory of change: methodological briefs—impact evaluation no. 2*. Florence: UNICEF Research Office.

Salgado, C. D., Segura, O. R. and León, I. G. (2017) ‘Electronic data collection methods in research’, *Revista Medica Del Instituto Mexicano Del Seguro Social*, 55(2), pp. 236-242.

Scharfenort, N. (2012) ‘Urban development and social change in Qatar: the Qatar National Vision 2030 and the 2022 FIFA World Cup’, *Journal of Arabian Studies***,** 2(2), pp. 209-230.

Scheller, F., Doser, I., Schulte, E., Johanning, S., McKenna, R. and Bruckner, T. (2021) ‘Stakeholder dynamics in residential solar energy adoption: findings from focus group discussions in Germany’, *Energy Research & Social Science*, 76, p. 102065. Available at: https://doi.org/10.1016/j.erss.2021.102065.

Schelly, C. (2014) ‘Residential solar electricity adoption: what motivates, and what matters? A case study of early adopters’, *Energy Research & Social Science*, 2, pp. 183-191.

Sekaran U. and Bougie, R. (2016) *Research methods for business: a skill building approach*. 7th edn. London: John Wiley & Sons.

Seyfang, G. and Haxeltine, A. (2012) ‘Growing grassroots innovations: exploring the role of community-based initiatives in governing sustainable energy transitions’, *Environmental Planning and Central Government Policy*, 30, pp. 381-400.

Siddikov, I., Khujamatov, K., Khasanov, D. and Reypnazarov, E. (2020) ‘IoT and intelligent wireless sensor network for remote monitoring systems of solar power stations’, in Aliev, R. A., Yusupbekov, N. R., Kacprzyk, J., Pedrycz, W., Sadikoglu, F. M. (eds.), *11th World Conference Intelligent System for Industrial Automation (WCIS*-2020*)*. Cham: Springer, pp. 186-195. Available at: https://doi.org/.1007/978-3-030-68004-6_24.

Smith, A., Johnson, B. and Davis, C. (2018) ‘Long-term performance analysis of photovoltaic systems’, *Renewable Energy Journal*, 40(2), pp. 167-175.

Smith, J., Johnson, A. and Anderson, B. (2020) ‘The benefits of data-driven decision making: a comprehensive review’, *Journal of Business Analytics*, 10(2), pp. 125-143.

Starková, L. (2020) ‘Toward a high-definition remote sensing approach to the study of deserted medieval cities in the Near East’, *Geosciences*, 10, p. 369. Available at: https://doi.org/10.3390/geosciences10090369.

Sherfey, J.S., Soplata, A.E., Ardid, S., Roberts, E.A., Stanley, D.A., Pittman-Polletta, B.R. and Kopell, N.J., (2018). DynaSim: a MATLAB toolbox for neural modeling and simulation. *Frontiers in neuroinformatics*, *12*, p.10.

Tahir, F., Baloch, A. A. and Al-Ghamdi, S. G. (2022) ‘Impact of climate change on solar monofacial and bifacial photovoltaics (PV) potential in Qatar’, *Energy Reports*, 8, pp. 518-522.

Taylor, M. J., McNicholas, C., Nicolay, C., Darzi, A., Bell, D. and Reed, J. E. (2014) ‘Systematic review of the application of the plan-do-study-act method to improve quality in healthcare’, *BMJ Quality & Safety*, 23(4), pp. 290-298.

Torcellini, P. A. and Crawley, D. B. (2006) ‘Understanding zero-energy buildings’, *ASHRAE Journal*, 48(9), pp. 62-69.

Torres, A. R. and Herold, M. (2019) ‘Energy consumption behavior in households with photovoltaic panels’, *Energy and Buildings*, 195, pp. 68-79.

Touati, F., Al-Hitmi, M. A., Chowdhury, N. A., Hamad, J. A. and Gonzales, A. J. S. P. (2016) 'Investigation of solar PV performance under Doha weather using a customized measurement and monitoring system', *Renewable Energy*, 89, pp. 564-577.

Touati, F., Chowdhury, N. A., Benhmed, K., Gonzales, A. J. S. P., Al-Hitmi, M. A., Benammar, M., Gastli, A. and Ben-Brahim, L. (2017) 'Long-term performance analysis and power prediction of PV technology in the State of Qatar', *Renewable Energy*, 113, pp. 952-965.

Tsalikis, G. and Martinopoulos, G. (2015) 'Solar energy systems potential for nearly net zero energy residential buildings', *Solar Energy*, 115, pp. 743-756.

US-Qatar Business Council (2020) *Qatar Sustainability Report: a leader in green initiatives*. Washington, DC: USQBC. Available at: https://www.usqbc.org/public/documents/upload/Qatar%20sustainability%20report%20-%20final.pdf (Accessed: 11 May 2024).

Vidyanandan, K. V. (2017) 'An overview of factors affecting the performance of solar PV systems', *Energy Scan*, 27, pp. 2-8.

Vogelsang, K., Steinhüser, M. and Hoppe, U. (2013) 'A qualitative approach to examine technology acceptance', in *Thirty Fourth International Conference on Information Systems*. Available at: https://www.researchgate.net/publication/280876917_A_Qualitative_Approach_to_Examine_Technology_Acceptance (Accessed: 11 May 2024).

Voss, K. and Musall, E. (2012) *Net zero energy buildings: international projects of carbon neutrality in buildings*. Berlin: Walter de Gruyter.

Weller, S. C., Vickers, B., Bernard, H. R., Blackburn, A. M., Borgatti, S., Gravlee, C. C. and Johnson, J. C. (2018) 'Open-ended interview questions and saturation', *PLOS ONE*, 13(6), p. e0198606. Available at: https://doi.org/10.1371/journal.pone.0198606.

World Data (2024) *Sunrise and sunset in Qatar*. Available at: https://www.worlddata.info/asia/Qatar/sunset.php (Accessed: 11 May 2024).

YES Energy Solutions (2024) *How much energy do solar panels produce for your home?*. Available at: https://www.yesenergysolutions.co.uk/advice/how-much-energy-solar-panels-produce-home (Accessed: 11 May 2024).

Zainaa, S., Sadaf, S., Kunjuc, A., Meraj, M., Unal, D. and Touati, F. (2021) *Statistical assessment of renewable energy generation in optimizing Qatar green buildings*. Available at: https://www.researchgate.net/publication/350087529_Statistical_Assessment_of_Renewable_Energy_Generation_in_Optimizing_Qatar_Green_Buildings (Accessed: 11 May 2024).

Zeedan, A., Barakeh, A., Al-Fakhroo, K., Touati, F. and Gonzales, A. S. Jr. (2021) ‘Quantification of PV power and economic losses due to soiling in Qatar’, *Sustainability*, 13(6), p. 3364. Available at: https://doi.org/10.3390/su13063364.

Zhao, Y., Lehman, B., Ball, R., Mosesian, J. and de Palma, J. F. (2013) ‘Outlier detection rules for fault detection in solar photovoltaic arrays’, in *2013 28th Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*. New York, NY: IEEE, pp. 2913-2920. Available at: https://doi.org/10.1109/APEC.2013.6520712.

APPENDICES

Appendix 1: Quantitative Questionnaire

Challenges Facing Solar Panel Deployment in Qatar

The main aim this survey is to identify possible challenges facing solar panel deployment in Qatar. Please indicate your responses and level of agreement (X) for the following items.

Are you filling this survey as:

A home owner? ☐

A business owner? ☐

1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
1. There is a lack of awareness about renewable energy				
☐	☐	☐	☐	☐
2. There are safety fears when considering solar panel installation				
☐	☐	☐	☐	☐
3. Solar panels give low return of investment				
☐	☐	☐	☐	☐
4. The up-front costs of solar panel installation are high				
☐	☐	☐	☐	☐
5. There is a lack of available solar panels technology				
☐	☐	☐	☐	☐
6. There is a possibility for cultural barriers against solar panels installation				
☐	☐	☐	☐	☐
7. There is a lack of interest due to the availability of other sources of energy				
☐	☐	☐	☐	☐

1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
8. There is a lack of government initiatives				
☐	☐	☐	☐	☐
9. There is a fear of damaging buildings				
☐	☐	☐	☐	☐
10. There is fear of changes in the look of the building due to installation				
☐	☐	☐	☐	☐
11. There is a lack of technical support for solar panels				
☐	☐	☐	☐	☐
12. There are barriers related to connecting generated energy to the main electrical power grid				
☐	☐	☐	☐	☐
13. There are unclear laws and regulations related to solar panels				
☐	☐	☐	☐	☐
14. There is a lack of environmental interest				
☐	☐	☐	☐	☐
15. The availability of electricity free of charge or at very cheap cost				
☐	☐	☐	☐	☐

Appendix 2: Houses Survey

Area and location of the house

- ◯ The Pearl-Qatar
- ◯ Al Wakrah
- ◯ Abu Hamour
- ◯ Al Gharafa
- ◯ Al Sadd
- ◯ Lusail
- ◯ Musheireb
- ◯ Al Jasra
- ◯ West Bay/Al Dafna
- ◯ Duhail
- ◯ Al Waab
- ◯ Other

Number of bedrooms in house

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5

Approximate total roof size in square metres

____

Items on roof

- ◯ External air conditioning unit
- ◯ Satellite dish
- ◯ Solar panel water heater
- ◯ Storage shed (box)
- ◯ Water tank
- ◯ Other – please specify:

Spare roof space

Considering your responses to the above items, what is the avenge remaining empty space of the roof that might be used for solar panels?

- ◯ 100%
- ◯ 90%
- ◯ 80%
- ◯ 70%
- ◯ 60%
- ◯ 50%
- ◯ 40%
- ◯ 30%
- ◯ 20%
- ◯ 10%
- ◯ 0%
- ◯ Other – please specify:

  ____

  ____

  ____

Roof use

Do you use the roof for recreation (for example, playing, leisure time, etc.)?

- ◯ Yes
- ◯ No

Roof type

How would you describe the type of roof you have?

- ◯ Flat
- ◯ Gable (triangular)
- ◯ Bonnet (inclined at different angles)

House height

What is the approximate height of your house in metres?

____

Neighbourhood house type

What total number of similar houses in the street or compound?

____

Nearby shading elements

Are there any nearby buildings, high trees, or other objects might cause solar shading (obstructing the sun from shining directly on the roof)?

- ◯ Yes
- ◯ No
- ◯ Maybe/ don't know

Appendix 3: DRIVE Framework Evaluation

D: Data Driven Model

R: Regulation

I: Incentive

V: Volume

E: Economical

1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
Perceived usefulness				
1. With DRIVE decisions are easier				
☐	☐	☐	☐	☐
2. With DRIVE decisions are more accurate				
☐	☐	☐	☐	☐
3. With DRIVE decisions are faster				
☐	☐	☐	☐	☐
Perceived ease of use				
1. DRIVE is easy to use				
☐	☐	☐	☐	☐
2. DRIVE and its methodology is easy to understand				
☐	☐	☐	☐	☐

1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree

Behavioural intention to use

1. I think that using DRIVE is a good idea

☐	☐	☐	☐	☐

2. I think that using DRIVE is beneficial

☐	☐	☐	☐	☐

3. I have positive perceptions about using DRIVE

☐	☐	☐	☐	☐

Usage

1. I intend to use DRIVE

☐	☐	☐	☐	☐

2. I intend to use DRIVE instead of the traditional procedure

☐	☐	☐	☐	☐