A MULTI-LEVEL DECISION SUPPORT FRAMEWORK FOR COMMUNITY SHARED SOLAR ADOPTION IN CITIES: A CASE STUDY IN HONG KONG

HUANG LIJIE

PhD

The Hong Kong Polytechnic University

2025

The Hong Kong Polytechnic University

Department of Building and Real Estate

A Multi-level Decision Support Framework for Community Shared Solar Adoption in Cities: A Case Study in Hong Kong

HUANG Lijie

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

April 2025

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

____

Signed

HUANG Lijie

Abstract

Renewable energy technologies are undergoing rapid development and implementation on a global scale as they are considered as pivotal alternatives that have the potential to curtail carbon emissions and mitigate reliance on fossil fuels. Among them, community solar offers accessible and affordable solar power to individuals facing financial or locational constraints. However, several barriers impede the adoption and scaling of community solar, highlighting the need to assess the feasibility of community shared solar (CSS) projects from social, techno-economic, and environmental perspectives to promote community solar adoption and facilitate energy transmission.

This research aims to develop a multi-level decision support framework for community solar adoption that considers social, techno-economic, and geographic feasibility to promote distributed solar generation through community solar adoption and to achieve energy democracy in a city. The specific objectives of this research are as follows: (1) To identify and categorize barriers to community solar adoption by importance and relevance (Social acceptance); (2) To develop a business model and a financial model for CSS projects, analyzing appropriate electricity pricing to benefit both developers and subscribers, and exploring the techno-economic performance of CSS projects (Techno-economic feasibility); (3) To propose a method for identifying suitable sites for CSS projects, considering multiple criteria (Geographic suitability); (4) To apply and validate the proposed multi-level decision support framework through case studies in Hong Kong, offering strategies to enhance community solar adoption in Hong Kong.

Initially, the study identified motivations and challenges in community solar adoption, particularly in niche markets, providing a theoretical foundation for further in-depth analysis. Based on it, this study comprehensively investigated key barriers to community solar adoption through integrated methods, revealing causal and hierarchical relationships among these barriers. In addition, this study proposed a new business model and a customized financial model for CSS projects in emerging markets, evaluating the financial performance of CSS projects under current and future market conditions. Moreover, this study identified feasible, suitable, and optimal sites for CSS projects. Ultimately, a multi-level decision support framework for community solar adoption was proposed by integrating three modules: social acceptance, techno-economic feasibility, and geographic suitability. The framework was validated in Hong Kong by conducting comparative and empirical analyses.

The key findings obtained in this study include the following aspects. First, the results of social acceptance indicate that immaturity is the most important barrier from the perspectives of customers and developers. Customers prioritize policy support, conversion efficiency, and reliability, while developers focus more on weather, lack of information, and reliability. The results emphasize the important role of technological advancement and policy support in community solar adoption. Second, the techno-economic feasibility analysis results reveal that CSS projects are currently financially unviable in Hong Kong, with PV-generated electricity prices (CSRs) being nearly two to three times higher than retail electricity prices (REPs). Conversely, future market conditions suggest that CSRs could be lower than REPs, thereby indicating the potential financial feasibility of CSS projects. To achieve acceptable financial performance under current market conditions, the estimated payback periods for CSS projects require at least over 20 years, and the minimum amount of extra subsidy required for the developer accounts for around 11% of the total upfront installation cost of PV systems. Moreover, a minimum subscription rate of approximately 75% is identified as necessary to ensure mutual benefits for developers and subscribers in the future market. Third, the findings from geographic suitability show that the final feasible sites cover 152.3 km^2, showing that 13.7 % of the study area is potentially useable. Moreover, 1.7 % of the study area is classified as very high, 0.9 % as high, 7.0 % as medium, 3.4 % as low, 0.02 % as very low, and 87.6 % as unsuitable for CSS projects. High and very high suitability areas are primarily located in industrial areas and new town rooftops in the northwest of the New Territories, dense urban areas, and vacant lands. Additionally, when CSS projects are installed in medium, high, and very high suitability areas, the amount of PV-generated electricity accounts for 15.20 % of total energy consumption in 2023, while carbon emissions can be reduced by 4.6 million tons. By prioritizing the proposed seven alternatives, this study identified an industrial center's rooftop and a residential building's rooftop as the best sites for a specific CSS project.

This research contributes to both theoretical knowledge and practical decision-making. Theoretically, first, this study introduces a hybrid tool to identify hierarchical and causal relationships among barriers to community solar adoption from the perspectives of different stakeholders. Second, this study proposes a new business model and a customized financial model for CSS projects in niche markets, which offers an innovative approach to analyze the techno-economic performance of CSS projects under different scenarios. Third, this study integrates several methods, quantitatively evaluating site selection for CSS projects. Finally, this study establishes a multi-level decision support framework for community solar adoption. Practically, the proposed framework serves as an effective tool for analyzing community solar issues before making decisions and implementing strategies. It offers valuable insights into adoption barriers, pricing and financial strategies, and site selection to promote community solar adoption in niche markets. Specifically, the framework's identification of key barriers provides constructive guidance for developing community solar projects, while the financial performance informs the design of appropriate pricing and other financial strategies. The exploration of suitable site determination at both city and project levels offers significant insights and decision support for CSS project site selection within cities. In conclusion, this research advances the field of community solar adoption by providing a comprehensive framework that addresses social, techno-economic, and geographic aspects. These contributions offer practical guidance for promoting community solar initiatives and pave the way for further advancements in sustainable energy solutions.

Publications Arising from the Thesis

Journal Papers:

1. Lijie Huang, Ruixiaoxiao Zhang, Minhyun Lee*, Geoffrey Qiping Shen, Varun Rai, Ariane Beck. Determining community solar rates and subsidy payments for a sustainable community shared solar project in Hong Kong. *Renewable Energy*, 242, 122405. https://doi.org/10.1016/j.renene.2025.122405
2. Lijie Huang, Ruixiaoxiao Zhang, Minhyun Lee*, Geoffrey Qiping Shen. Economic feasibility analysis for sustainable community solar projects in Hong Kong considering the community solar rates and subscription rates under different market conditions. Under review.
3. Lijie Huang, Ruixiaoxiao Zhang, Minhyun Lee*, Geoffrey Qiping Shen. Research on barriers to community solar adoption based on DEMATEL-ISM model. Under review.
4. Lijie Huang, Ruixiaoxiao Zhang, Minhyun Lee*, Geoffrey Qiping Shen. Optimal site identification for community shared solar projects through GIS-MCDA model. Under review.

Conference Papers:

5. Lijie Huang, Minhyun Lee*, Ruixiaoxiao Zhang, Geoffrey Qiping Shen. (2023) Economic feasibility analysis of community solar projects in Hong Kong. Energy Proceedings. *The 15th international conference on applied energy*, December 2023, Doha, Qatar.

Other Publications

Journal Papers:

6. Lijie Huang, Ruixiaoxiao Zhang, Minhyun Lee*, In Hyee Hwang, Geoffrey Qiping Shen, Ping He. Key determinants of residential photovoltaic adoption and their regional disparities in China. Under review.
7. Lijie Huang, Wei Zheng, Jingke Hong*, Yong Liu, Guiwen Liu. Paths and strategies for sustainable urban renewal at the neighbourhood level: A framework for decision-making. Sustainable Cities and Society, 55, 102074. https://doi.org/10.1016/j.scs.2020.102074.
8. Shujun Li, Minghao Zhuang, Peng Wang*, Yi Yang, Jiashuo Li, Lijie Huang, Xianda Huang, Weiqiang Chen, Yongguan Zhu. Heterogeneity analysis of solar farm expansion on cropland in China. Nature food. Under review
9. Ruixiaoxiao Zhang, Minhyun Lee*, Lijie Huang. Grid parity analysis of photovoltaic systems considering feed-in tariff and renewable energy certificate schemes in Hong Kong. Renewable and Sustainable Energy Reviews, 181, 113326. https://doi.org/10.1016/j.rser.2023.113326
10. Ruixiaoxiao Zhang, Minhyun Lee*, Lijie Huang, Shiqi Mei. Household attitudes and characteristics towards photovoltaic adoption in Hong Kong: Identifying the determinants for sustainable energy transition. Energy & Buildings, 330, 115347. https://doi.org/10.1016/j.enbuild.2025.115347
11. Ruixiaoxiao Zhang, Minhyun Lee*, Lijie Huang, Meng Ni. Optimization of battery energy storage system (BESS) sizing in different electricity market types considering BESS utilization mechanisms and ownerships. Journal of

Cleaner Production, 470, 143317. https://doi.org/10.1016/j.jclepro.2024.143317

12. Xuange Zhang, Minhyun Lee*, Xue Cui, Lijie Huang, Ruixiaoxiao Zhang, Mohannad Nyme Uddin. Thermophysiological responses and thermal comfort of occupants in indoor spaces under different speaking and non-speaking conditions. Building and Environment, 260, 111682. https://doi.org/10.1016/j.buildenv.2024.111682
13. Vincent Gbouna Zakka, Minhyun Lee*, Ruixiaoxiao Zhang, Lijie Huang, Seunghoon Jung, Taehoon Hong. Non-invasive vision-based personal comfort model using thermographic images and deep learning. Automation in Construction, 168, 105811. https://doi.org/10.1016/j.autcon.2024.105811
14. Xin Zhou, Lijie Huang, Hengqin Wu*, Geoffrey Qiping Shen, Lizi Luo. Modeling stakeholder-associated productivity performance risks in modular integrated construction projects of Hong Kong: A social network analysis. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.138699

Conference Papers:

15. Xue Cui, Minhyun Lee*, Xuange Zhang, Mohammad Nyme Uddin, Lijie Huang, Ruixiaoxiao Zhang. (2024). Impacts of COVID-19 on U.S. household energy consumption. *International conference on sustainable energy and green technology 2024*, December 2024, Bangkok, Thailand.

Acknowledgements

Three years of doctoral studies has provided me with the most valuable and memorable experience of my life. I would like to reflect on the many people who have supported and encouraged me so much throughout this period.

First of all, I would like to express my sincere gratitude to my chief supervisor, Dr. Minhyun Lee, and co-supervisor, Prof. Geoffrey Qiping Shen, for their continuous support and guidance throughout my Ph.D. studies. They always assisted me in my study and research work in an inclusive, patient and loving way. Their warm-hearted attitude also gave me confidence and encouraged me to keep up the studies during the years of my Ph.D. Without their selfless encouragement and support, I could not have successfully completed my PhD.

I wish to express my sincere appreciation to the Department of Building and Real Estate of The Hong Kong Polytechnic University for funding my research project and providing comfortable leaning environment. I also really appreciate the academic and administrative staff of the BRE department, especially Ms. Chloe Shing and Ms. Irene Pang, for their professional work, patience and advice.

I am also grateful for the help from my team members, Dr. Jin Xue, Dr. Xin Zhou, Dr. Hengqin Wu, Dr. Jin Xin, Dr. Mohammad Nyme Uddin, Han Wang, Ping He, Siqi Fan, Xiaohan Wu, Xue Cui, Xuange Zhang, and Vincent Gbouna Zakka, who were like a big warm family to me also helped me so much in both my research and daily life.

I also wish to thank the faculty and staff of Solar Energy Application Lab at RMIT university and the Department of Data Science and AI at Monash University, especially Dr. Rebecca Yang and Dr. Hao Wang, for their hospitably hosting and for providing an exemplary academic platform for communicating and exchanging ideas during my stay in Australia.

I would like to give a special thanks to Dr. Ruixiaoxiao Zhang, who always motivated me with valuable insights and inspiring ideas to overcome all the difficulties and challenges placed before me while working on my papers. Special appreciation also goes to Xiaolong Xu who provided data collection support by helping me with interviews and questionnaire surveys, and giving me valuable suggestions and technical guidance.

Sincere gratitude also goes to all colleagues and friends in Hong Kong who helped to make my doctoral journey enjoyable and impressive.

Last but not least, I would like to gratitude the continuous support of my family and thank them for their understanding, encouragement, and unconditional love.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Introduction

This chapter outlines the foundational research proposition of this study, encompassing the research background, research questions, research aim and objectives, and research scope. Following this, the overall research design and structure of the thesis are presented. Finally, the significance of the research is highlighted.

1.2 Research Background

In the context of climate change, numerous countries have adopted ambitious targets aimed at promoting energy conservation, reducing emissions, and increasing the use of renewable energy sources (Balta-Ozkan et al., 2015). Concerns regarding energy consumption in buildings have therefore achieved a high level of global attention, as the mitigation of climate change effects and environmental degradation caused by buildings has proven to be a substantial challenge (Hong et al., 2019). Building energy consumption accounts for roughly 40% of the total global energy consumption (Hong et al., 2016). Reducing this consumption can significantly contribute to energy conservation, emission reduction, and environmental protection. Renewable energy sources (e.g., wind, solar, and biomass) are considered as pivotal alternatives that have the potential to curtail carbon emissions and mitigate reliance on fossil (Balta-Ozkan et al., 2015). Consequently, renewable energy technology is rapidly developing and being widely applied worldwide. Among renewable energy technologies adopted in buildings, solar photovoltaic (PV), which converts solar energy directly into electricity, is extensively gaining traction (Jayaweera et al., 2018). Global demand for solar PV has continuously grown in recent years, with a cumulative global solar PV capacity of 942 GW in 2021 (REN21, 2022). According to the Trends in PV Applications 2022 report (IEA, 2022a), the top five PV markets in 2021 were China, the European Union (EU), the United States (U.S.), India, and Japan, comprising approximately 75% of newly installed capacity (see Figure 1.1).

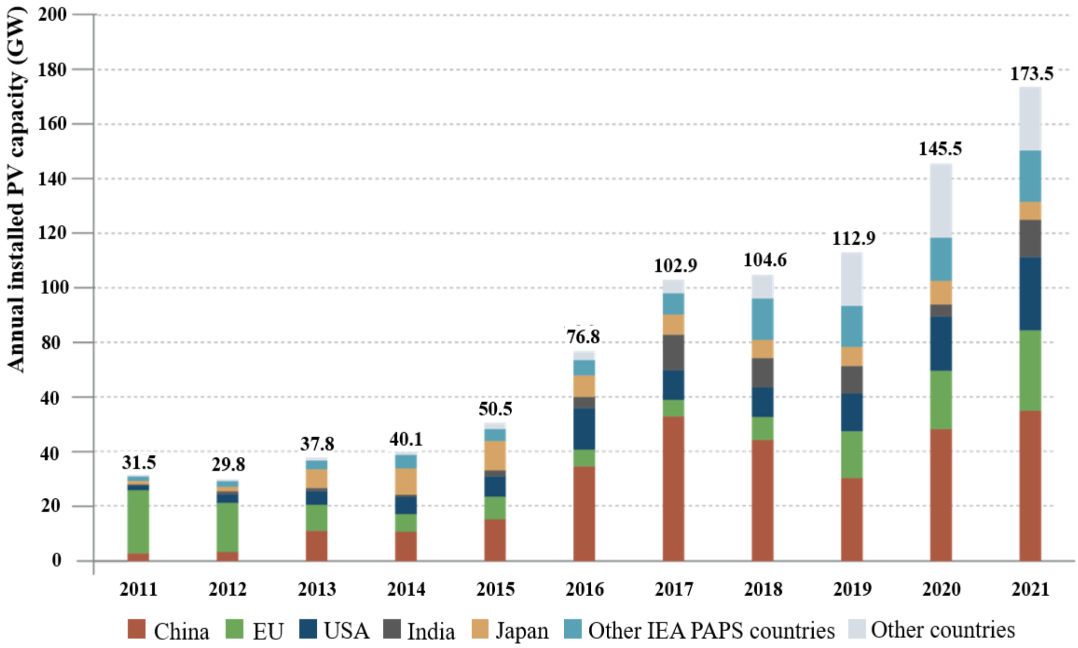


Figure 1.1 Annual installed PV capacity (2011–2021)

(Source: the International Energy Agency (IEA, 2022a))

PV technology has gradually attracted extensive attention from both industry and academia due to its potential for clean energy. Various studies on different aspects of PV have been carried out by scholars worldwide. These studies primarily focus on two areas: improving PV system performance through PV technologies (Panchenko, 2021; Sharma et al., 2021; Simsek et al., 2021) and exploring PV application in different local contexts (Balta-Ozkan et al., 2021; Lüthi & Wüstenhagen, 2012; Ozcan & Ersoz, 2019). The adoption of PV is regarded as a significant action in the sustainable energy transition (Schulte et al., 2022). Consequently, generation from photovoltaic (PV) systems and other renewable energy technologies has garnered substantial policy support, significantly contributing to the expansion of the renewable energy sector, particularly solar energy. Developed countries have generally led this transition, having initiated efforts earlier than their developing counterparts. Notably, in 1978, the U.S. pioneered the promotion of solar energy by incorporating it into the Public Utility Regulatory Policies Act (Dijkgraaf et al., 2018). Similarly, in 1994, Japan introduced the Residential PV Dissemination Scheme, which provided subsidies covering one-third of the capital cost for residential PV systems with capacities under 4 kW (Kurokawa & Ikki, 2001). Over the years, various nations have progressively implemented support policies tailored to their unique geographic, topography, and climate conditions to advance the development of renewable energy for electricity generation (Firozjaei et al., 2020).

In the application of PV technology, residential rooftop solar and utility-scale solar are the most common practices. Despite the mature and promising potential of PV technology to reduce global reliance on fossil fuels, PV development faces complex challenges, including land use conflicts (Adeh et al., 2019; Calvert & Mabee, 2015), financial access (Swain, 2019), and social resistance (Batel et al., 2013; Wüstenhagen et al., 2007). For example, while rooftop solar offers residents a powerful means to replace fossil fuel-generated power with cleaner energy, it is not an option for everyone. Some individuals do not own their homes, lack access to their rooftops due to shared spaces, have insufficient rooftop space for panels, or cannot afford the upfront costs of PV systems (Lo et al., 2018; Mah et al., 2018). Growth in utility-scale solar can lead to land use disputes, particularly when land is contested between agricultural and energy production purposes (Nonhebel, 2005). Moreover, traditional utility-owned solar projects often do not benefit specific end-users or fully incorporate local preferences of project host communities (Beck et al., 2020). Accordingly, community solar has emerged as a viable approach to harnessing solar energy for those seeking to overcome the limitations of rooftop PV installations (Burch et al., 2012; Noll et al., 2014). Individual properties frequently fail to meet the requirements for PV system installation due to factors (e.g., excessive shading, insufficient roof space, improper orientation, and high upfront costs), resulting in substantial investment risks. As an alternative, groups of homeowners can collaborate on community solar projects through collectively investing in PV systems and sharing the benefits of electricity generation (Konkle & Specialist, 2013).

The term "community solar" lacks a universally accepted definition, with varying interpretations by different organizations and researchers. For the purposes of this study, the definition from Beck et al. (2020) is used: "Community solar is a solar installation with multiple off takers (referred to as 'subscribers') who enter into a contractual relationship with the owner or operator of the installation (or an intermediary) to receive some or all of the financial returns from a predefined share of the installation's output". The potential benefits of community solar include: (1) providing tangible financial benefits to many retail electricity customers from offsite solar arrays, including those unable to benefit from solar because of inappropriate rooftop space or because they are renters, owners in a multistory building, or lack sufficient financial resources to otherwise adopt solar; (2) allowing for greater community engagement and local preference in influencing the siting and design of solar projects; and (3) creating benefits for individuals and communities who can become local stewards of renewable energy projects (Beck et al., 2020; Fontaine & Labussière, 2018; Joshi & Yenneti, 2020; Mah, 2019).

In recent years, various community solar practices have emerged. In the conventional model, PV systems are installed off-site, either at another facility or elsewhere within the community. Customers who subscribe to the shared electricity generated by these systems receive benefits proportional to their share in PV systems (Siegrist et al., 2013). This practice is normally employed when the location of the community is unsuitable for PV systems installation. Alternatively, another practice involves houseowner within a community collectively funding the installation of PV systems on suitable rooftops. Investors in this practice receive a share of the profits based on the electricity generated by the installed systems (Coughlin et al., 2011). Community solar provides affordability and accessibility to solar power for individuals constrained by financial or location limitations.

1.3 Research Questions

Community solar initiatives offer accessible and affordable solar energy solutions for individuals who face financial or locational constraints that prevent them from utilizing solar power. These initiatives simultaneously address challenges related to electrification, greenhouse gas emissions, and the fossil fuel crisis, thereby contributing to the achievement of Sustainable Development Goals (SDG 7: Affordable and Clean Energy and SDG 11: Sustainable Cities and Communities) and the pursuit of net-zero emissions targets. Despite these benefits, several barriers impede the adoption and expansion of community solar projects. To effectively address these challenges, a sophisticated methodology is required to thoroughly analyze the causal and hierarchical relationships among these barriers and to prioritize them based on their importance and impact. This is a question about the social feasibility of implementing of community shared solar (CSS) projects.

CSS projects enable a business model in which customers, developers, and non-profit organizations can customize projects to meet their specific needs, allowing consumers to reduce energy bills or address climate change without waiting for the utility company to increase their renewable portfolios. However, CSS adoption faces multiple challenges. Financial challenges are broadly recognized as impediments to CSS adoption. For new adopter of CSS projects, no tool clearly shows the appropriate electricity price with the consideration of both developers' and subscribers' benefits and financial performance. Consequently, it is difficult to determine whether a CSS project is attractive to developers and subscribers, especially in niche solar markets. This raises questions on the tech-economic feasibility of CSS projects.

Beyond financial issues, optimal site selection is also critical for the viability of solar PV projects (Jain et al., 2011). The implementation and success of conventional CSS projects largely depend on land availability, as ground-mounted solar requires space. The location of CSS projects also affects PV system output and transmission loss within a boundary. In addition, CSS projects that defer siting decisions frequently encounter considerable delays in permitting, approvals, and assessments (Hirsh Bar Gai et al., 2021). These issues underscore the necessity of addressing project siting and land allocation early in the development process. The optimal siting of solar PV projects, particularly CSS projects, has been guided predominantly by techno-economic criteria in previous studies. However, energy systems are deeply embedded within societal frameworks and exert a profound influence on our lifestyles and work environments. Consequently, factors driving energy transitions, such as individual attitudes, risk perceptions, and environmental impacts, should be carefully considered in decisions regarding renewable energy development. Selecting an appropriate location for a solar project is a critical decision in the development process, as it significantly affects the project's feasibility and economic viability.

Given the research background and identified gaps, this study addresses the following research questions:

(1) What factors influence the implementation of CSS projects and how do these barriers affect the implementation from different stakeholders' perspective?

(2) What would the techno-economic performance of a CSS project be like in different market statuses and what is the appropriate price for electricity generated from CSS projects from the perspectives of both the developer and subscriber?

(3) What is the optimal site for a CSS project and how can appropriate siting be identified considering multicriteria?

1.4 Research Aim and Objectives

To address the aforementioned research questions, the main research aim is to develop a multi-level decision support framework for the adoption of CSS projects considering the social, techno-economic, and geographic feasibilities, to promote distributed solar generation through community solar adoption and achieve energy democracy in a city. The specific research objectives are as follows:

(1) To identify barriers to community solar adoption and categorize these factors by importance and relevance (Social acceptance);

(2) To develop a business model and financial model for CSS projects, analyze appropriate electricity price considering the benefits of both developer and subscriber,

and explore the techno-economic performance of CSS projects (Techno-economic feasibility);

(3) To propose a method to identify suitable siting for CSS projects, considering multicriteria including tech-economic and social-environmental feasibilities (geographic suitability);

(4) To apply and validate the proposed multi-level decision support framework through case studies in Hong Kong, proposing solar strategies to promote community solar adoption in Hong Kong.

To this end, firstly, a comprehensive investigation of key barriers to community solar adoption was conducted (Objective 1), which provides a theoretical foundation and guides the further framework development on techno-economic and geographic sustainability. Subsequently, a business model and financial model for CSS projects were developed to analyze the techno-economic performance, particularly the appropriate electricity price (Objective 2). Additionally, by integrating tech-economic and social-environmental feasibilities, an advanced analysis tool was proposed to identify suitable siting for CSS projects considering multicriteria (Objective 3). Finally, this developed multi-level decision support framework for the adoption of CSS projects was validated through an experimental study in Hong Kong and two expert interviews (Objective 4).

1.5 Research scope

Defining the research scope is essential to develop a multi-level decision support framework for CSS project adoption, considering the tech-economic, social, and geographic feasibilities, and verifying its validity. This research established the research scope based on the following criteria:

- Regional scope: Hong Kong, a city and special administrative region of China on the eastern Pearl River Delta in South China, was selected as the regional scope of this research. With 7.5 million residents of various nationalities in a 1,115-square-kilometre territory, Hong Kong is one of the world's most densely populated places. It is also a major global financial center and one of the most developed cities worldwide. Since the 1980s, solar cells have been employed to generate power for weather stations in remote locations in Hong Kong. Currently, the largest solar energy generation system in Hong Kong is installed at Hong Kong Disneyland Resort, with a capacity of 2,100 kW, comprising over 5,000 monocrystalline solar panels on the rooftops of 20 buildings at the Resort. It is expected to generate 2,300,000 kWh annually. Apart from promoting renewable energy (RE) development through large-scale Government RE facilities, the Government has introduced the Feed-in Tariff (FiT) Scheme to encourage private sector participation in small-scale distributed RE generation by installing RE systems at their own premises.
- Community scope: A community could be qualitatively described as a geographically delineated subarea with several blocks in a city district where residents sometimes share daily life services, facilities, or common interests. A community is not a separated area in a city but is connected to other city areas. It is not necessarily delineated by a tangible boundary.
- Temporal scope: This research considered various market conditions of the PV industry (e.g., installation cost, policies and support schemes, operation and maintenance, market segments) as well as the demographic and socioeconomic

characteristics, and the retail price of electricity sold by utility companies in Hong Kong in 2021 under current scenarios and starting from 2022 under future scenarios.

- Technological scope: Community solar represents a form of distributed solar energy system that is established either on-site or off-site within communities to provide electricity or financial benefits to participating members through net energy metering (see Figure 1.2). This approach enables individuals and organizations within the community to access solar energy without the need for individual installations, thereby promoting broader participation in renewable energy initiatives. Community solar in this study can be any solar project within a geographic area (a community), where the benefits of a solar project flow to multiple subscribers such as individuals, businesses, nonprofits, and other groups. The sizes of CSS projects can vary from project to project, ranging from 20 kW to 2,000 kW or more. The average size of CSS projects is 1,000 kW (EPA, 2016), which will be considered in the data analysis in this study.

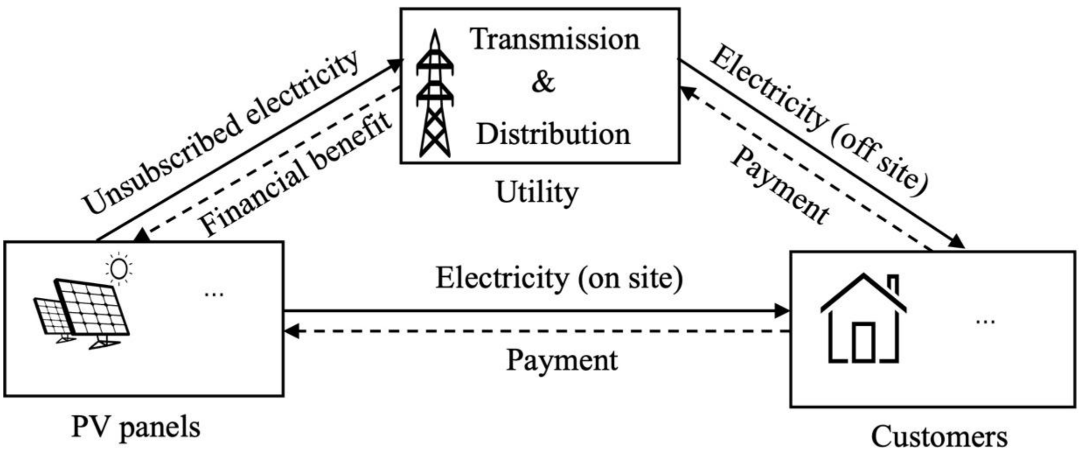


Figure 1.2 Demonstration of community shared solar projects.

1.6 Research Design

This study aims to develop a multi-level decision support framework for CSS project adoption, considering the social, techno-economic, and geographic feasibilities, to promote distributed solar generation through community solar adoption and achieve energy democracy in a city. To achieve these research objectives, both qualitative and quantitative research approaches were elaborately designed in a logical research process, as shown in Figure 1.3. Four research objectives, corresponding methods and analytical tools, and expected results, are illustrated.

First, a literature review is conducted to articulate the research problems, research trends on solar PV, community energy, and community shared solar, and research gaps.

Second, barriers to community solar adoption are identified to determine what critical factors influence the implementation of CSS projects and how these factors affect the implementation from perspectives of different stakeholders, helping act accordingly to mitigate these barriers. In this step, crucial barriers to community solar adoption are firstly identified through literature review and expert interviews. Based on it, a hybrid Interpretive Structural Modeling (ISM) - Decision Making Trail and Evaluation Laboratory (DEMATEL) approach is adopted to comprehensively understand the causal and hierarchical relationships among barriers to community solar adoption. Subsequently, the results of a questionnaire survey will be compared with the results of ISM-DEMATEL, which is expected to further our understanding of how factors affect CSS implementation and help in implementing CSS projects in an organized and effective way.

Third, a business model and a financial model are developed and used to analyze the financial performance of CSS projects. This financial model is expected to work as an effective tool for clearly analyzing the appropriate price of electricity generated by CSS projects with the consideration of both developers' and subscribers' benefits as well as financial performance of CSS projects from the perspectives of both developer and subscriber. In this step, life cycle analysis will be adopted to develop the financial model for CSS projects. Scenario analysis and sensitivity analysis will be used to explore economic performance under different conditions and analyze key issues affecting cost and revenue of CSS projects.

Fourth, the optimal location for a CSS project is identified, as the selection of a suitable site is a critical decision in the project development process, influencing both the feasibility and economic viability of the project. This phase entails the identification of multiple criteria, including exclusion and decision criteria, through a comprehensive review of the literature and consultations with experts. Subsequently, an integrated Geographic Information System and Multi-Criteria Decision Analysis (GIS-MCDA) approach will be employed to determine the suitable sites for the CSS project.

Fifth, case studies in Hong Kong will be conducted to validate the proposed decision support framework and propose strategies to promote CSS adoption.

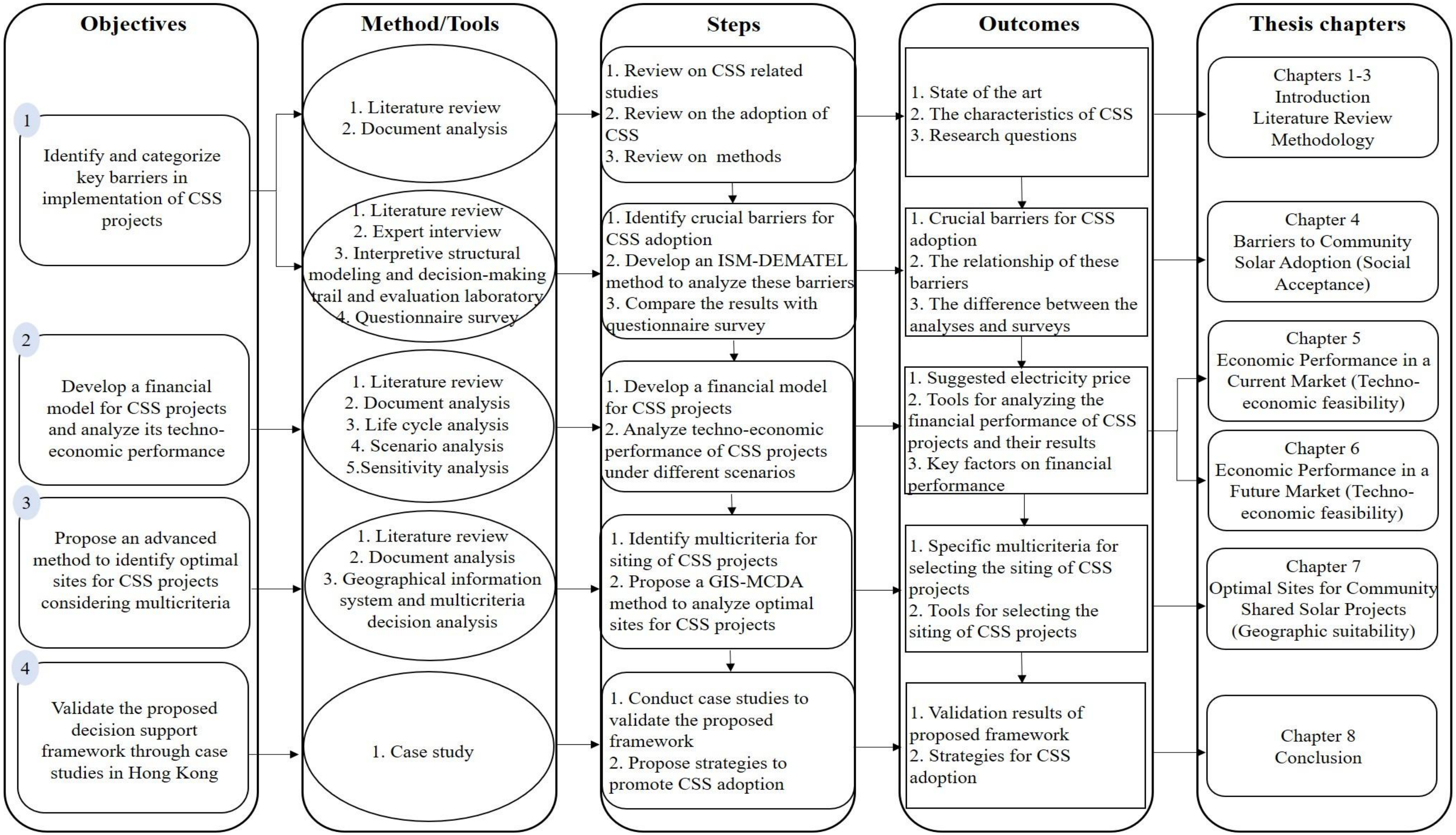


Figure 1.3 Overall framework of the thesis

1.7 Significance of the Research

The research has both theoretical and practical significance, as follows.

Theoretically, (1) this study proposes a hybrid ISM-DEMATEL tool to identify hierarchical and causal relationships among barriers in the adoption of community solar. This novel method can help decision-makers and policymakers comprehensively understand the barriers and requirements of different stakeholder types and can be expanded and adopted in similar research topics. (2) This study develops a financial model for CSS projects, which can be used to analyze the tech-economic performance of CSS projects under different scenarios and be adopted and adjusted as an effective analyze tool in different locations. (3) This study proposes multicriteria for community solar siting, incorporating tech-economic feasibility, social-environmental feasibility, and local people's interests, which can be adopted and expanded in future work, especially when other energy-shared infrastructures (e.g., electric vehicle charging stations) are included in a CSS project. (4) This study establishes a multi-level decision support framework for the adoption of CSS projects considering the benefits of different stakeholders.

Practically, (1) the proposed framework is an effective and comprehensive tool for analyzing community solar issues before making decisions and implementing relevant strategies. This research provides a scientific foundation for decision-makers to understand the implementation of CSS projects in a sustainable way, promoting the CSS adoption. (2) The proposed ISM-DEMATEL tool can be used to identify barriers to community solar adoption, filtrate these barriers, and provide suggestions to different types of decision-makers. (3) The proposed financial model helps to understand the appropriate price of electricity generated from CSS projects and their financial performance from the perspectives of both developer and subscriber, especially for new projects in niche markets. (4) The proposed multi-criteria for community solar siting, which integrates the interests of local residents and their interactions with the surrounding environment, would enhance the siting process for developers and be adopted to mitigate the inequities that have historically characterized the siting of energy facilities. By incorporating social and environmental considerations, the approach seeks to ensure more equitable and sustainable outcomes in the development of community solar projects.

1.8 Structure of the Thesis

This thesis comprises eight chapters.

Chapter 1 is an overall introduction highlighting the essential information of the whole research, including research background, research questions and objectives, research scope and design, research significance, and the structure of the whole thesis.

Chapter 2 presents a comprehensive review of the literature regarding community energy and community shared solar. Four categories of literature were reviewed: the development of recent community energy research; barriers to solar PV diffusion; economic analysis of solar PV; and optimal site identification of solar PV. Moreover, the knowledge gaps and trends were also identified to improve the significance of the study.

Chapter 3 describes the methodologies adopted throughout the research. This chapter firstly discusses the research framework, followed by the illustration of detailed methods employed such as document analysis, questionnaire survey, case study, scenario analysis, and sensitivity analysis. In addition, three major data analysis methods, namely ISM-DEMATEL, Life Cycle Cost Analysis (LCCA), and Geographic Information System - Multiple Criteria Decision Analysis (GIS-MCDA) were described in detail.

Chapter 4 presents identify key barriers to community solar adoption and categorize these factors based on their importance and relevance from the perspectives of different stakeholders by conducting ISM-DEMATEL and comparison analysis.

Chapter 5 provides analysis of determining the appropriate price of CSS-generated electricity, the expected payback period (PP), and the necessary subsidies considering the benefits to both developers and subscribers in the current Hong Kong market, through proposing a business model and a financial model for CSS projects using LCCA.

Chapter 6 investigates the techno-economic performance of CSS projects under future market conditions by proposing a new business model for CSS projects in Hong Kong and developing a financial model using LCCA.

Chapter 7 proposes a GIS-MCDA model integrating GIS spatial analysis, fuzzy-Analytic Network Process (fuzzy-ANP), and fuzzy - Vlsekriterijumska Optimizacija I Kompromisno Resenje (fuzzy-VIKOR) methods to identify feasible sites, suitable sites, and optimal sites for CSS projects.

Chapter 8 summarizes the primary research findings and examines the achievement of the research objectives proposed at the beginning of the study. The theoretical and practical contributions of this study are highlighted. Finally, the limitations of this research and direction for future related studies are discussed.

1.9 Summary of the Chapter

This chapter outlines the overall research proposition, including background information, research questions, research aim and objectives, research scope, research design, and research significance. Community solar offers accessible and affordable solar power to individuals facing financial or locational constraints. However, the feasibility of CSS projects from social, techno-economic, and environmental perspectives to promote community solar adoption and facilitate energy transmission remains unknown. This research therefore aims to develop a multi-level decision support framework for community solar adoption that considers social, techno-economic, and geographic feasibility to promote distributed solar generation through community solar adoption and to achieve energy democracy in a city. The results are expected to advance the field of community solar adoption by providing a comprehensive framework that addresses social, techno-economic, and geographic aspects. These contributions offer practical guidance for promoting community solar initiatives and pave the way for further advancements in sustainable energy solutions.

Chapter 2 Literature Review

2.1 Introduction

This chapter critically reviews existing literature pertaining to community solar. Emerging evolution trends of research on community solar are summarized, including a systemic perspective to community solar, barriers from all aspects and their relationship, financial model of community solar, and siting for community solar. Moreover, several knowledge gaps have been identified to improve the significance of the present study.

2.2 Community Energy and Community shared solar

2.2.1 Community Energy

2.2.1.1 Concept and Types

Policy narratives and early scholarly discussions on renewable energy have predominately highlighted that, beyond environmental benefits, large-scale renewable energy production can significantly contribute to poverty alleviation, remote region development, and 'new eco-economies' creation (Chakrabarti & Chakrabarti, 2002). In light of this, there is a growing interest in the emergent phenomenon of community energy (CE) and its relation with sustainability transitions from academics, policy institutions and citizens (Hielscher et al., 2011). The term "community energy" lacks a singular definition, as its meaning varies depending on the social, spatial, and cultural contexts in which it operates (Middlemiss & Parrish, 2010). For example, in the United Kingdom (UK), CE projects are typically initiatives led by third-sector actors, such as charities, cooperatives, and community groups, whereas in Germany, the term CE denotes projects owned and controlled by citizens (Ruggiero et al., 2018). CE initiatives are typically characterized as distributed generation systems that facilitate direct or indirect community involvement in both the production and consumption of energy (Walker et al., 2010). These initiatives empower communities to actively participate in energy-related activities, fostering local engagement and promoting sustainable energy practices.

Various modes of community involvement give rise to different models of CE projects, including energy cooperative, community charity, community share project, and land-lease rental project (Thapar et al., 2017; Walker, 2008). In an energy cooperative, community members collectively own the project and receive shares for having invested in it. This model is particularly prevalent in Europe, where primary project financing is derived from members' shared investments, and the revenues generated are used for community socioeconomic upliftment (Heras-Saizarbitoria et al., 2018; Li et al., 2013). The model, known as community charities, involves charitable organizations providing renewable energy access solutions. This approach is common in India, where solar power plants have been installed by charitable organizations to meet residents' needs (India, 2016). Additionally, community share projects involve offering local communities limited shares in the holding by investors, a practice mandated in some countries, such as Denmark and Canada, as a condition for project approval (Thapar et al., 2017). The land-lease rental model, often utilized by farmers with extensive land holdings, involves landowners leasing their land to renewable energy project developers in exchange for rental payments (Munday et al., 2011).

The concept of CE has gained significant traction in recent years, with an increasing number of studies highlighting their role in facilitating the transition to clean and sustainable energy. Much of the existing literature focuses on evaluating CE projects in countries such as the UK, the U.S., and various European countries (Gorroño-Albizu et al., 2019; Koirala et al., 2016; van der Schoor & Scholtens, 2019). Additionally, some research has sought to delineate CE and integrated community energy systems, suggesting evaluation criteria and attributes for such systems (Bauwens & Devine-Wright, 2018; Hicks & Ison, 2018). More recently, citizen participation in energy initiatives was classified into three distinct types in the European Union's Clean Energy Package introducing new policy provisions for clean energy initiatives, namely "renewable energy community", "collective self-consumption", and "citizen energy community" (Lowitzsch et al., 2020).

2.2.1.2 Benefits and Participants

CE projects contribute to achieving economic and climate change targets, providing clean energy to remote communities, and offering social benefits and essential valued functioning, such as access to jobs and energy resource (Brummer, 2018; Soeiro & Ferreira Dias, 2020; Walker et al., 2014). For example, Rogers et al. (2012) provides a qualitative study of the social impacts of a community wood fuel project in the UK, demonstrating that the project altered the local social context of biomass heating, reduced risks for all actors involved in the future development of the local wood fuel market, and, to some extent, benefited the region as a whole. Warren and McFadyen (2010) explored the impact of a wind farm project owned by Gigha community in the UK, finding that bottom-up community energy projects can directly contribute to the community's economic and social benefits. Young and Brans (2017) used the Feldheim project as a case study to analyze community energy shift in Germany, highlighting the socio-environmental benefits of CE by reducing air pollution and improving local air quality through the displacement of fossil-fuel-based energy generation. According to these scholars, community ownership of renewable energy production results in equitable and fair outcomes. While many researchers emphasize the importance of fairness in the distribution of benefits as an outcome of CE projects, others argue that community ownership of energy projects can facilitate legitimacy in decision-making and democratic participation. Legitimacy in decision-making processes and maintaining community entitlement to development projects can potentially increase trust between developers and communities

(Cass et al., 2010). Therefore, sustainable CE projects require the consideration of benefits for different participants from multiple perspectives.

A diverse range of stakeholders play vital roles in the development of CE projects. Participants from both the private and public sectors engage to varying degrees, contributing to the formation of a cohesive community (Creamer et al., 2018; Rogers et al., 2012). Citizen involvement in decision-making and CE projects can significantly enhance the acceptance and adoption of RE sources. Typically, CE projects involve citizens as volunteers, investors, or active participants; local residents of an energy-community (Vihalemm & Keller, 2016), social entrepreneurs, community organizations, and public authorities (Saunders et al., 2012), collaborate in the energy transition (Ruggiero et al., 2018; Seyfang & Smith, 2007). These initiatives are instrumental in facilitating the transition to a low-greenhouse-gas-emission energy system, enhancing consumer engagement and trust, and offering valuable flexibility in market operations, decision-making, and local trading. Active participation, local involvement, and co-ownership are essential for strengthening energy communities (Boon & Dieperink, 2014). While the roles of these participants may vary, they collectively contributing to the development, management, and success of CE projects. Table 2.1 provides a summary of the main participants and their roles in the CE. The diverse range of activities within an energy community includes energy generation, electricity distribution, energy supply, aggregation, energy consumption, energy sharing, energy storage, the provision of energy-related services, and the implementation of other technologies.

Table 2.1 The main participants and their roles in the community energy

Participant	Participant's Role
Citizens	• Participate in decision-making on the planning, development, and management of energy-related projects. • Invest in and utilize renewable energy sources within the community. • Be consumers of renewable energy projects within the community.
Local Businesses	• Invest in renewable energy projects by providing funding and services related to clean energy technologies.
Local Government	• Facilitate permits and regulations for renewable energy projects. • Provide incentives and policies to encourage renewable energy adoption. • Collaborate with other stakeholders to achieve sustainable energy goals.
Investors	• Providing investments as non-prosumer co-owners.
Energy Producers and Consumers	• Generate renewable energy through various resources (e.g., solar, wind, biomass). • Consume the energy generated.
Energy System Actors	• Maintain smooth operation and efficient energy distribution within renewable energy communities.

2.2.2 Community Shared Solar

2.2.2.1 Concepts and Types

Cities worldwide are exploring a diverse array of alternative energy transition pathways to meet global and local climate objectives. In their pursuit of various supply-side (e.g. nuclear expansion, wind power) and demand-side technology choices (e.g. smart grid technologies), many cities are motivated to introduce solar initiatives at the community level for several reasons. Firstly, solar PV technology has experienced substantial cost reductions, with the average cost of solar electricity decreasing by 65% over the past five years (IEA, 2022b). Secondly, policymakers are increasingly acknowledging the untapped potential of solar energy as a complementary approach to achieving ambitious climate and energy objectives (Cleland, 2016). Thirdly, CSS projects are often viewed as a supplementary strategy to renewable energy initiatives led by governments, utilities, or private developers (Brummer, 2018). CSS projects introduce new possibilities with respect to technological choices, architectural designs, and funding opportunities, achieving aggregate effects that were previously attainable only through collective community efforts (Seyfang et al., 2013). The active involvement of communities in energy governance can enhance the legitimacy of policies and the trust of the public, fostering an inclusive society that is grounded in shared goals and collective solution perceptions (Brummer, 2018; Stagl, 2006). Fourthly, the potential for green growth and associated economic and social benefits, such as the creation of green jobs, is also appealing to policymakers. This green growth strategy is deemed essential for cities to maintain international competitiveness. An international review of selected community solar initiatives indicates that diverse strategies and models are being employed to maximize benefits for sustainable urban development (Table 2.2).

Researchers have developed various models of community solar for decision-making. For instance, Lee et al. (2021) introduced a virtual community-owned solar model, which enables customers to have independent control over their share of the system and to optimize the cost of electricity for their homes. DeVar (2019) identified several community solar models, including community-led and individual-owned, community-owned and externally-owned, on-site and off-site models. DeVar (2019) also proposed equity-focused community solar models that prioritize marginalized communities, aiming to make community solar initiatives more inclusive. Recent research on community solar has primarily concentrated on financial benefits. Typically, community solar offers two forms of compensation, namely the electricity model, where participants receive solar power as repayment for their share, and the investment model, where participants receive financial benefits, such as interest payments or cash settlements, as compensation (Stauch & Gamma, 2020).

Table 2.2 Cases of community solar initiatives worldwide.

Solar communities	Key actors	Initiatives	Strategies	Illustrations	References
Tucson, Arizona, the U.S.	Utility: Tucson Electric Power	Bright Tucson Community Solar program	Utility investment	• Offer customers a simple choice to purchase a block of output at a fixed fee monthly; • Tie customer value back to the local community	(Peters et al., 2018)
Lisbon, Portugal	Non-profit organization: Local Partnership of Telheiras	Telheiras Renewable Energy Community	Pay upfront	• During the installation of the REC, all members invest a certain amount • All members receive a parcel of the generated energy	(Ferreira et al., 2024)
Uttar Pradesh, India	Non-profit organization: Development Alternatives	Rampura Community Solar Power Plant	Community ownership	• Entire project cost funded by Scatec • Collected one-time security deposit of from each household • Charge for applicable electrical appliances at a fixed one-time payment	(Joshi & Yenneti, 2020)
Brixton, UK	Government: Greater London Authority	Low Carbon Zone development	Public private partnership	• Deliver community owned solar project • Sale shares of solar panels to community members	(Fuller, 2014)

Solar communities	Key actors	Initiatives	Strategies	Illustrations	References
Luonan, Foshan, China	Government: Luonan Villagers' Committee	First solar PV village in China	Feed-in tariffs and subsidies	• Government provides installation subsidies for solar investment • Committee's leadership enables villagers to adopt solar PV systems	(Mah, 2019)
Newstead, Australia	Community group: Newstead 2021	Setting up an Incorporated company to develop solar energy	Collaboration among interested community members	• Enter into memorandum with network company • Enable community to understand energy load profile • Provide technical advices	(Hinchliffe, 2016)
Ashiya, Japan	Private sector: Panasonic	"Shioashiya Solar-Shima" project Development	Residential community development	• Create a community microgrid by installing solar PV and energy storage systems in 117 homes • Develop smart city by integrating solar energy and energy management systems	(Burger, 2017)
Saskatoon, Canada	NGO: Saskatchewan Environmental Society	Renewable energy future for Saskatchewan	Crowdfunding	• Setup solar power plant by selling membership to community members • Rebate gains from solar electricity to members	(SES, 2015)

2.2.2.2 Benefits and Participants

The deployment of solar PV systems is significantly influenced by the interactions and collaborations among various stakeholders. These stakeholders can be categorized into three primary sectors: the public sector, the private sector, and the people sector. (Xue et al., 2021). The public sector encompasses policy-making institutions and relevant government departments, focusing on achieving energy objectives, implementing incentive programs, and ensuring societal acceptance of PV technologies. The private sector comprises financial institutions, consulting firms, management entities, and supplier organizations, with a primary emphasis on financial benefits and associated risks. Meanwhile, the people sector involves end-use consumers, who are primarily concerned with financial considerations such as loans, PPs, and the economic and environmental advantages of PV systems (Xue et al., 2021). Cities are increasingly adopting community solar initiatives, driven by declining solar costs, solar being recognized as a viable energy mix option, being integrated into renewable energy projects spearheaded by municipalities, utilities, or private developers, and being recognized by policymakers as providing social and economic benefits (Mah, 2019). From a utility perspective, CSS projects are advantageous as they contribute to meeting the rising demand for electricity from renewable sources and facilitate the deployment of utility-scale solar installations (Augustine & McGavisk, 2016). Furthermore, utility companies are motivated to promote community solar not only to satisfy client demand but also to compensate for revenue losses due to client migration to residential solar installations (Funkhouser et al., 2015).

Thakur and Wilson (2022) identified three critical factors for the substantial advancement of community-scale renewable energy projects: the community's readiness to create a corporate entity to manage the project, the community's acceptance to facilitate the necessary infrastructure for installation, and redefining the utility-consumer relation. Many researchers

(Gamma et al., 2017; Stauch & Vuichard, 2019) suggest a substantial market potential for community solar initiatives, with acceptance rates for community energy surpassing 60 percent. In an investigation of consumer intent to engage in community solar initiatives, Stauch and Vuichard (2019) noticed that consumers favored community solar over conventional solar and building-integrated solar systems. Jones et al. (2017) highlighted the importance of interactions and collaboration among key stakeholders, including utilities, policymakers, and third-party entities, as well as the influence of market and technological forces on community solar expansion and the achievement of local energy objectives. Mah (2019) underscored the significance of the socioeconomic and political factors, alongside the involvement of local stakeholders, in facilitating the transition to community solar and broader energy transitions.

2.3 Barriers to Solar PV adoption

2.3.1 The Importance of Social Acceptance

The renewable energy sector has seen considerable growth and development over the past few years. From 2012 to 2022, the share of renewables used to generate electricity increased by almost 9 percentage points (REN21, 2023), with renewables accounting for almost one-third (30%) of global electricity production in 2022. Despite this progress, the transition to renewable energy remains sluggish due to several factors. For instance, some solar power projects have faced fluctuating raw material prices, delays due to local unacceptance, delays attributed to supply chain disruptions, and shipping delays during 2021-2022 (REN21, 2023). Among these factors, social acceptance is a key factor in the facilitation of the transition to renewable energy.

Social acceptance of renewable energy in existing studies encompasses both market acceptance and community acceptance. Market acceptance involves the adoption of renewable energy technologies (Rogers, 1995) by stakeholders such as consumers, investors, and developers (Bell et al., 2005). Devine-Wright et al. (2017) emphasized that the diffusion of renewable energy technologies is contingent upon their integration into markets and the stimulation of investment, underscoring the significance of business and revenue models in securing acceptance among market actors. Recognizing the importance of local contexts, research has increasingly concentrated on addressing resistance and siting conflicts at the community level (Swain, 2019). Numerous studies (Devine-Wright & Wiersma, 2020; Prehoda et al., 2019; Walker & Devine-Wright, 2008) have demonstrated that the successful initiation of renewable energy projects necessitates sensitivity to the preferences and values of local communities. On the other hand, community acceptance, characterized by local support, is arguably the most vital component of project implementation (Boyd & Paveglio, 2015). Place-based elements significantly influence community perceptions and attitudes (Devine-Wright, 2009), highlighting the need to consider community preferences and values to ensure the acceptance of localized renewable energy projects.

Neglecting social acceptance as a critical factor in its development has exacerbated the gap between project proposals and final implementation (Wüstenhagen et al., 2007). Existing studies suggest that societal opposition can arise from various factors, including inadequate social safeguards, views on economic growth, political ideology, and perceived environmental risks associated with projects (Sovacool et al., 2022). Additionally, planning and permitting barriers pose significant challenges for renewable energy projects, leading to delays at various stages of development. In the U.S., renewable energy generation projects have an average permitting time of 2.7 years, resulting in the abandonment of many projects due to excessive delays (REN21, 2023). Consequently, numerous studies have explored barriers to renewable energy adoption from diverse perspectives. For example, Asante et al. (2020) employed a multi-objective optimization approach by integrating Ratio Analysis with the Evaluation Based on Distance from Average Solution method to evaluate renewable energy barriers in developing countries, and concluded that political and regulatory barriers emerged as the most critical category. Oryani et al. (2021) utilized the Analytical Hierarchy Process (AHP) method to identify and rank main barriers to solar PV development, wind turbines, and biomass in Iran. Tseng et al. (2021) compared the drivers and barriers to renewable energy adoption using fuzzy Delphi method and fuzzy-DEMATEL method, indicating that adoption is driven by technical capabilities, with technical analysis being the primary barrier.

2.3.2 Barriers to Community Shared Solar

Given that solar PV accounted for three-quarters of all renewable power capacity additions in 2023 (IEA, 2024), it is imperative to continually scale up solar energy deployment to accelerate renewable energy adoption. Research on the barriers to solar PV adoption has garnered increasing attention to address the high level of public support for solar energy, but low rates of local deployment. Existing research primarily focuses on four groups of factors: project characteristics, communication channels, social systems, and adopter characteristics. Table 2.3 summarizes the main barriers to solar PV in previous studies.

Table 2.3 The main barriers to solar PV

Barriers	Description	Sources
Physical constraints	Physical conditions unsuitable for solar PV installation (e.g., shading, roof condition, spatial availability)	(Klein & Coffey, 2016; Stauch & Vuichard, 2019)
Lack of technical support	Lack of technical support from energy utilities during installation, operation and maintenance stages (e.g., grid penetration, maintenance support)	(Gai et al., 2021; Michaud, 2020)
Immature solar technologies	Immature solar technologies related to PV systems (e.g., low reliability of PV systems, low conversion efficiency of PV systems)	(Michaud, 2020; Xue et al., 2021)
Lack of funding	Lack of financial support or incentives for solar projects from the government or private bodies	(Beck et al., 2020; Xue et al., 2021)
Financial viability ambiguity	Financial obstacles of solar PV projects (e.g., long PP, unclear remuneration)	(Gai et al., 2021; Klein et al., 2021; Oluoch et al., 2021)
Lack of willingness to participate	Consumers' unwillingness to adopt community solar	(Oluoch et al., 2021; Stauch & Gamma, 2020)
Lack of awareness	Consumers' unawareness of solar projects and are reductant to participant in	(Beck et al., 2020; Xue et al., 2021)
Stakeholder management	Difficulties in stakeholder management as solar projects involve various stakeholders (e.g., developers, consumer, financial institutions, local government, utilities)	(Mah et al., 2021; Michaud, 2020)
Market uncertainties	Lack of local market for unstable priced solar products	(Beck et al., 2020; Gai et al., 2021)
Capacity building	Lack of existing national capacity/infrastructure to mitigate technology risk	(Beck et al., 2020)

Barriers	Description	Sources
Lack of energy services company availability	Lack of companies that can handle energy-related services/projects (e.g., consumer training service, customer acquisition)	(Karakaya & Sriwannawit, 2015; Mah et al., 2018)
Legal/regulation constraints	No/uncertain legal/regulatory framework for different types of solar projects	(Xue et al., 2021)
Lack of policy support	Insufficient and ineffective policy support for solar projects	(Karakaya & Sriwannawit, 2015; Mah et al., 2018)

In terms of project characteristics, Studies by Qureshi et al. (2017) and Van Opstal and Smeets (2023) have identified high upfront cost and technological obsolescence as primary barriers for residential solar PV in Flanders and Pakistan. This is despite the fact that the International Renewable Energy Agency (2020) reported that the cost of solar PV has decreased by 82% from 2010 to 2019. Additionally, a long PP was a significant barrier to the adoption of solar energy technologies by households in the Seychelles (Etongo & Naidu, 2022), while a reduced PP effectively improves potential adopters' attitude towards installing solar in Hong Kong (Mah et al., 2018). As for community shared solar, barriers such as project complexity, limited financial incentives, and energy project operation have been identified (Bovarnick & Johnson, 2017; Fina & Auer, 2020). Chan et al. (2018) found that a pay-as-you-go subscription method and monthly payment plan could increase community solar project participation by increasing the availability and flexibility of financing.

In terms of adopter characteristics, conclusions varied across studies. Vasseur and Kemp (2015) found that solar adopters tend be higher income earning, while Wolske (2020) suggested that high-income and low-to-moderate income solar adopters are more alike than not. Age, gender, and education level have also been examined, with differing findings on their influence on PV adoption. For instance, Jayaweera et al. (2018) identified varying correlations between PV adoption and different age groups, while Kwan (2012) found that individuals in the middle age group have a higher probability of adopting solar PV. Regarding education level, Sardianou and Genoudi (2013) observed that individuals who adopt solar energy technologies tend to possess higher levels of education, a view not shared by Islam (2014). Additionally, Bashiri and Alizadeh (2018) identified a positive correlation between being female and the intention to adopt solar energy, whereas Sardianou and Genoudi (2013) concluded that gender does not significantly influence the adoption of renewable energy technologies.

In terms of communication channels, it consistently plays a crucial role in solar PV adoption as it provides essential information about solar PV products that individuals might otherwise lack (Qureshi et al., 2017; Yuan et al., 2011). Peer effects, stemming from communication and imitation, significantly influence individual decisions to adopt solar PV technology (Islam, 2014; Rai & Beck, 2015; Schelly, 2014). However, Palm (2017) found that passive peer effects, such as seeing PV systems, were less important than active peer effects in Sweden. Moreover, direct marketing from providers also plays a crucial role in shaping adoption decisions (Rai et al., 2016). Similar observations related to communication channels were observed in community shared solar (Bovarnick & Johnson, 2017; Chang et al., 2017; Koch & Christ, 2018). Horváth and Szabó (2018) revealed that communication and education about community solar projects could reduce people's unfamiliarity and increase adoption. Such processes can be expedited through social media platforms (Chan et al., 2018).

In terms of social systems, previous studies have not reached a consensus on their influence, with differing preferences for government or private providers and varying attitudes towards regulatory and legal uncertainty (Van Opstal & Smeets, 2022). For example, Zhou et al. (2017) found that respondents preferred government over private providers for solar products, whereas Lee et al. (2018) reported that privately operated small-scale solar power plants were more attractive than government-managed ones. Koch and Christ (2018) identified that individuals' concerns about air pollution motivated them to adopt individual solar PV projects, although this was not significant in (Fleiß et al., 2017). Additionally, barriers are experienced differently across societal segments and change over time (Palm, 2018), suggesting the need to understood them within their institutional and cultural settings (Reindl & Palm, 2021).

Among these studies, literature reviews, expert interviews, and questionnaire surveys are the most common methods used to identify and understand barriers to solar PV adoption (Lo et al., 2018; Mah et al., 2018; Xue et al., 2021; Yuan et al., 2011). Various regression analysis methods and hypothesis testing have been commonly adopted to analyze the influence of various factors on solar PV adoption (Bashiri & Alizadeh, 2018; Islam, 2014; Sardianou & Genoudi, 2013). Advanced methods have also been increasingly used by researchers to better understand barriers to solar PV adoption. For example, motivation theory and experimental investigation were adopted by Stauch and Gamma (2020) to explore the financial barriers to community solar adoption, while Horváth and Szabó (2018) used Business Model Canvas and Lean Canvas for identification of key barriers to the diffusion of distributed energy solutions.

2.4 Economic Analysis of Solar PV

2.4.1 Economic Analysis of Solar PV

Recent research in CE has predominately focused on assessing economic feasibility. By employing various economic indicators, researchers can evaluate the attractiveness of energy system investments for end users (Aldahmashi et al., 2021). Table 2.4 presents a comprehensive overview of existing studies analyzing CE. Several studies have explored monetary benefits of community solar PV projects. For example, Guerrero et al. (2019) conducted a simulation of a fixed 100-household peer-to-peer (P2P) energy-sharing community, with a 50% prosumer ratio. The findings demonstrated a benefit of 36% in a single day, without causing voltage violations in the electric grid, resulting in decreased expenses and increased gains for the entire community. Sayed et al. (2024) proposed an Internet of Things-enabled, cost-effective, and automated P2P solar energy sharing system for rural communities self-sufficient, investigated its feasibility, and found that the system increases the community’s self-sufficiency by 13.66% and self-consumption by 11.16%. In this regard, comprising three functional blocks has been. Using real-world data, Hafiz et al.

(2019) determined the optimal community storage size and minimum electricity cost for an all-prosumer energy community of five members with PV systems ranging in size from 3 to 6 kW. They found that energy sharing within the community reduces electricity costs by 3% on a summer day and decreases storage sizes by 50%. Similarly, Long et al. (2018) conducted a simulation in a P2P energy-sharing community with a prosumer rate of 40 percent and PV systems ranging from 2 kW to 4 kW. Their findings indicated energy-sharing increased self-sufficiency and self-consumption by 20% and 10-30%, respectively, potentially reducing the battery demand to achieve energy cost savings. It is worth noting that current studies concentrate primarily on cost savings and do not thoroughly examine how varying PV system affect technical performance, cost savings, and overall prosumer profitability.

Table 2.4 Existing studies on economic analysis of community solar projects

Community (households)	PV System Capacity (kWp)	Prosumer Ratio	Metrics (Results)	Analysis Period	Study
10	4	70%	Cost savings (£4,170 (−59%))	4 weeks	(Zepter et al., 2019)
2	3.5-5	100%	Cost savings (A total daily cost reduction of 62.71% in summer and 68.99% in winter); Breakeven time (16.35 years)	20 years	(Kusakana, 2020)
5	8	60%	Community profits (615€ on average); Revenue distribution (Distributional fairness through a fixed pricing approach)	1 year	(Henni et al., 2021)
4	3-110	100%	Energy efficiency (Increase self-sufficiency and self-consumption of the community by 13.66% and 11.16%)	1 year	(Sayed et al., 2024)
5	3-6	100%	Prosumer NPV (Differences between various houses); Cost savings (Reduce the overall electricity purchase costs for a summer day up to 11%)	20 years	(Hafiz et al., 2019)
16	2	25%	Payback times (3.3 years)	1 year	(Ferreira et al., 2024)
5	3-6	80%	NPV (Different for each member); Profits (Different for each member); Social welfare (Different for each member)	1 year	(Perger, 2020)

Regarding design and simulation tools for commercial solar PV, SAM (Oozeki et al., 2010), PVsyst (Realini et al., 2003), Homer (Skoczek et al., 2009), and the Community Solar Tool (Kato et al., 2009) are widely used deterministic applications. PVsyst is one of the most widely used software tools for the design and simulation of both grid-connected and standalone PV systems (Mermoud, 2012). It allows users to define environmental and physical uncertainties within the model. Nonetheless, PVsyst operates with a deterministic engine and does not support probabilistic simulations to account for variability in model input parameters. Additionally, PVsyst primarily focuses on standalone PV systems and is not suitable for community solar system (CSS) projects designing.

Homer is another widely recognized software in the market, designed to simulate various types of renewable energy systems based on NPV. The financial metrics in this application are largely deterministic, which limits its ability to perform probabilistic analysis or minimum viable product analysis (Energy, 2016). It also offers sensitivity analysis for models with varying solar PV and storage capacities to determine the optimal system size. Its main drawback is the extensive computation time due to the large number of cases it assesses. Additionally, it employs a 'black box' approach, preventing examination of the cost calculation algorithm (Lai & McCulloch, 2017). In contrast, the coding that SAMs use to calculate costs and design systems is well known and easily available.

RETScreen is a tool used to manage renewable energy technologies that provides Excel spreadsheets designed to calculate numerous valuable financial indicators. Its main shortcoming is that solar radiation input is not loaded daily, so fluctuations in renewable energy generation are not considered (Lai & McCulloch, 2017). Conversely, SAM supports simulations on a sub-hourly basis and can handle minutely updated weather data (Gilman, 2014).

SAM, developed by the National Renewable Energy Laboratory (NREL) in 2015, is one of the most comprehensive free applications available for PV system design. Unlike other applications, SAM allows users to define physical and environmental uncertainties through statistical distributions. It employs Monte Carlo simulation to conduct probabilistic analysis based on varying model input variables. However, SAM is limited to designing no more than four systems concurrently, which restricts its applicability for designing CSS projects. Additionally, the financial assessment in SAM is deterministic and, like Homer, is not intended for minimum viable product analysis.

In 2016, NREL also developed the Community Solar Tool, an Excel-based model for the economic evaluation of CSS projects (NERL, 2016). This tool is deterministic in nature and does not account for any sources of uncertainty. Its inputs include project lifetime, system size, the number of shares, and accrued costs. The outputs provide basic information on monthly generated electricity and its costs, without incorporating financial metrics for comparing different scenarios. Similarly, Elevate developed the Community Solar Business Case Tool in 2017 (Elevate, 2017), providing a flexible financial model projecting costs and benefits to the system developer and subscriber of a single CSS project.

Nonetheless, Shakouri et al. (2017) identified several limitations in existing applications, such as their emphasis on standalone PV systems, geographical constraints, and accuracy issues. To address these shortcomings, they proposed a quantitative decision-support model aimed at optimizing the design of CSS projects to maximize electricity generation. Similarly, Hachem-Vermette et al. (2016) employed EnergyPlus and TRNSYS simulation platforms to examine energy generation and demand, as well as greenhouse gas emissions. Freitas et al. (2018) explored the effects of PV generation, electricity storage, cumulative demand, and on-site consumption by utilizing real-time data. Shakouri et al. (2017) proposed a probabilistic model incorporating social, environmental, and physical factors to enhance PV generation performance and reduce volatility. Rudge (2021) evaluated the feasibility of solar canopies in Connecticut by adopting geospatial methods, concluding that these canopies could generate 37% of the electricity consumed. Similarly, Schunder et al. (2020) assessed the solar potential for CSS and conventional projects in Erie County, New York, by utilizing remote sensing and land use data. These commercial applications, however, do not provide insights into appropriate prices of electricity generated by CSS projects under the benefits of both developer and subscriber, which is essential for a new CSS project in a new market to understand investment attractiveness for investors and given end users.

2.4.2 Economic Analysis of Community Shared Solar

A CSS project can be adopted to maximize the benefits of energy transitions by creating advantages for both individuals and communities while allowing for greater engagement and local preference (Beck et al., 2020; Fontaine & Labussière, 2018; Joshi & Yenneti, 2020). While the potential of CSS projects is immense, the economic viability of these projects remains a challenging issue requiring thorough investigation as financial challenges have been broadly listed as impediments to CSS adoption. Previous studies have explored the financial feasibility of CSS projects in various contexts, primarily focusing on two remuneration forms: the electricity model, where shareholders receive payment in solar power, and the investment model, where payment is given as interest or monetary compensation (Stauch & Gamma, 2020). Based on this, existing studies have evaluated various financial performance metrics (e.g., NPV, levelized cost of electricity (LCOE), internal rate of return (IRR), etc.) to analyze the financial feasibility of CSS projects. Awad and Gül (2018) analyzed the feasibility of community solar based on cost minimization metrics using Monte Carlo Simulation. Mirzania et al. (2020) provided insight into NPV, LCOE, and IRR to investigate the financial viability of a CSS project in a post-subsidy era by setting the electricity price as suggested by the Department of Business Energy and Industrial Strategy of the UK. Mansó Borràs et al. (2023) proposed a model to evaluate the techno-economic potential of solar energy communities, using NPV and IRR as economic performance metrics. Deutsch and Berényi (2020) explored the economic competitiveness of CSS projects in Hungary by comparing their NPV and LCOE with those of traditional energy sources. Lage et al. (2024) conducted a techno-economic analysis of various types of CSS projects in Italy and Portugal, using NPV and IRR as performance indicators. It can be seen that most studies analyzing the financial viability of CSS projects have focused on relatively mature markets where such projects have been adopted to harness energy transaction advantages.

Despite these efforts, the techno-economic feasibility of CSS projects in emerging markets remains uncertain, highlighting the need for robust business models and financial frameworks for CSS projects in niche markets. Some previous studies have attempted to develop models or frameworks to explore the techno-economic feasibility of CSS projects in niche markets, particularly focusing on business model development and optimization. Awad and Gül (2018) developed a systematic framework using Monte Carlo methods to simulate and optimize CSS projects in Edmonton, Canada, thereby investigating the viability of CSS applications. Aghamolaei et al. (2020) proposed an integrated evaluation model combining PV system design and optimization to assess the feasibility of CSS projects in Yazd, Iran. Additionally, some studies have incorporated economic feasibility analysis into business models to explore the techno-economic performance of CSS projects. Mansó Borràs et al. (2023) assessed the potential of CSS projects by evaluating both energy and economic performance indicators in Lisbon, Portugal. It is important to note that most research evaluated the financial feasibility of CSS projects using various financial performance metrics (e.g., NPV, LCOE, IRR, etc.)

based on various financial parameters (e.g., discount rate, electricity price, total capital costs of solar PV systems, etc.).

Regarding electricity pricing, subscription-based pricing methods are increasingly popular in practice as they allow consumers to support renewable energy generation without on-site solar installations, providing access to renewable energy benefits for low-income households and communities (Adarsh Nagarajan, 2019). However, the community solar rate (CSR), representing the price or rate at which electricity generated by a CSS project is sold or provided to subscribers or customers, needs to proper investigation for new CSS projects, especially in new markets, as CSR is crucial for indicating the attractiveness of a CSS project for both the developer and subscribers. Additionally, benefits for the developer and subscribers are usually somewhat contradictory. More specifically, although both the developer and subscribers highly value financial performance of CSS projects, the developer expects to invest in a CSS project with a sufficient CSR for profitability, whereas subscribers prefer a CSS project with a lower CSR, particularly when the CSR is lower than the retail electricity price (An et al., 2022a; Mah et al., 2018; Tan et al., 2022). To satisfy the benefits of both the developer and subscribers simultaneously and to facilitate the establishment of CSS projects in new markets, it is critical to explore the CSR under assumed financial goals for both the developer and subscribers. This can serve as a benchmark value for decision-makers (e.g., the developer and subscribers) to effectively respond to a CSS project.

However, the determination of the specific CSR has not been extensively explored in existing literature. Instead, previous studies have primarily focused on determining trading prices of electricity generated from PV systems. For instance, An et al. (2022a) proposed an optimal trading price for electricity in South Korea using a genetic algorithm and Pareto optimal solution, considering both energy consumers and prosumers. Henni et al. (2021) suggested a fixed trading pricing approach for residential communities to ensure fairness. As such, it is evident that these previous research efforts were not solely dedicated to community solar. Although some attempts were made to apply different business models to CSS projects in (Lee et al., 2021; Mehta & Tiefenbeck, 2022; Mirzania et al., 2020), their focuses were more on evaluating economic performance of the project rather than providing pricing strategies or determining specific CSRs under different subscription models. Additionally, it should be noted that these models are associated with complex business structures, time-consuming processes, and extensive data requirements, making them impractical for quick and effective decision-making in nascent community solar markets.

To effectively analyze CSR, it is important to understand the contractual relationship between the developer (or operator) and consumers of CSS projects across different types of subscription models. The three most popular subscription models proposed and applied worldwide are (Beck et al., 2020): (i) the "Pay-upfront (PUF)" subscription model, which requires customers to pay the upfront cost for solar capacity and receive a monthly bill credit for the agreed term; (ii) the "Loan/lease (LL)" subscription model, which enables customers to settle the monthly payments based on the amortized upfront cost of solar capacity and receive monthly bill credits for the agreed term; (iii) the "Pay-as-you-go (PAYG)" subscription model, which allows customers to pay a certain rate of unit electricity or a certain amount of money monthly for solar electricity without any upfront payments. Characteristics of different subscription models are summarized in Table 2.5. Among them, the PAYG model is proven to effectively increase the participation rate due to enhanced financial availability and flexibility (Beck et al., 2020; Chan et al., 2018). This model is particularly appropriate for CSS projects in new markets as it can efficiently improve customer acquisition, which is considered as a critical challenge for the adoption of CSS projects (Beck et al., 2020; Mah et al., 2018; Thakur & Wilson, 2022). However, optimal

CSRs for new CSS projects under the PAYG subscription model have not been investigated, especially for nascent markets.

Table 2.5 Characteristics of different subscription models

Subscription methods	**Upfront cost of OV systems**		**Electricity bill**
	Upfront cost for solar capacity	Amortized upfront cost of solar capacity	Receiving monthly bill
PAYG	×	×	√
PUF	√	×	√
LL	×	√	√

2.5 Optimal Site Identification for Solar PV

2.5.1 Importance and Criteria for Siting

Transitioning to renewable energy sources is essential for fostering a cleaner, more resilient, and prosperous future. Increasing numbers of renewable energy projects are being developed globally to combat climate change, reduce reliance on imported fossil fuels, and enhance energy security. Siting which involves identifying suitable land for renewable energy projects, has become a critical decision in the project development, significantly impacting feasibility, efficiency, and environmental sustainability. Consequently, siting for various types of renewable energy has been explored worldwide. For example, Ashraf et al. (2024) proposed a comprehensive "Climate-Smart Siting" framework to identify renewable energy siting pathways with the aim to minimize potential harm and maximize benefits to local surroundings, which was validated in the U.S.. Elkadeem et al. (2021) developed a systematic decision-making framework using a GIS-based MCDA method for site suitability and optimal design of hybrid renewable energy systems, with an application on a regional scale in

Kenya, Sub-Saharan Africa. Giamalaki and Tsoutsos (2019) identified the most suitable locations for solar energy project installations in Rethymno by employing GIS and AHP. By carefully selecting suitable locations based on various considerations, developers can maximize clean energy generation benefits while addressing potential challenges and risks associated with project development.

Within the renewable energy landscape, solar energy plays a pivotal role by offering a sustainable, versatile, and increasingly cost-effective solution for meeting energy needs. Effective site selection of solar energy projects is of great importance to optimize energy production, maximize benefits, and enhance project performance by choosing sites with high solar irradiance levels and minimal shading from trees, buildings, or other obstructions, and considering local climate conditions and regulatory compliance. Previous studies have attempted to identify suitable sites for solar energy projects worldwide. For example, Hernandez et al. (2014) used a siting decision support tool to categorize land in California as suitable, potentially suitable, or incompatible, and to identify synergies for utility-scale solar development. Kim et al. (2018) formulated siting criteria for solar PV projects on national highways in South Korea, determining candidate sites for potential future solar highway projects. Li et al. (2019) analyzed the impact of roof design on the energy production of rooftop solar PV systems in Australia by comparing five typical roof design patterns.

To achieve site identification for solar projects, two types of criteria were commonly considered in previous studies: exclusive criteria and decision criteria. Exclusive criteria were used to identify unsuitable areas, while decision criteria were applied to resolve the fit issue. Existing research on site selection for solar projects identifies conservation and legal constraints, agricultural land, and open water or wetlands as the top three exclusion criteria, while solar radiation, the slope and orientation of the land, and proximity to electrical infrastructure are the primary decision criteria (Al Garni & Awasthi, 2018). Solar radiation is crucial as it directly influences the amount of electricity generated, thereby impacting the revenue potential of a solar project. The land slope and orientation are critical considerations, as they can substantially influence the initial investment required for site preparation and the availability of solar insolation during solar project operation. Additionally, the distance to electrical infrastructure is a significant factor because it affects both the cost of interconnection and the efficiency of electricity transmission. Table 2.6 enumerates various criteria commonly employed in solar siting selection research. Beyond the prevalent criteria (e.g., solar radiation, slope and orientation, and proximity to electrical infrastructure), there exists a notable diversity of criteria adopted across studies.

Table 2.6 Commonly used criteria in solar siting selection research

Type	Criteria	References
Suitability with exclusion threshold	Slope	(Ali et al., 2019; Doorga et al., 2019; Sward et al., 2019)
	Aspect	(Al Garni & Awasthi, 2017; Deshmukh et al., 2019)
	Distance to electrical infrastructure	(Ali et al., 2019; Sward et al., 2019)
	Distance from transportation network	(Al Garni & Awasthi, 2017; Giamalaki & Tsoutsos, 2019)
	Visual Impacts	(Giamalaki & Tsoutsos, 2019; Sindhu et al., 2017; Watson & Hudson, 2015)
Suitability	Solar Resource	(Ali et al., 2019; Doorga et al., 2019; Sward et al., 2019)
	Climate conditions	(Huang et al., 2018; Sindhu et al., 2017)
	Water availability	(Deshmukh et al., 2019)
	Land cover	(Deshmukh et al., 2019; Giamalaki & Tsoutsos, 2019)
	LCOE	(Deshmukh et al., 2019; Huang et al., 2018; Sindhu et al., 2017)
	Distance from load centers	(Deshmukh et al., 2019; Huang et al., 2018)

Type	Criteria	References
Exclusion	Protected areas	(Majumdar & Pasqualetti, 2019; Watson & Hudson, 2015)
	Developed areas	(Deshmukh et al., 2019; Sindhu et al., 2017)
	Risk areas	(Majumdar & Pasqualetti, 2019; Palmer et al., 2019)
	Agricultural lands	(Deshmukh et al., 2019; Majumdar & Pasqualetti, 2019; Watson & Hudson, 2015)
	Potential for colocation with other RE technology	(Deshmukh et al., 2019; Shiraishi et al., 2019)
	Public acceptance	(Majumdar & Pasqualetti, 2019; Sindhu et al., 2017)
	Government policy	(Sindhu et al., 2017)

It can be concluded that optimization-based techniques for solar PV project siting predominantly rely on techno-economic criteria (Sward et al., 2021). Recently, social considerations have gradually been incorporated into renewable energy siting analysis as the desire for renewable energy does not always equate to support for specific projects in specific locations (O'Neil, 2021). Sütterlin and Siegrist (2017) discovered that support diminished in Switzerland when participants were presented with concrete examples of potential disadvantages and compromises associated with solar power. As local opposition emerges as a growing challenge, there is heightened interest among researchers in understanding public perceptions of renewable energy development (McAdam & Boudet, 2012). Carlisle et al. (2015) conducted studies in California, the Southwest, and across the U.S., to examine public perceptions of utility-scale solar development both in general and in nearby areas. Roddis et al. (2018) suggested that local economic health, project capacity, and visual impact were significant factors influencing the performance of renewable energy development.

In addition, PV systems offer significant environmental advantages compared to conventional energy sources and facilitate the reuse of marginal lands (Mitigation, 2011). However, the required area for implementing large PV systems may cause undesirable impacts on landscape, land use, and biodiversity (Graebig et al., 2010). Ideally, these implementations should be located on unused, low productivity lands to minimize such impacts (Turney & Fthenakis, 2011). Non-ideal locations include forests, extreme remote areas, and areas with instability and high degrees of existing development. Furthermore, solar power may not be 'zero-emissions' or completely clean from a life-cycle perspective (Li et al., 2021). The production and construction processes of PV panels consume large amounts of materials, energy, and resources, resulting in significant emissions of atmospheric environmental pollutants. Therefore, researchers have increasingly sought to integrate environmental criteria into the site selection process for solar projects by assessing geographic suitability to better understand environmental impacts. Hernandez et al. (2014) employed a siting decision support tool to categorize land in California as suitable, potentially suitable, or unsuitable for solar development, thereby identifying opportunities for utility-scale solar projects with minimal environmental impact. This concept has recently been expanded to include a comprehensive framework that considers potential techno-ecological synergies between solar energy and land, food, water, or built systems (Hernandez et al., 2019). Hoffacker et al. (2017) examined solar development potential in agricultural region in California, demonstrating that utility-scale solar could generate nearly five times California's projected electricity demand for 2025 by installing on saline or contaminated land, developed areas, and aquifers. This finding underscores the feasibility of conserving land while meeting energy needs. Additionally, life cycle assessment (LCA) is recognized as an effective method for quantifying the environmental impacts of solar technologies (Al Garni & Awasthi, 2017).

It is worth noting that existing studies on solar siting have focused more on rooftop solar power, solar power plants, or utility-scale solar projects (Sward et al., 2021; Yousefi et al., 2018), which can serve as references for land siting of CSS projects. However, the need to optimize sites for CSS projects cannot be ignored as community solar offers distinct advantages that make them an important component of the solar energy landscape by providing accessibility to solar energy benefits for individuals without the constraints of PV system installations and fostering local engagement and participation in renewable energy initiatives with community preferences. Moreover, the locations of CSS projects differ significantly from rooftop solar and utility-scale solar projects. In conventional community solar practice, a PV system is installed off-site elsewhere in the community. Additionally, significant delays in permitting, approvals, and assessments have occurred for CSS projects that delay the siting issue (Hirsh Bar Gai et al., 2021), indicating the importance of determining project locations early in the decision process. Optimal geographic location of

CSS projects can maximize project performance and minimize project risks during development (e.g., transition loss of several PV systems within a community). However, siting for CSS projects has been rarely explored in previous studies. In the few existing studies related to CSS projects, criteria that have a direct or indirect impact on the return on investment are most often in use (Al Garni & Awasthi, 2017; Wanderer & Herle, 2013).

2.5.2 Analysis Tool for Siting

The choice of criteria and the threshold for each criterion are remarkably diverse across siting studies and are heavily affected by factors, such as geographic scope, data availability, climate factors, and solar markets. For example, Palmer et al. (2019) utilized a threshold of 1,050 kWh/m² for annual global horizontal irradiation in the UK with relatively limited solar resources, while Majumdar and Pasqualetti (2019) applied a threshold of 1,750 kWh/m² annual global horizontal irradiation in the U.S. where solar resources are more abundant. Conversely, Conversely, a study conducted in Saudi Arabia, which boasts excellent solar resources, employed solar radiation as a suitability criterion without specifying an exclusion threshold (Al Garni & Awasthi, 2017). Moreover, siting studies in mature solar markets (e.g., the Southwestern U.S. (Majumdar & Pasqualetti, 2019) and Germany (Drechsler et al., 2017)), often incorporate non-technical criteria (e.g., social consideration, environmental impact, and public perception). On the other hand, studies from emerging solar markets (e.g., Turkey (Topkaya, 2012) and India (Kumar Singh et al., 2022)) pay more attention to techno-economic criteria.

To account for multiple criteria and associated complexities, multicriteria decision analysis (MCDA) is commonly employed alongside GIS analyses. Given that site selection is inherently a spatial decision, GIS analysis is a crucial component of the decision-making process. MCDA offers a mathematical framework that assists decision-makers in evaluating multiple, often conflicting, criteria to reach optimal choices. The effectiveness of MCDA as a decision-making tool hinges on the calibration of criteria weights, which reflect the relative importance of each criterion within performance rating scales (Steele et al., 2009). Commonly used MCDA algorithms to achieve weight assignments include AHP, Elimination and Choice Translating Reality (ELECTRE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Weighted Linear Combination (WLC). These methods have been applied in solar site selection analyses, either independently or combined with other algorithms (Aly et al., 2017; Eldemir & Onden, 2016; Sánchez-Lozano et al., 2014; Watson & Hudson, 2015). For example, Al Garni and Awasthi (2017) identified suitable locations for solar power plants in Saudi Arabia by utilizing AHP, while Aly et al. (2017) applied AHP to pinpoint hotspots for concentrated solar power projects in Tanzania to meet electricity demand. Sánchez-Lozano et al. (2014) employed ELECTRE to identify suitable areas for solar facilities within a region in Spain. Eldemir and Onden (2016) combined TOPSIS with AHP for site selection and criteria weighting, respectively. Additionally, methods akin to MCDA (e.g., multi-choice objective programming), have also been utilized for land use allocation and solar PV site selection (Chang, 2007). The AHP is the most widely used and useful systematic expert tool for handling MCDA (Choi et al., 2019) due to its uncomplicated mathematics. However, the AHP method has shortcomings that cannot be ignored, including: 1) AHP does not consider the inherent uncertainty and inaccuracy of expert judgment in the calculation (Davtalab & Alesheikh, 2018); 2) as the number of alternatives increases, multiple pairwise comparisons must be performed, requiring complex calculations (Saeidi et al., 2023); and 3) AHP does not consider the correlations among criteria associated with site evaluation. Therefore, updated methods need to be adopted in solar siting.

2.6 Research Trends and Gaps

A variety of studies have been conducted on community solar, and the research trends and gaps are summarized as follows:

First, there is growing interest in the emergent phenomenon of community energy and its relationship with sustainability transitions among academics, policy institutions, and citizens alike (Hielscher et al., 2011). Community solar is emerging as a novel market model within the evolving energy landscape, wherein consumers are progressively assuming an active role (Parag & Sovacool, 2016). Recent real-world projects have contributed to a growing understanding of the planning and operation associated with community solar initiatives. While a socio-technical transition perspective can enhance our understanding of community energy, the relevant literature generally lacks a systemic perspective for analyzing community energy, particularly for newly CSS projects. In response to the complex nature of the transition process, a systemic perspective is necessary to build connections between key components, including social, economic, and environmental. However, such a systemic perspective remains underdeveloped in the community solar literature.

Second, with the increasing interest in community solar, research on the barriers or drivers of solar PV diffusion has gained more and more attention to bridge the gap between high public support for solar energy and low success in concrete local developments. Relevant studies provide insights into various barriers, their influence, and relevant research methods. However, several gaps persist. 1) The objectives of most previous studies are other renewable energy technology and other kinds of distributed solar PV projects. CSS projects have distinct characteristics involving more stakeholders and different operational modes. CSS projects are relatively new in most regions worldwide except for the U.S.. Therefore, understanding the barriers to the adoption of CSS projects based on previous renewable energy studies is necessary. 2) Previous analyses of community solar barriers have primarily focused on financial aspects. However, energy development is a social matter that is inextricably linked to technical components (Batel et al., 2013). The facilitation of energy transitions towards community solar is contingent upon the consideration of the socio-economic and political context, as well as the incorporation of local or community elements (Mah, 2019). Therefore, a comprehensive understanding of barriers from all aspects is required. 3) Most previous studies did not explore the mutual relationships among barriers or prioritize them according to their importance. Relevant research would benefit from understanding these barriers and providing recommendations to different stakeholders including customers, developers, utilities, government, etc. 4) Barriers analyzed in most previous studies were summarized through literature reviews and did not include perspectives from different stakeholders. Although a few studies conducted interviews, they lacked statistical analysis to indicate how barriers influence the adoption of community solar.

Third, recent research on community solar has primarily concentrated on assessing the economic viability of these initiatives. Analytical tools such as PVsyst, Homer, SAM, and the Community Solar Tool are frequently employed as quantitative instruments in the design and simulation of commercial solar PV systems. However, it is crucial to acknowledge the limitations of these applications, including their geographic constraints, accuracy concerns, and narrow focus on stand-alone PV systems (Shakouri et al., 2017). Consequently, the development of a quantitative decision-support model to overcome these limitations and enhance the design of community solar initiatives is imperative. In addition, the investment viability for solar projects depends on diverse factors, such as electricity generation, electricity demand, upfront installation cost, operation and maintenance costs, surplus electricity sale plan, etc. The commonly adopted financial analysis for solar projects is to estimate the electricity generation from PV systems that makes investments feasible by considering retail electricity price (REP) as a fixed rate (Richter, 2008). However, for new CSS projects in emerging markets, the appropriate price of electricity generated that is attractive for both developer and subscriber remains unknown, necessitating an advanced tool for analysis. Furthermore, most tools developed and CSS projects designed in previous studies focus on a single scenario or the current market status. For example, commonly used subscription models include three types (Beck et al., 2020). There is no tool showing the financial performance of community solar under different type of subscription model. The lack of comparison hinders decision-makers from making more rational decisions.

Finally, systems are complex components of our societies, exerting a profound influence on both our daily lives and professional activities. While a significant number of studies have examined energy transitions from the perspective of techno-economic, relatively few have considered the social and environmental dimensions inherent in energy systems, especially for solar PV projects. The success of energy project largely depend on local support and contexts, which top-down planning exercises often overlook (Sindhu et al., 2017). Additionally, environmental impacts (e.g., GHG emissions) of solar PV projects during the production and construction process are often ignored in siting analyses. Considering multiple criteria and associated complexities, MCDA is a suitable method to be used. Although MCDA is a mathematical tool known for its objective framework; however, it is crucial to recognize its dependence on inputs from decision-makers or experts. These inputs, inherently subjective, are essential for the operationalization of MCDA and require diverse mathematical algorithms to guide decision-makers toward suitable siting. Moreover, solar PV projects considered in current studies on siting analysis are typically rooftop solar or utility-scale projects. Relevant methods require to be validated or adjusted for CSS projects. Additionally, previous research has predominantly concentrated on regions with high capacities of solar generation (e.g., the Southwestern U.S., Germany, and Spain). It is imperative for future research to expand its scope to include regions with nascent or underdeveloped solar markets. This expansion is essential for determining the extent to which conclusions from these initial studies can be generalized into broader principles.

2.7 Summary of the Chapter

This chapter initially reviewed the concept, types, benefits, and participants identified in recent studies concerning community energy. The primary focus was on and community shared solar at social, techno-economic, and geographic aspects. Specifically, three major research directions in community shared solar were summarized: barriers to community solar adoption, economic analysis of CSS projects, and optimal site identification for CSS projects. Finally, research trends and gaps were identified.

Chapter 3 Methodology

3.1 Introduction

This chapter begins by presenting the proposed research framework for this study. It then discusses the scientific methodologies employed, from both qualitative and quantitative perspectives, followed by a detailed description of the research methods adopted to achieve the research objectives in this study.

3.2 Research Methodologies

Table 3.1 outlines the methods utilized at each stage of this study. Initially, critical barriers on the adoption of community solar will be identified through a literature review and document analysis. The ISM-DEMETEL method will be adapted to analyze these barriers, with results compared to those obtained from a questionnaire survey. Life Cycle Cost Analysis (LCCA) will be used to develop a financial model for CSS projects, and scenario analysis will be employed to assess their financial performance under various conditions. The GIS-MCDA method will then be adopted to analyze community solar siting. The proposed multi-level decision support framework will be validated through case studies in Hong Kong.

Table 3.1 Methods and tools used in the study.

Stage	Objective	Methods/Tools
Stage 1	Identify and categorize barriers in the implementation of CSS projects	• Literature review • Document analysis • Expert interview • ISM-DEMATEL • Questionnaire survey

Stage	Objective	Methods/Tools
Stage 2	Develop a financial model for CSS projects and analyze financial performance	• Literature review • Document analysis • Life cycle cost analysis • Scenario analysis • Sensitivity analysis
Stage 3	Propose an advanced method to identify suitable siting for CSS projects considering multicriteria	• Literature review • Document analysis • GIS-MCDA
Stage 4	Validate the proposed decision support framework through case studies in Hong Kong	• Case study

3.2.1 Document Analysis

Document analysis is a form of archival research that addresses research problems by examining various groups of documents. Archival research involves using public records as units of analysis (Dane, 1990). Document analysis can complement information obtained through other methods, such as interviews and questionnaire survey, under certain circumstances (Babey, 2020). It is a qualitative method that includes content analysis and review of existing data. In this research, document analysis will be applied to explore official documents issued in the case study area and other cities, such as the relevant policies on renewable energy, solar PV, and community solar. This method can identify current issues in renewable energy and community solar practices, relevant decision-making challenges, and valuable experiences in community solar. Existing data from official statistical records will be analyzed to identify past trends in renewable energy and community solar practices.

3.2.2 Questionnaire Survey

Survey research involves directly asking respondents questions to obtain information from a group of individuals. The can be done through interviews or questionnaires (Dane, 1990). Questionnaire surveys typically collect quantitative data (numeric information), which can be used for statistical analysis. In this research, a questionnaire survey will be applied to gather opinions on the barriers to community solar adoption from different stakeholders for both quantitative and qualitative analyses. The primary objectives are to identify crucial barriers to community solar adoption and to collect data on the influence of these barriers. Another questionnaire survey will be employed to gather opinions from several experts on the relatively importance of various criteria for CSS project siting.

3.2.3 Case Study

A case study is defined by Yin (1984) as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used". Key features of this approach include its context-based nature, the non-specificity of contextual conditions, and its combination with other methods, utilizing both qualitative and quantitative data sources. The case study approach facilitates the investigation of phenomena within specific context, where no single survey or data collection approach can capture the complexity of numerous variables (Babey, 2020). In this research, case studies will be adopted to develop a financial model for CSS projects and to validate the innovative approach for CSS project siting proposed within the framework, allowing the conceptual framework to be applied in practice.

3.2.4 Scenario Analysis

Scenario analysis is a method for predicting the possible occurrence of event or the consequences of situations, assuming that a phenomenon or trend will continue in the future (Yuan et al., 2017). It is used to evaluate the potential impacts of future events on the performance of a given system. This analytical process involves a detailed examination of various alternative outcomes, commonly referred to as “scenarios”. Furthermore, scenario analysis offers a spectrum of possible pathways for future development, each characterized by distinct outcomes and associated implications (Balaman, 2019). Scenario analysis forecasts the expected value of a performance indicator, given a time period, the occurrence of different situations, and related changes in system parameters under uncertainty (Balaman, 2019). It is an important concept in financial modeling, providing flexibility to change assumptions and reflect important operational changes. Therefore, this method will be adopted in this study to reflect changes in electricity prices and financial performance of CSS projects under different scenarios based on the proposed financial model. Additionally, this method will be employed to reflect changes in scenarios to validate the results on CSS project siting.

3.2.5 Sensitivity Analysis

Sensitivity analysis is a methodological approach that entails a detailed examination of how variations in independent variables influence a particular dependent variable, within the framework of a defined set of assumptions (Song et al., 2015). It is often used in conjunction with scenario analysis to assess the robustness of proposed framework or models. In this research, it will be adopted to evaluate the robustness of the proposed financial model by examining how changes in key assumptions impact outcomes. This method will also be employed to evaluate the robustness of siting results for CSS projects by examining how changes in final suitable sites and the ranking of alternatives for the most suitable site for a CSS project.

3.3 Analytical Tools

3.3.1 ISM-DEMATEL

3.3.1.1 Overview of ISM and DEMATEL

- The Application of ISM

The ISM method originally proposed by Warfield (1973), serves as a tool for analyzing complex socioeconomic systems. ISM is an interactive learning process that organizes complex relationships among different variables into a comprehensive systematic model, thereby illustrating the relationships and hierarchies among elements (Rajesh et al., 2013). This visual representation aids in understanding the underlying structure and functioning of the system, enabling researchers to identify key drivers, dependencies, and feedback loops (Jayant & Singh, 2015). As a powerful tool, ISM has gained significant traction across various domains as an instrumental medium for decision-making. Its application has been particularly pronounced in the process of differentiating and ranking the variables identified. (Majumdar et al., 2021; Sahu et al., 2021; Sindhu, 2022).

In research applications, ISM helps identify key drivers or influencers within a system by analyzing the interrelationships among factors, thereby determining which factors have a greater impact on the overall system (Chen & Qiao, 2023). This identification is instrumental in prioritizing resources, focusing research efforts, and understanding the critical factors that shape the behavior or outcomes of the system (Sorooshian et al., 2023). For example, Singh and Gupta (2021) applied ISM to investigate factors affecting the purchase of green products and establish a contextual relationship among them by developing a hierarchical paradigm.

He et al. (2021) analyzed influencing factors of fuel consumption of vehicles on the superhighway by using ISM. Moreover, ISM can be used to identify barriers or constraints within a system, enabling researchers to pinpoint key obstacles or bottlenecks in achieving desired goals and design interventions or strategies to overcome these barriers and improve the system's performance (Farooq et al., 2020). For instance, Ali et al. (2020) used ISM to identify barriers to lean six sigma implementations in supply chains and suggested practical implications. R and Vinodh (2021) developed a structural model based on ISM to analyze barriers to integration of Lean with Industry 4.0.

Beyond factor identification, ISM provides insights into the structure and dynamics of complex systems by allowing for the identification and visualization of interdependencies among various factors, elements, or variables within the system. By mapping out the relationships, researchers can understand the underlying structure and hierarchy of the system, leading to a deeper understanding of its functioning (SG, 2013). For example, Beikkhakhian et al. (2015) categorized the identified criteria to evaluate agile suppliers using ISM, while Jadhav et al. (2015) presented a roadmap for Lean implementation in the Indian automotive component industry by comparing the ISM Model and UNIDO–ACMA Model.

- The application of DEMATEL

The DEMATEL method, developed by the Geneva Research Centre of the Battelle Memorial Institute, is a mathematical procedure designed to address significant issues in global societies (Fontela & Gabus, 1976). It is employed to analyze interdependencies and causal relationships among factors or criteria in a decision-making context. This approach entails the transformation of the cause-and-effect relationships inherent in elemental composition into perceptible structural models, providing a structured approach to understanding the relationships and impacts among various elements in a system. DEMATEL has also been widely adopted in various research fields due to its effectiveness in analyzing complex relationships and dependencies.

The DEMATEL model enables researchers to analyze the impacts and influences of different factors or criteria on the overall system or decision-making process (Chen & Qiao, 2023). By quantifying causal relationships and dependencies, the model helps identify the key drivers or influencers, as well as the direct and indirect impacts of each factor (Mirosław-Świątek et al., 2021). This analysis provides insights into the relative importance and contributions of different elements, aiding in prioritization and resource allocation (Ahmadi et al., 2023). For example, Tsai (2018) utilized the DEMATEL model to explore the job satisfaction of research and development personnel in China's PV cell industry, while Kashyap et al. (2022) employed a DEMATEL model to identify the most important factors for implementing circularity in the aluminum industry.

Moreover, the DEMATEL model serves as a decision support tool by providing a structured framework for evaluating and comparing different options or scenarios. Researchers can use the model to assess the potential consequences and impacts of different decisions or interventions, aiding in evidence-based decision-making (Ahmadi et al., 2023). For instance, Peleckis (2021) developed a DEMATEL model to assess the concentration of business entities in IT sectors affecting the competitive situation of economy. Wang et al. (2012) proposed a DEMATEL-based model to identify divisions responsible for poor performance in design project within a matrix organization, with the aim of improving performance.

- The Comparison of ISM and DEMATEL

Both the ISM model and DEMATEL model are powerful tools for simplifying complex relationships, examining cause-effect relationships among multi-criteria in a system, and supporting decision-making processes (Chuang et al., 2013). While they share some similarities, there are notable differences between the two approaches. ISM primarily focuses on understanding the hierarchical structure and interrelationships among factors within a system (Chuang et al., 2013), aiming to identify levels of influence and dependence among factors. In contrast, DEMATEL is primarily designed for decision-making contexts, focusing on evaluating the causal relationships and impacts among factors to support decision-making processes (Yin et al., 2012). In terms of modeling approach, ISM uses a qualitative approach to model relationships among factors, often represented through a digraph or a hierarchical structure (Chen & Qiao, 2023), focusing on the directionality of influence and the relative importance of factors. DEMATEL, on the other hand, employs a quantitative approach and uses matrices to capture causal relationships and interactions among factors, allowing for the measurement and evaluation of the strength and magnitude of relationships (He, 2022). It can be concluded that ISM provides a framework for understanding the structure and hierarchy of factors within a system, which can assist in decision-making. However, its primary focus is on understanding the system rather than providing explicit decision support. DEMATEL, on the other hand, is explicitly designed as a decision support tool, quantifying relationships and impacts among factors to facilitate the evaluation and comparison of different options or scenarios (Ou et al., 2022).

To overcome limitations of ISM and DEMATEL while leveraging their strengths, the integration of these methods has been adopted across various domains (Ashtianipour & Zandhessami, 2015). For example, Shakeri and Khalilzadeh (2020) employed the hybrid ISM-DEMATEL technique to explore factors affecting project communications. Similarly, Trivedi et al. (2021) explored the barriers associated with implementing inland waterway transport by employing a hybrid ISM-DEMATEL approach. Additionally, Kumar and Dixit (2018) utilized ISM-DEMATEL to analyze hierarchical relationships among barriers affecting the implementation of e-waste management in India, while Mousavizade and

Shakibazad (2019) applying this integrated approach to identify and rank key success factors in the implementation of knowledge management within Iranian urban water and sewage companies.

3.3.1.2 Analysis Steps

Given the wide applicability of these two methods together, an integrated ISM and DEMATEL technique will be applied in this study to achieve constructive outcomes. The general flow of ISM-DEMATEL is illustrated in Figure 3.1. Firstly, barriers to the objective will be identified through a literature review and a questionnaire survey. Moreover, related experts will be interviewed for gather responses for applying ISM and DEMATEL methods. A comparison of the results obtained from the ISM and DEMATEL methods will be conducted to ascertain the most salient barriers, which will also be compared with opinions from experts to validate its robustness.

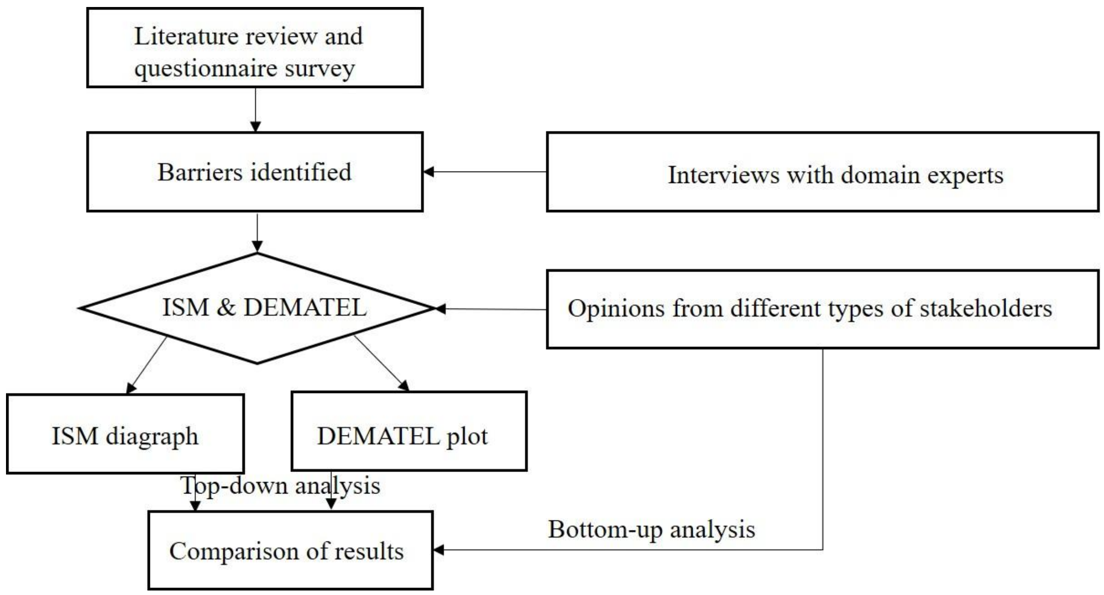


Figure 3.1 The general flow of ISM & DEMATEL method

ISM has proven to be an effective tool for addressing complex issues across various disciplines. As depicted in Figure 3.2, the ISM method consists of several sequential steps.

Additionally, the DEMATEL method aids in converting cause-and-effect relationships among elements into concrete structural models. The steps involved in the DEMATEL process are illustrated in Figure 3.3.

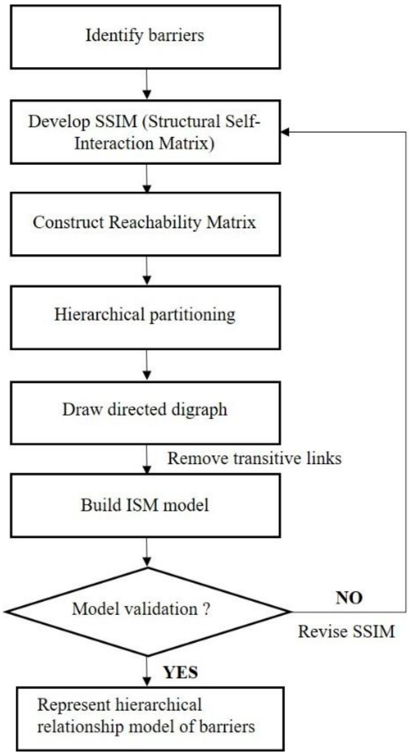


Figure 3.2 The steps involved in ISM method

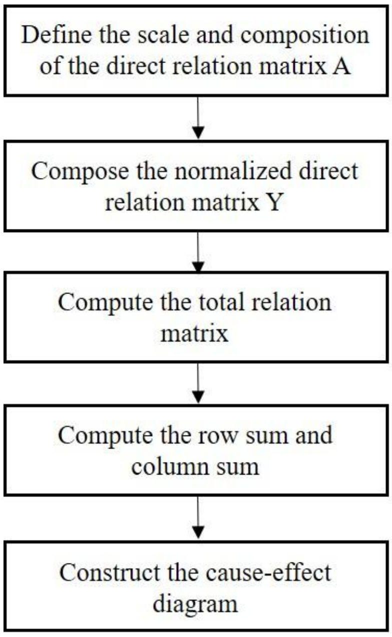


Figure 3.3 The steps involved in DEMATEL method

3.3.2 Life Cycle Cost Analysis (LCCA)

3.3.2.1 Overview of LCCA

Life cycle cost was defined by National Institute of Standards and Technology as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time (NIST, 1995). LCCA is a methodology used to calculate the entire cost of a system from its inception to its disposal. LCCA has been employed to estimate the costs of various products, such as electrical and electronic components in the automotive sector (Alonso et al., 2007), as well as some construction facility projects like ground source, heat pump, air conditioners (Esen et al., 2006, 2007), and building components (Jansen et al., 2020; Ramos et al., 2020). This study utilizes LCCA to quantify and evaluate the economic performance of CSS projects. The LCCA of each project alternative should include the following elements (DEED, 2018):

- A brief description of the project alternative.
- A brief explanation of the assumptions made during the LCCA.
- Conceptual or schematic documentation indicating the design intent of the alternative.
- A detailed LCCA of the project alternative.
- A summary table comparing the total life cycle costs of Initial Investment, Operations, Maintenance & Repair, and Residual Value of all the project alternatives.

3.3.2.2 Analysis Steps

LCCA need address cost categories relevant to the scope of a project.

The first step in the completion of the LCCA of a project alternative is to define all initial investment costs. Initial investment costs are those incurred prior to the occupation of the facility. All initial costs should be added to the LCCA total at their full value.

The second step involves defining all future operation costs of the project. Operation costs are annual expenses, excluding maintenance and repair costs, associated with the operation of the facility. All operation costs should be discounted to their present value before being added to the LCCA total.

The third step is to define all future maintenance and repair costs. Maintenance costs are scheduled expenses associated with tasks intended to keep the project in good condition. Repair costs are unanticipated expenditures required to prolong the life of the project. Some maintenance costs are incurred annually, while others occur less frequently. Repair costs, by definition, are unpredictable. All maintenance and repair costs should be discounted to their present value before being added to the LCCA total.

The fourth step is to define the residual value of the project. Residual value is the net worth of a project at the end of the LCCA study period.

Once all pertinent costs have been established and discounted to their present value, they can be summed to generate the total life cycle cost of the project. LCCA generally adopts a discounted cash flow approach using the present worth method, considering costs, real discount rate, and inflation rate over the entire life cycle of an investment. According to previous studies related to the solar PV systems, the results of LCCA can be presented in various financial indices, as shown in Table 3.2. The NPV and payback period (PP) are the most common metrics used for evaluating the economic performance of solar PV projects. The initial investment cost (IIC), on the other hand, is less frequently used as it does not account for various economic factors, focusing solely on the cost item.

Table 3.2 Financial indices for LCCA.

Index	**Equation**	**Units**
NPV	$\sum_{t=1}^{n}\frac{B_t}{(1+r)^t}-\sum_{t=1}^{n}\frac{C_t}{(1+r)^t}$	US$
Payback period (PP)	T, when $\sum_{t=1}^{T}\frac{B_t}{(1+r)^t}-\sum_{t=1}^{T}\frac{C_t}{(1+r)^t}=0$	Years
Internal rate of return (IRR)	r, when $\sum_{t=1}^{n}\frac{B_t}{(1+r)^t}-\sum_{t=1}^{n}\frac{C_t}{(1+r)^t}$	%
LCOE	$\sum_{t=1}^{n}\frac{C_t}{(1+r)^t}/\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}$	US$/kWh
Return on investment (ROI)	$\sum_{t=1}^{n}\frac{B_t}{(1+r)^t}/\sum_{t=1}^{n}\frac{C_t}{(1+r)^t}$	-
Initial investment cost (IIC)	C_1	US$

Note: B_t means the benefit in year t (US$); C_t means the cost in year t (US$); E_t means the energy produced in year t (kWh); r means real discount rate; and n means the analysis period.

3.3.3 GIS-MCDA

3.3.3.1 Overview of GIS-MCDA

MCDA offers a mathematical framework that assists decision-makers in evaluating multiple, often conflicting, criteria to reach optimal choices. Although definitions of MCDA vary in the literature, it is generally described as a method for quantifying suitability using weights (i.e., weighted summation procedures). This This method is primarily adopted by analysts engaged in high-level electricity planning, as well as by leading developers, with the aim of informing future development strategies. Given the inherently spatial nature of site selection, GIS analysis is a crucial component of the broader decision-making process. Additionally, assessing land suitability for siting requires consideration of multiple criteria. In this context, MCDA method is used alongside GIS analyses to manage the inherent complexity.

Since the effectiveness of MCDA as a decision-making tool hinges on the calibration of criteria weights reflecting the relative importance of each criterion within performance rating scales (Steele et al., 2009), MCDA employs visual representations generated through GIS to effectively communicate trade-offs among various criteria to decision-makers. The most commonly used MCDA algorithms include AHP, TOPSIS, ELECTRE, and WLC. These MCDA methods have been applied in solar siting analysis, either independently or combined with other algorithms (Aly et al., 2017; Eldemir & Onden, 2016; Sánchez-Lozano et al., 2014; Watson & Hudson, 2015). AHP is the most widely used systematic expert tool for handling MCDA (Choi et al., 2019) due to its straightforward mathematics. However, AHP has notable shortcomings, including 1) it does not account for the inherent uncertainty and inaccuracy of expert judgment in calculations (Davtalab & Alesheikh, 2018); 2) as the number of alternatives increases, multiple pairwise comparisons are required, necessitating complex calculations (Saeidi et al., 2023); 3) it does not consider correlations among criteria associated with site evaluation. Therefore, updated methods are needed in solar siting. Fuzzy set theory can be integrated into AHP to accommodate uncertainty (Bandaru et al., 2021). Additionally, many studies rely on a single method and may not provide comprehensive results, requiring the integration of multiple methods for more accurate and reliable results. Given this, integrating GIS and different MCDM approaches (Fuzzy-ANP) can be adopted to optimize site identification for CSS projects by incorporating technical, economic, social, physical, and environmental criteria. The utilization of GIS for data processing and analysis enables the generation of thematic maps accurately identifying and prioritizing potential sits for CSS projects. The fuzzy-ANP method has proved effective in managing imprecise criteria and in evaluating and ranking alternatives efficiently.

3.3.3.2 Analysis Steps

The majority of studies that employ a GIS-MCDA method generally adhere to a similar procedure (Sward et al., 2021). GIS-MCDA basically relies on two main approaches: Boolean overlay operators and weighted summations procedures (Choi et al., 2019). The Boolean overlay determines whether any conditions are satisfied, and analyzes the feasible area that meets all conditions. These results can be used as constraints in weighted summation analysis methods. Weighted summation can be subdivided according to the method of weighting each factor.

As depicted in Figure 3.4, the general process of GIS-MCDA for siting involves several distinct stages. First, the geographical area of interest is defined, with the scope ranging from the municipal scale up to national levels. Following this, a comprehensive literature review and/or expert consultation is conducted to identify the relevant criteria. The criteria in existing studies can be commonly divided into two types, namely exclusion criteria, which serve as constraints or restrictive factors, and decision criteria, which represent suitability criteria or preferences. The exclusion criteria are then processed using Boolean overlay in GIS to generate a feasible region map. Once the feasibility map is created, the relative importance of diverse decision criteria is determined by applying MCDA algorithms. Subsequently, the feasible region is classified into different tiers of suitability. Furthermore, many studies also perform sensitivity analyses to evaluate the robustness of the siting tool. When possible, researchers employ existing solar facilities to validate their analyses.

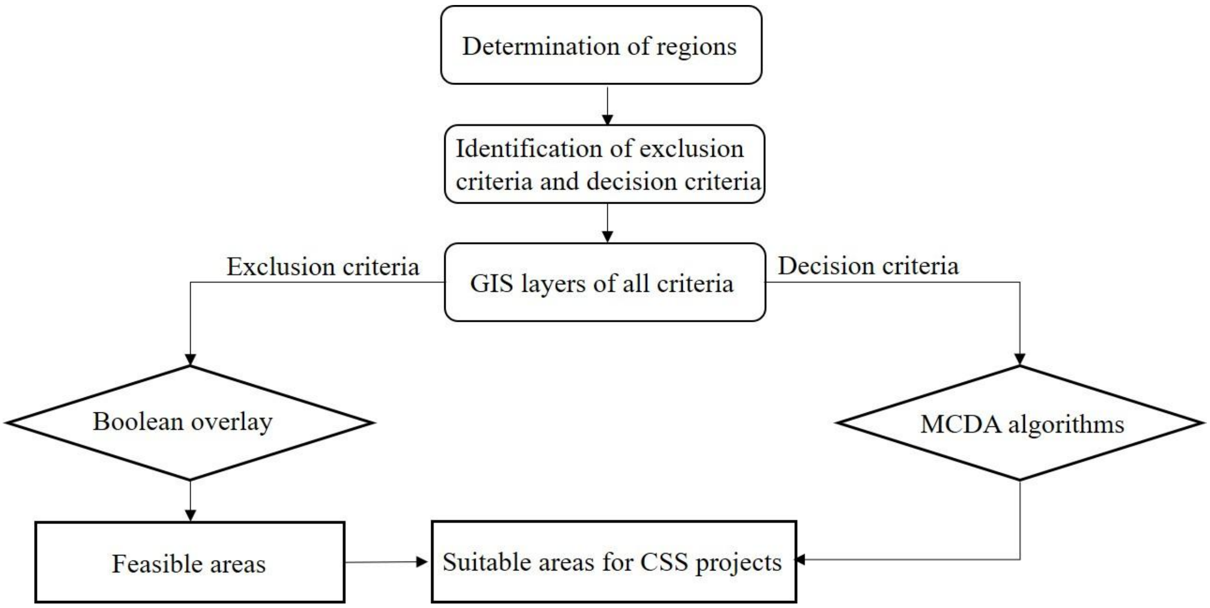


Figure 3.4 A general flow chart of GIS-MCDA methods for site evaluation

3.4 Summary of the Chapter

This chapter firstly discussed research methodologies and illustrated the overall research framework. Detailed research methods, namely document analysis, questionnaire survey, case study, scenario analysis, and sensitivity analysis were discussed separately. The analytical tools used for data analysis included ISM-DEMATEL, LCCA, and GIS-MCDA, serving as a theoretical foundation for comprehensively understanding the multi-level decision supports for community solar adoption from social, techno-economic, and geographic aspects.

Chapter 4 Barriers to Community Solar Adoption (Social Acceptance)

4.1 Introduction

Escalating concerns about climate change, resource exhaustion, and environmental pollution have prompted various countries to set ambitious targets for energy conservation, recognizing the crucial role of transitioning to renewable energy sources (e.g., wind, solar, tide) in addressing climate change and achieving sustainable development (Hong et al., 2017; Kwan, 2012). The renewable energy sector has witnessed substantial growth and progress in recent years. The renewable share of electricity generation increased by nearly 9% from 2012 to 2022 (REN21, 2023), with renewable energy accounting for almost one-third (30%) of global electricity production in 2022. This shift in renewable energy supply is driven by specific technologies, notably the rapid expansion of total installed solar PV capacity, with significant growth in both utility-scale and distributed solar installations. In 2022, solar PV power represented 70% of renewable power capacity additions (REN21, 2023). Despite the addition of 473 GW of renewable power capacity in 2023, which is a new record, this falls short of the 1,000 GW required annually to meet global climate and sustainable development commitments (REN21, 2024).

Given that solar PV accounted for three-quarters of all renewable power capacity additions in 2023 (IEA, 2024), it is imperative to continually scale up solar energy deployment to accelerate the adoption of renewable energy. Research on the barriers to solar PV adoption has therefore garnered increasing attention to bridge the gap between high public support for solar energy and low success rates for local developments. Existing research has primarily focused on residential rooftop solar, wall-mounted solar, and utility-scale solar (Joshi &

Yenneti, 2020; Qiu et al., 2022; Stack & Narine, 2022). However, factors such as rental or ownership limitations, improper orientation, and limited roof space prevent many individuals and communities from participating in solar energy generation (Konkle & Specialist, 2013; Noll et al., 2014). Community shared solar emerges as a promising solution to overcome these barriers and ensure broader access to the benefits of solar energy by utilizing centralized solar arrays in offsite locations with optimal sunlight exposure, allowing renters, low-income households, and those without suitable rooftops to participate in solar energy generation.

Nevertheless, barriers pose challenges to the adoption of community solar initiatives. While some studies have attempted to identify key barriers to community solar adoption, research gaps remain. Firstly, previous studies have focused on barriers from the perspective of customers (Mah et al., 2018; Solangi et al., 2015). However, community solar projects involve multiple stakeholders, including customers, developers, official offices etc. Therefore, it is essential to identify barriers from multiple perspectives to enable informed decision-making, collaboration opportunities, and risk mitigation. Secondly, previous studies have rarely categorized key barriers according to their importance and relevance (Shakeel et al., 2023). Categorizing barriers in this manner provides stakeholders with a structured approach to address obstacles more efficiently and accelerate the adoption of community shared solar, enabling prioritization of resources, targeted interventions, and enhanced decision-making. Finally, previous studies have primarily applied questionnaire survey or interviews to explore key barriers to community solar adoption (Jayaraman et al., 2017; Lo et al., 2018). Such bottom-up analyses incorporate data on community preferences, local challenges, and consumer behavior to uncover community-specific barriers that may be unique to certain regions or demographics. However, these studies often fail to identify systemic and structural barriers that require policy changes or regulatory interventions. Therefore, a combination of top-down and bottom-up analyses is necessary to provide a comprehensive understanding, align macro-micro perspectives, and facilitate scalability and replicability. This approach enhances the effectiveness of efforts to overcome barriers and promotes the broader adoption of community solar.

Thus, this chapter aims to identify key barriers to the adoption of community solar from the perspectives of different stakeholders and categorize these factors according to their importance and relevance. Decision-makers will become aware of the barriers which have the most significant influence from their perspectives and can act accordingly to mitigate these barriers, thereby facilitating the implementation of community solar projects in an organized manner. To this end, crucial barriers to community solar adoption for different stakeholders (i.e., customers and developers) will first be identified through a literature review and expert interviews. Subsequently, a hybrid ISM-DEMATEL approach will be adopted to comprehensively understand the hierarchical and causal relationships among barriers to the adoption of community solar. The results of this study are expected to provide valuable insights for removing barriers and enhancing the successful implementation of community solar projects. The ISM-DEMATL method represents a novel approach to understanding the relationship between barriers to community solar adoption and may serve as a basis for future research in this field.

4.2 Research Methods

To identify and categorize key barriers to community solar adoption based on their importance and relevance, this study explores the significance of barriers to community solar adoption from the perspectives of both customers and developers. To this end, a three-step research approach was undertaken, as illustrated in Figure 4. 1. The first step involves identifying common barriers to community solar adoption through a comprehensive literature review and a questionnaire survey. The second step entails analyzing key barriers to community solar adoption and categorizing these factors based on their importance and relevance. To yield constructive outcomes, an integrated ISM and DEMATEL technique is applied in this step. This top-down analysis is expected to provide insights for decision-makers in comprehending the primary obstacles in the development of sustainable community solar projects. The final step focuses on comparing the results obtained from the ISM, DEMETEL, and questionnaire survey, with the aim of determining the most prominent barriers in the implementation of CSS projects. The combination of top-down and bottom-up analyses can further our understanding of the barriers to community solar adoption.

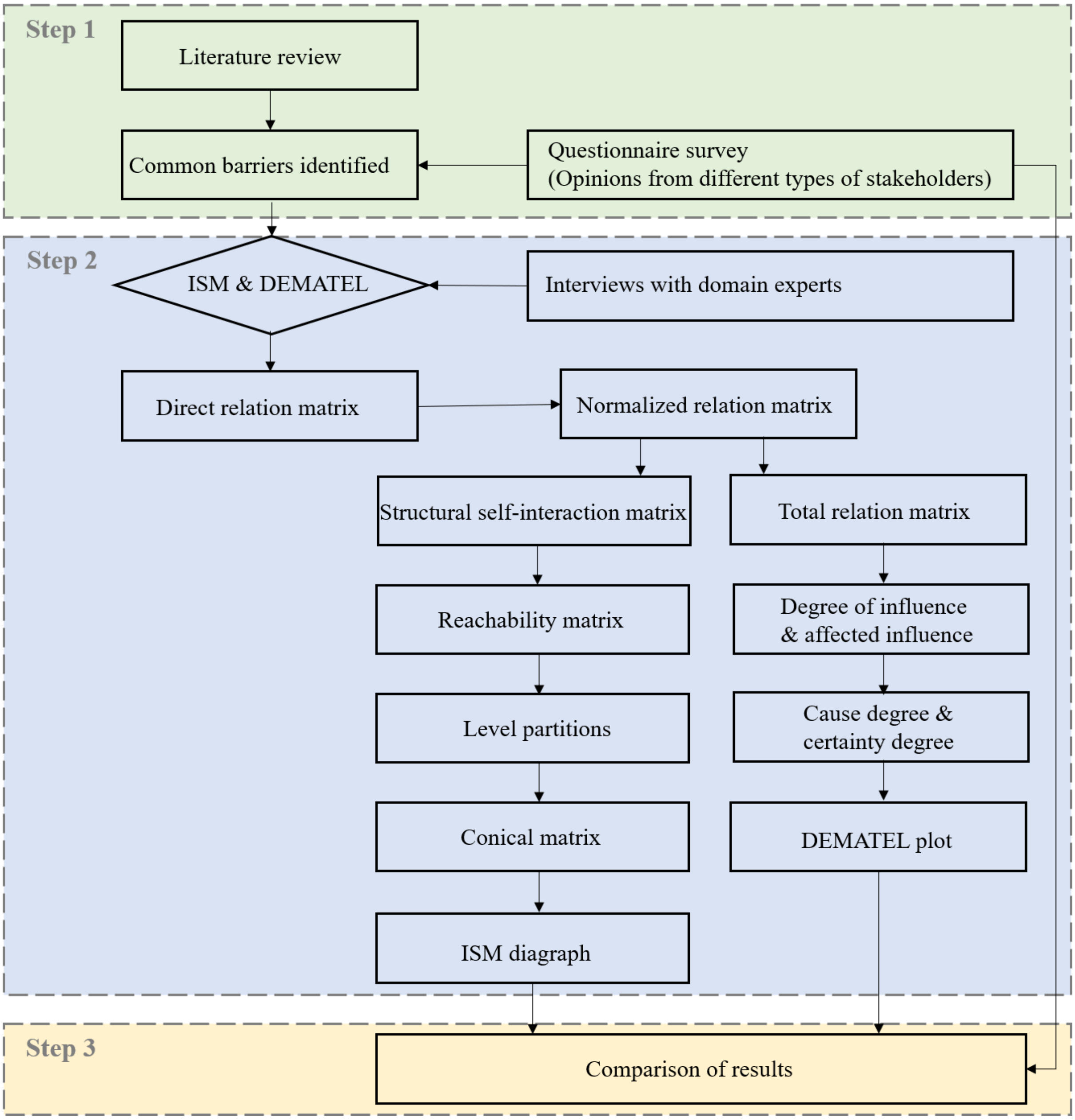


Figure 4.1 Research design of barriers to community solar adoption.

4.2.1 ISM

Step 1 involves developing a structural self-interaction matrix (SSIM) to establish contextual relationship among the variables. In this step, expert opinions are commonly incorporated through management techniques such as brainstorming and the nominal group technique. The contextual relationship between each variable is defined by specifying the relationship direction between two variables (i and j) using four symbols:

A: Variable i unidirectionally influences j (i→j);

S: Variable j unidirectionally influences i (j→i);

D: Bidirectional interdependence (i↔j);

F: No significant relationship (i⊥j).

Step 2 entails developing a reachability matrix (RM) by converting the SSIM into a binary adjacency matrix using mapping rules:

A→ RM(i,j)=1, RM(j,i)=0;

S→ RM(i,j)=0, RM(j,i)=1;

D→ RM(i,j)=RM(j,i)=1;

F→ RM(i,j)=RM(j,i)=0;

Step 3 involves hierarchical partitioning and reachability analysis based on RM. This step firstly computes the reachability set R(k), which includes elements reachable from k, and the antecedent set A(k), which comprises elements that can reach k. Following this, hierarchical levels are determined using the following criterion: If $R(k) \cap A(k) = R(k)$, then k belongs to the current top level. This process iteratively extracts hierarchical levels until all elements are classified, aiding in the construction of the digraph and the ISM model.

Step 4 consists of developing a conical matrix (CM) by reorganizing RM into a block-diagonal matrix based on hierarchical levels. This involves calculating driving power (row sum) and dependence power (column sum), followed by ranking elements according to driving power to identify priority factors.

Step 5 involves obtaining the ISM Model from the conical form of RM, which includes a preliminary digraph with transitive links. This step develops an initial digraph with direct and transitive relationships, applying minimum edge-set principles to remove redundant connections. The digraph undergoes semantic conversion by replacing nodes with structured problem statements.

Step 6 includes conducting Matrice d' Impacts Croisés-Multiplication Appliquée à un Classement (MICMAC) analysis, aimed at examining the driving power and dependence power of factors. This analysis classifies factors into four quadrants through driving-dependence power analysis:

- Autonomous factors (Low driving/Low dependence): Peripheral elements that require validation for potential elimination.
- Dependent factors (Low driving/High dependence): Outcome indicators influenced by system dynamics.
- Linkage factors (High driving/High dependence): Critical leverage points with bidirectional feedback effects.
- Driving factors (High driving/Low dependence): Strategic intervention levers for systemic change.

4.2.2 DEMATEL

Step 1 involves defining the scale and composition of direct relation matrix (DRM) and developing the DRM. The DRM captures the direct effect between each pair of elements based on the responses provided by the sample population. Pairwise comparisons are made using a Likert scale, with values ranging from 1 to 5 representing "No influence," "Low influence," "Equal influence," "High influence," and "Very high influence," respectively.

The DRM (see Eq. (4.1)) is an n × n matrix and formatted as A, where a_{ij} is denoted as the degree to which the element i affects the element j.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (4.1)$$

Step 2 is to normalize DRM and format it as Y. The normalized matrix Y can be obtained from Eqs. (4.2) and (4.3).

$$Y = \frac{1}{S} A \quad (4.2)$$

$$S = max \left[max \sum_{\substack{j=1 \\ 1 \le i \le n}}^{n} a_{ji} , max \sum_{\substack{i=1 \\ 1 \le j \le n}}^{n} a_{ij} \right] i, j\{1,2, \dots , n\} \quad (4.3)$$

Step 3 involves computing the total relation matrix T by deriving the total influence matrix T through convergent matrix power series, which can be obtained by Eq. (4.4).

$$T = \lim_{m \to \infty} \sum_{k=1}^{m} Y^k = Y \times (1 - Y)^{-1} \quad (4.4)$$

Step 4 involves the development of the causal diagram. This process includes influence analysis through the aggregation of rows (d_i) and columns (c_j) of matrix T, which establishes the foundation for determining the degree of influence and being affected, as shown in Eqs. (4.5) and (4.6). Based on this analysis, the causal diagram is constructed by calculating causal metrics of prominence (P_i) and relation (R_i), which represent outgoing and incoming influences, respectively, through Eqs. (4.7) and (4.8).

$$d_i = \sum\nolimits_{j=1}^{n} t_{ij} \quad (4.5)$$

$$c_j = \sum_{i=1}^{n} t_{ij} \tag{4.6}$$

$$P_i = d_i + c_j \tag{4.7}$$

$$R_i = d_i - c_j \tag{4.8}$$

4.2.3 Data Collection

4.2.3.1 Literature Review (Variable Identification)

Identification of initial barriers is fundamental to the ISM and DEMATEL methods. Therefore, a comprehensive literature review is conducted to examine the reported barriers to community solar adoption from the perspectives of both customers and developers. Barriers that have been frequently explored in previous studies are extracted as the initial list in this research. To this end, a systematic literature review is conducted based on a transparent four-step process. The Social Sciences Citation Index (SSCI) of the Web of Science Core Collection, a widely used database for review studies (Crossan & Apaydin, 2010; Karakaya & Sriwannawit, 2015), was utilized to retrieve publications. In the first step, a combination of keywords, including (diffuse∗ OR adopt∗) AND (photovoltaic∗ OR PV∗ OR CSS∗ OR "community shared solar∗") AND (barriers), was searched in the abstracts, titles, and keywords of the publications from the SSCI from 2011 to 2023. In the second step, publications relevant to community solar adoption by both customers and developers were selected respectively. Subsequently, any kind of barriers to community solar adoption by both customers and developers were included in the initial list. Finally, barriers to community solar adoption by both customers and developers were identified by categories, as shown in Tables 4.1 and 4.2.

Table 4.1 Barriers to community solar adoption from the customer's perspective.

Code	Barrier	Description
A1	Immaturity	Immature solar technologies related to solar PV project installation, operation, management
A2	Reliability	Reliability of PV systems (e.g., performance problems)
A3	Conversion efficiency	The conversion efficiency of PV systems
A4	Safety issues	Safety issues for installing/developing a community solar project
A5	High prices	High PV-generated electricity prices
A6	High upfront cost	High upfront cost for joining community solar
A7	Lack of financing mechanism	The lack of suitable financing mechanisms to join community solar
A8	Lack of subsidies	The lack of subsidies for customers to join community solar
A9	Lack of information	The lack of information about community solar (e.g., subscription methods, market information)
A10	Accessibility	Accessibility of community solar (i.e., whether it is easy to join community solar)
A11	Lack of energy services company	The lack of availability of companies that can handle different aspects of energy projects
A12	Legal and regulation constraints	Legal and regulation constraints for community solar (e.g., uncertain application procedures)
A13	Insufficient policy support	The lack of policy support to join community solar, such as technical support
A14	Ineffective policy support	Ineffectiveness of existing policy support to join community solar, such as renewal energy certificate scheme

Table 4.2 Barriers to community solar adoption from the developer's perspective.

Code	Barrier	Description
B1	Immaturity	Immature solar technologies related to solar PV project installation, operation, management
B2	Grid access	Restricted grid access to a community solar project

Code	Barrier	Description
B3	Limited space	Limited space for the installation of solar PV systems
B4	Reliability	Reliability of PV systems (e.g., performance problems)
B5	Conversion efficiency	The conversion efficiency of PV systems
B6	Weather	Local weather conditions (e.g., humidity, solar irradiance)
B7	Long payback period	Long payback period of a community solar project
B8	High upfront cost	High upfront cost for developing community solar
B9	High maintenance cost	High maintenance cost of PV systems
B10	High transaction costs	High transaction costs of community solar
B11	Grid connection costs	Grid connection costs of community solar
B12	Lack of financing mechanism	The lack of suitable financing mechanisms to develop community solar
B13	Insufficient incentives	Insufficient incentives for developers in developing community solar
B14	Uncertainty over cost	Uncertainty over cost of community solar
B15	Lack of knowledge	Knowledge about developing or managing community solar, such as appropriate pricing and recruitment strategies
B16	Existing technical capacity	Existing national technical capacity and infrastructure which can reduce technology risk
B17	Ineffective policy support	Ineffectiveness of existing policy support to develop community solar

4.2.3.2 Questionnaire Survey

To ensure that identified barriers are dominant barriers, a semi-structured questionnaire survey was conducted to gather opinions from various stakeholders involved in solar PV projects. The questionnaire consists of five sections designed to capture the perspectives of both customers and developers on different aspects of barriers to community solar adoption (see Appendix I). Additionally, the sixth and seventh sections collect respondents' demographic information (e.g., age, sex, education, income, job position) and their attitudes toward community solar adoption through open-ended questions. Respondents, including individuals and developers, use a Likert scale to record their opinions, with grades ranging from “1” to “5”, denoting the least agree and most agree, respectively. The mean score for each barrier was calculated and used to evaluate the relative significance of the barriers. Barriers with scores higher than the mean score of all barriers were considered in this research.

The survey sought to elicit the opinions of customers (e.g., residential, non-residential, and large customers), and developers (e.g., technical staff, project managers, and researchers and professionals) with knowledge and experience in solar energy projects. The questionnaires were developed at the Qualtrics platform and issued online via the Dynata platform. Finally, a total of 275 questionnaires were issued, and 214 valid questionnaires were returned with a response rate of 77.8%, including 81 from developers and 133 from customers.

4.2.3.3 Expert Interview

As the establishment of contextual relationship among identified barriers is of great importance for ISM and DEMATEL methods, expert interviews were conducted to develop SSIM and DRM based on the results of questionnaire survey. For the SSIM, contextual relationships between each pair of identified barriers were identified by the experts using four symbols (i.e., A, S, D, F). Within DRM, experts rank the identified barriers using a 1-to-5 scale, with ascending numerical values reflecting the relative influence of each barrier, as determined by its capacity to affect or amplify other barriers. To this end, another questionnaire (see Appendix II) showing question related to relationships between barriers to community solar adoption in cities was established at the Qualtrics platform and issued via emails or offline.

Prior to conducting expert interviews, a group of 50 professionals (e.g., technical staff, project managers, and researchers and professionals) with extensive experience and knowledge in applying solar energy in Hong Kong was identified from related publications and websites. Except for face-to-face interviews, questionnaire with invitation letters were emailed to the group, whereupon of 50 acceptances were received. 19 useable questionnaires were returned, representing a good response rate of 76%.

4.3 Results and Discussion

4.3.1 ISM Analysis Results

Based on the responses regarding interrelationships between barriers, the SSIMs from the perspectives of both customers and developers are obtained, as shown in Appendix III. The SSIM is then used to develop the RM, following the procedure outlined in the step 4 of ISM. The procedures are displayed in Appendix III. The results of RM from the perspectives of both customers and developers are presented in Appendix III. Subsequently, a level partition matrix is derived from the RM following the ISM methodology (Step 5). In this phase, barriers are divided into distinct hierarchical levels based on their driving power and dependency. Barriers with the lowest relative driving power and thus minimal capacity to influence the system, are assigned to the lowest hierarchical level. As the hierarchy ascends, barriers exhibit progressively greater influential capacity, reflecting their increased role in driving interdependencies within the system. The partition matrix from the perspectives of both customers and developers are shown in Tables 4.3 and 4.4. From the levels and the RM, an ISM digraph that shows a diagrammatic representation of the interrelations among the barriers is developed. The final model for both customers and developers are presented in Figures 4.2 and 4.3.

Table 4.3 The final results of level partitions from the perspective of customers.

Barriers	Reachability set	Antecedents set	Interaction set	Level
A1	1,13,14	1,13,14	1,13,14	VII
A2	2,4	1,2,4,11,13,14	2,4	II
A3	3	1,3	3	VI
A4	4	1,4,6,13,14	4	III
A5	5,	1,3,4,5,6,7,8,11,13,14	5	II
A6	6	1,6,11,13,14	6	IV
A7	1,7	1,7,13,14	1,7	III
A8	8	1,8,13,14	8	VI
A9	6,9	9,11,13,14	9	II
A10	9,10	1,2,4,5,7,8,9,10,11,12,13,14	9,10	I
A11	1,11	1,3,8,11,13,14	1,11	V
A12	12,13,14	1,4,12,13,14	12,13,14	II
A13	1,13,14	1,13,14	1,13,14	VII
A14	1,13,14	1,13,14	1,13,14	VII

Table 4.4 The final results of level partitions from the perspective of developer.

Barriers	Reachability set	Antecedents set	Interaction set	Level
B1	1,15	1,15	1,15	VIII
B2	2,17	1,2,17	2,17	V
B3	3	3,17	3	III
B4	4,5,16	1,4,5,6,16	4,5,16	V
B5	5	1,5,6,15	5	VII
B6	6	6	6	VIII
B7	7,12	1,4,5,6,7,8,9,10,11,12,13,14,16,17	7,12	I
B8	8	1,4,8,11,14,15,16,17	8	II

Barriers	Reachability set	Antecedents set	Interaction set	Level
B9	9	1,3,4,6,9,14,15,16	9	II
B10	10	1,4,6,10,14	10	II
B11	11,16	1,2,11,14,15,16,17	11,16	III
B12	12	1,5,12,14,17	12	III
B13	1,13	1,2,3,4,5,12,13,15,17	1,13	II
B14	14	2,4,5,6,14,16,17	14	IV
B15	1,15	1,15	1,15	VIII
B16	1,16	5,15,16	16	VI
B17	1,2,16,17	1,2,6,16,17	1,2,16,17	V

From the perspective of customers, it is evident from Figure 4.2 that there is a complex relationship between barriers to community solar adoption. Barriers at level VII, including immaturity (A1), insufficient policy support (A13), and ineffective policy support (A14), were positioned at the lowest level of the ISM model due to their high driving power but low dependence power. This means these barrier drives all other barriers but are unaffected by any other barrier, making them the most critical barriers in the context of community solar adoption in Hong Kong. Since community solar PV is a relatively new technology in Hong Kong, a lack of technical functionality and inadequate policy supports may diminish consumer trust and confidence in the technology, as well as limit opportunities for individuals to gain further knowledge about PV, leading to reluctance in choosing community solar PV (Arroyo & Carrete, 2019; Mundaca & Samahita, 2020). Moreover, the lack of policy support, such as guidelines on installation, regulatory measures, and technical support or the unsatisfied effectiveness of existing solar policies further reduce the solar adoption potential. Barriers at level VI (i.e., conversion efficiency (A3) and lack of subsidies (A8)) were found to be the next most critical barrier in the ISM hierarchy. The absence of subsidies, high upfront costs, and long payback period were perceived by interviewees as major barriers to solar PV deployment in the questionnaire survey. Renewable feed-in tariff (FiT) scheme, renewable certificate scheme (RCS), and governmental subsidies have been proven effective in boosting solar PV development in Hong Kong (Mah et al., 2018; Zhang & Lee, 2023), which are also encouraged to be implemented in community solar projects.

The barrier placed in level V was the lack of energy services company (A11). Active participation and enthusiasm from energy services companies are crucial for the successful implementation of CSS projects, as they play a pivotal role in providing products, grid connection, subscription services, and other essential components (Lo et al., 2018). Additionally, the barrier placed in level V was high upfront cost (A6). As indicated in the questionnaire survey, the payment with high upfront cost for joining a CSS project significantly influences customers' willingness to participate, as it makes PV a less attractive avenue for investment (Wei & Saad, 2020). Furthermore, the barriers placed in level III were safety issues (A4) and lack of financing mechanism (A7). When customers perceive investment in solar PV as high-risk due to safety issues, the likelihood of adoption diminishes (Arroyo & Carrete, 2019). Alam et al. (2021) found that the opportunity to experience the technology may offset some of the fears and facilitate the use of solar PV. These nine barriers mentioned above exhibit high driving power and low dependence power, indicating they influence other barriers but are not influenced to the same degree by other barriers. Therefore, decision-makers should exercise extra care in understanding and addressing these barriers to ensure the successful implementation of CSS projects.

According to Figure 4.2, five variables exhibit low driving power and high dependence power, including lack of information (A9), legal and regulation constraints (A12), reliability (A2), high prices (A5), and accessibility (A10). This indicates that these variables do not exert influence on others but are influenced by other variables. For instance, the lack of correct information, such as understanding how CSS projects operate, the experiences of other users, and the impact on reducing electricity bills, serves as a determining factor in the decision-making process and subscription to solar energy. Consequently, community solar adoption among customers with limited knowledge is infrequent (Solangi et al., 2015). Similarly, high prices for PV-generated electricity can impose a financial burden on households, discouraging the embrace of community solar, as economic return or monetary benefits positively affect investment in solar PV (Jayaraman et al., 2017). Notably, the barrier present at the top level is A10, which could be mitigated by providing easy access to or participation in a CSS project.

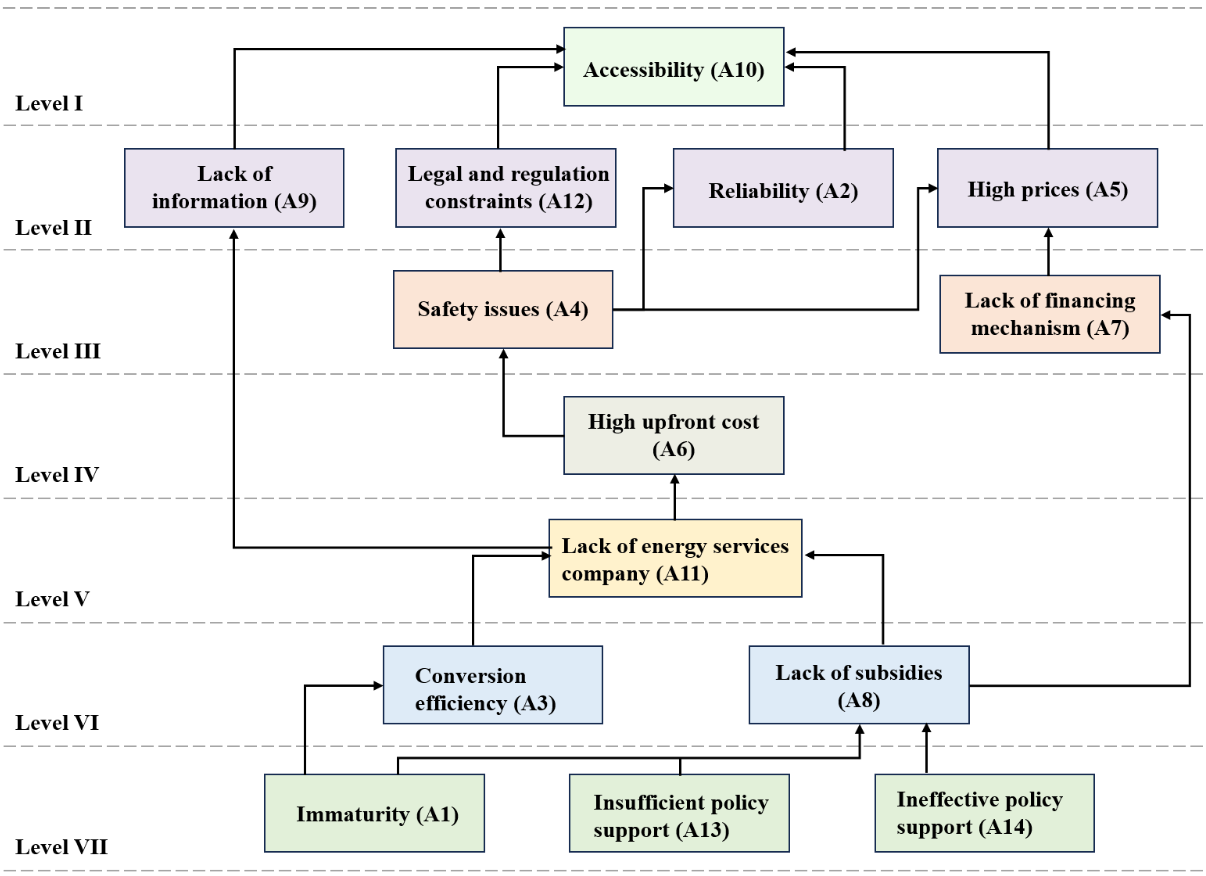


Figure 4.2 The calculated ISM model from the perspective of customers

From the perspective of developers, the relationship between barriers to community solar adoption is also complex, as dispatched in Figure 4.3. Factors including immaturity (B1), weather (B6), lack of knowledge (B15), conversion efficiency (B5), and existing technical capacity (B16) exhibit strong driving power, as these factors occupy the bottom levels of the ISM model. Conversely, long payback period (B7), insufficient incentives (B13), high maintenance cost (B9), high upfront cost (B8), and high transaction costs (B10) demonstrate strong dependence power, as these factors occupy the top levels of the ISM model. Obstacles present at the level VIII are B1, B6, and B15, which dominates and suggest the need for advancements in PV-related technologies by the entire PV industry for sustainable development. Mature solar technologies related to solar PV project installation, operation, and management can further boost the confidence and interests of developers in solar projects (Lo et al., 2018). B5 at level VII is associated with the perceived poor performance of PV, which may be due to underdeveloped PV technologies, unfavorable climate, the local air pollution levels, etc. Developers need to pay more attention to those aspects to obtain a more feasible economic performance of PV projects. B16 at level VI implies that PV projects are developed in a relatively mature PV market with high technical capacity could reduce developers' technical and financial risks, especially for those in a relatively early phase of development. Barriers at level V are B17, B2 and B4, which require a conducive environment for solar by policy and technical supports. B14 at level IV is uncertainly over cost, emphasizing the financial burden and investment risks in solar projects. Obstacles at level III are B3, B12, B11, which underscore the need for environments conducive to the successful implementation of solar PV projects from technical, economic, and physical aspects. All these aspects lead to higher costs throughout the entire life of cycle (B9, B8, B10) and affect insufficient incentives (B13). Eventually, acceptable payback period (B7 at the top level) could be achieved by removing the obstacles at level II.

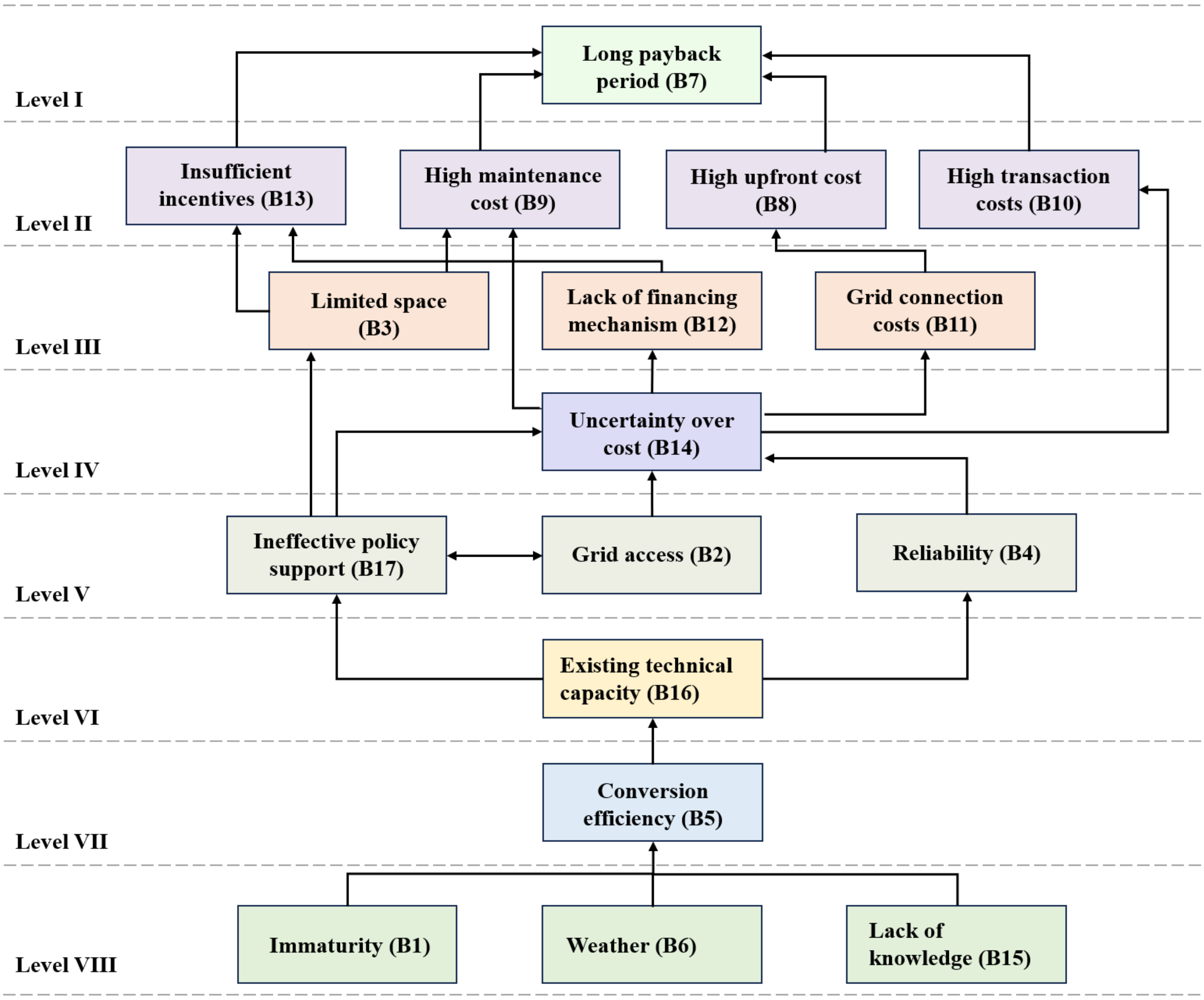


Figure 4.3 The calculated ISM model from the perspective of developers

In MICMAC analysis, barriers are divided into four clusters: (I) autonomous, (II) dependent, (III) linkage, and (IV) independent. The MICMAC analysis from the perspective of customers is depicted in Figure 4.4. It can be observed that A2, A3, A4, A6, A7, A8, A9, A12 exhibit both feeble dependence and driving power in cluster I. These autonomous variables can mostly be handled independently during the intervention and moderately affect the overall system. A5 and A10 in cluster II participate in interrelationships and show strong dependence and weak driving power. They should have lower priorities than the variables on which they depend. No issue is depicted in cluster III even if the elements are unstable. None of them has both strong dependence and strong driving power, which means that the action of all variables and their feedback do not affect others. A1, A13, A14 in cluster IV that dominate the bottom portion of Figure 4.4 significantly drive the variable above them and affect the whole system. Early intervention produces a more suitable environment for solar PV projects and increase their accessibility due to their low dependence and high driving power.

As for developers, it can be seen from Figure 4.5 that the barriers with weak driving power and weak dependency, including B2, B3, B4, B5, B6, B8, B9, B10, B11, B12, B13, B14, are generally disconnected from the system and are located in cluster I. B7, located in cluster II, has weak driving power and strong dependence. No barriers were found in cluster III that consists of barriers with both strong driving power and dependence. Cluster IV, which includes variables with strong driving power and weak dependence encompasses B1, B15, and B17.

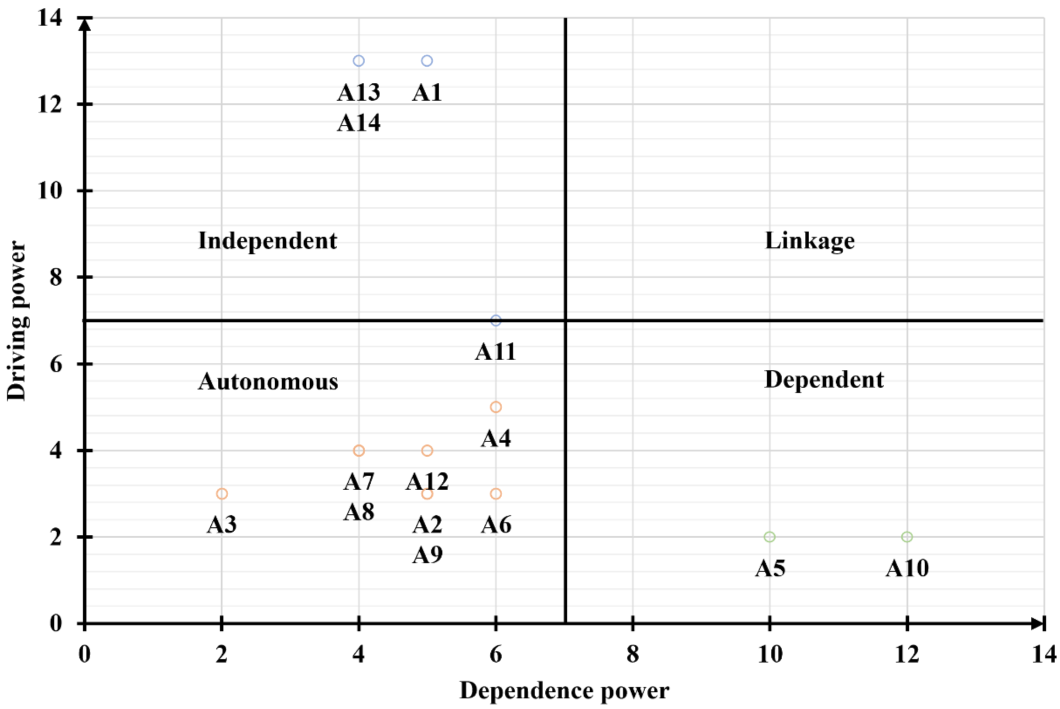


Figure 4.4 MICMAC analysis results for customers

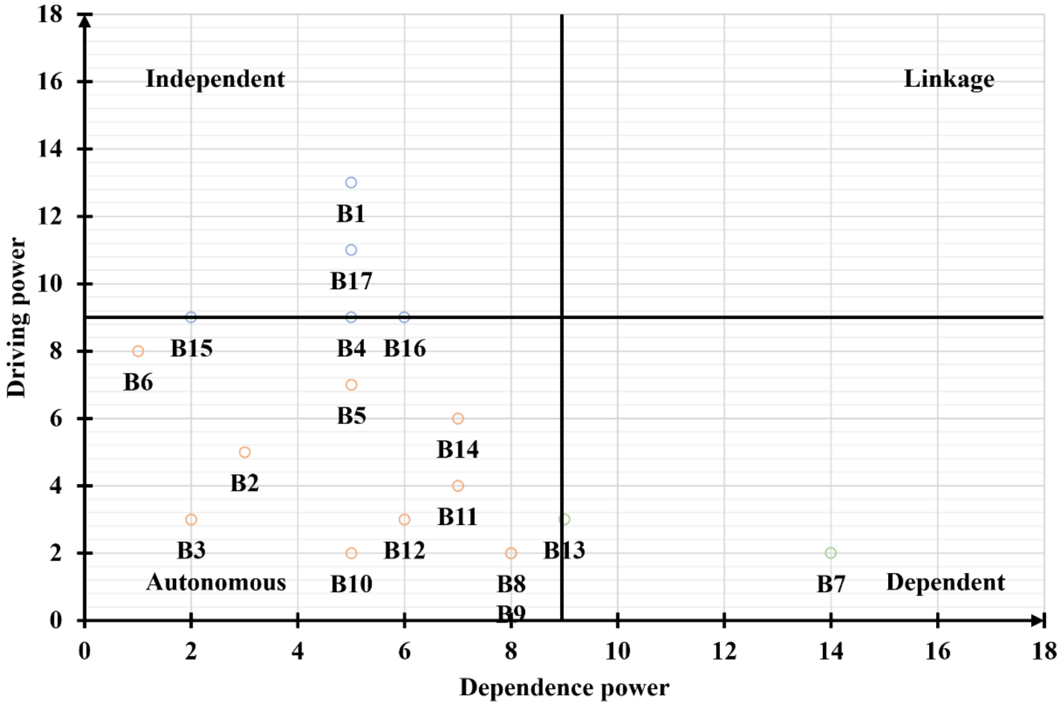


Figure 4.5 MICMAC analysis results for developers

4.3.2 DEMATEL Analysis Results

Following procedures of the DEMATEL, the DRM, normalized DRM, T are computed and presented in Appendix III. Based on T, influence degrees of each barrier are calculated and shown in Tables 4.5 and 4.6. The centrality metric (Di + Ci) quantifies the total influence exerted and received by a factor, indicating its overall prominence within the system. The net influence metric (Di − Ci) defines the causal role of each factor. A positive value designates the factor as a net influence dispatcher, meaning it exerts more influence on other factors than it receives. Conversely, a negative value identifies the factor as a net influence receiver, indicating it is primarily affected by external influences. These metrics are used to construct causal diagrams (Figures 4.6 and 4.7), which provide a synthesized visual representation of the hierarchical structure and directional interdependencies among barriers, as perceived by customer and developer stakeholder groups, respectively.

Table 4.5 Calculation results of causation and centrality from the perspective of customers.

Barrier	Influence degree (Di)	Influenced degree (Ci)	Cause degree (Di − Ci)	Centrality degree (Di + Ci)	Centrality ranking
A1	3.21	2.03	1.28	5.24	1
A2	2.43	2.14	0.29	4.57	10
A3	2.4	1.11	1.19	3.51	11
A4	2.4	2.2	0.2	4.6	9
A5	2.48	2.62	-0.14	5.1	2
A6	2.37	2.5	-0.13	4.87	3
A7	2.14	2.58	-0.44	4.72	8
A8	1.88	2.4	-0.52	4.28	14
A9	1.63	2.21	-0.58	3.84	5
A10	2.32	2.55	-0.23	4.87	3
A11	1.96	2.84	-0.88	4.8	7
A12	2.22	2.26	-0.04	4.48	12
A13	2.48	2.35	0.13	4.83	6
A14	2.14	2.27	-0.13	4.41	13

Table 4.6 Calculation results of causation and centrality from the perspective of developers.

Barrier	Influence degree (Di)	Influenced degree (Ci)	Cause degree (Di − Ci)	Centrality degree (Di + Ci)	Centrality ranking
B1	2.18	1.05	1.13	3.23	1
B2	1.15	1.28	-0.13	2.43	9
B3	1.04	0.8	0.24	1.84	17
B4	1.58	1.09	0.49	2.67	4
B5	1.33	1.07	0.26	2.4	12
B6	1.53	0.76	0.77	2.29	14
B7	1.12	2.02	-0.9	3.14	2
B8	1.17	1.26	-0.09	2.43	9
B9	1.05	1.18	-0.13	2.23	15
B10	1.01	1.34	-0.33	2.35	13
B11	1.05	1.12	-0.07	2.17	16
B12	1.39	1.23	0.16	2.62	6
B13	1.16	1.38	-0.22	2.54	7
B14	0.99	1.44	-0.45	2.43	9

Barrier	Influence degree (Di)	Influenced degree (Ci)	Cause degree (Di − Ci)	Centrality degree (Di + Ci)	Centrality ranking
B15	1.34	1.35	-0.01	2.69	3
B16	1.11	1.52	-0.41	2.63	5
B17	1.11	1.42	-0.31	2.53	8

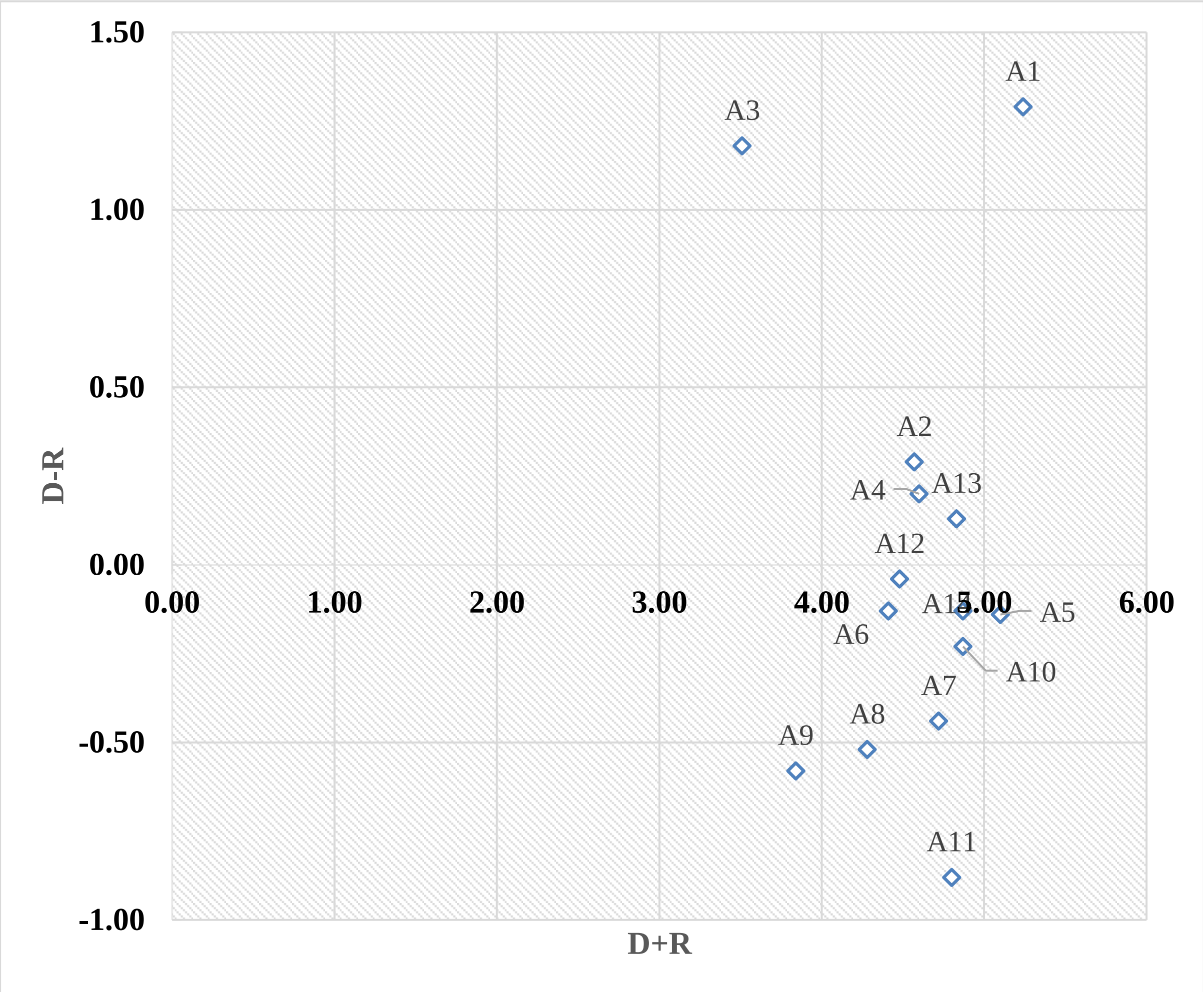


Figure 4.6 The degree of influence from the perspective of customers.

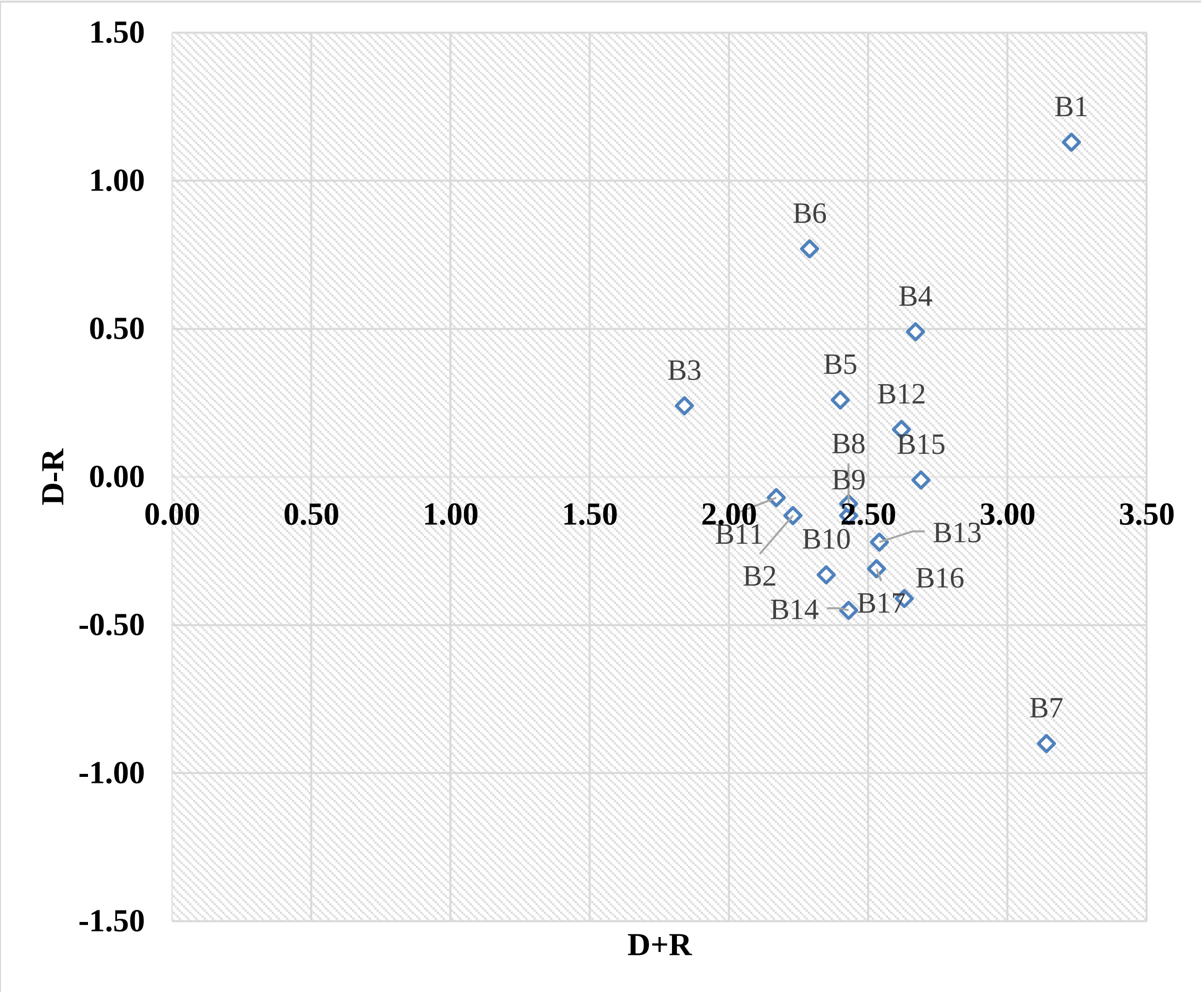


Figure 4.7 The degree of influence from the perspective of developers.

The cause degree, which represents the influence degree of factors on community solar adoption, is visually depicted in the graphics. Factors with a positive causation value are considered causal factors, while those with a negative value are regarded as result factors. From the perspective of customers, as illustrated in Figure 4.5, A1, A2, A3, A4, and A13 are identified as causal factors affecting community solar adoption. Among them, A1 exhibits the greatest causation and exerts the most significant influence on other factors. Result factors, including A5, A6, A7, A8, A9, A10, A11, A12, and A14, are influenced by the causal factor and consequently impact community solar adoption. Additionally, Table 4.5 indicates that A1 has the highest centrality, signifying its substantial contributes to community solar adoption and its pivotal role in influencing the adoption process. As indicated in the open-ended questions in questionnaire survey, respondents expressed concerns primarily about the technologies related to community solar, with some indicating uncertainty about the maturity, completeness, and safety of the technology, while others expressed concerns about the stability of the power supply system. At the same time, previous studies have also highlighted technical barriers, particularly those related to the performance of PV systems, as critical factors affecting community solar adoption (Mah et al., 2018).

Figure 4.6 presents the results of cause and result factors from the perspective of developers. Cause factors, including B1, B3, B4, B5, B6, and B12, are identified, with B1 exhibiting the greatest causation and exerting the most significant influence on other factors. Result factors influenced by the cause factor and consequently impacting community solar adoption include B2, B7, B8, B9, B10, B11, B13, B14, B15, B16, and B17. Moreover, as shown in Table 4.6, B1 is identified as the factor with the highest centrality, indicating its substantial contribution to community solar adoption and its significant role in influencing the adoption process. Some respondents also expressed concerns in the questionnaire survey about the potential cost implications of investing in immature technology, which could hinder the implementation of community solar projects.

4.3.3 Comparison and Discussion

To obtain constructive results, a comparison among the results of ISM, DEMETEL, and questionnaire survey is conducted. From the perspective of customers, immaturity (A1), insufficient policy support (A13), and ineffective policy support (A14) were located on the lowest level of the ISM model, signifying that these barrier drives all other barriers but are unaffected by any other barrier and making them the most critical barriers in the context of community solar adoption in Hong Kong. As a relatively new technology in the energy transition in Hong Kong, community solar projects might raise concerns among customers regarding safety issues or investment benefits, potentially reducing customer interest and trust due to a lack of technical functionality, ineffective and insufficient policy support. In Hong Kong, the Feed-in Tariff and Renewable Energy Certificate Schemes represent pivotal policy mechanisms introduced by the government to catalyze the adoption and expansion of wind and solar energy systems across residential and non-residential sectors, which are demonstrated to be efficient and effective (Zhang, Lee, & Huang, 2023). However, these policies primarily focus on the financial aspects. Hong Kong's solar PV market is still in a relatively early stage of development (Mah et al., 2018), especially for community solar market, which requires more supports from different aspects to promote its development, including social acceptance, technical supports, energy service capacity, etc. Officials are suggested to introduce more policies related to community solar PV development from these aspects.

Additionally, the ISM method, as visualized in the ISM levels plot, organizes criteria into a limited number of discrete levels, emphasizing structural interdependencies. However, this approach does not account for intra-level prioritization of criteria or quantify the magnitude of causal linkages between them. In contrast, the DEMATEL method employs a quantitative framework to rank criteria and measure relationship intensities, thereby enabling a granular assessment of causal dynamics. This reveals heterogeneity in the strength of interdependencies, demonstrating that relational intensities within the system are not uniformly distributed (Shahedi et al., 2023). DEMATEL's capacity to differentiate between weak and strong causal influences underscores its analytical superiority in modeling complex, non-uniform relationships. According to the DEMATEL results from the perspective of customers, immaturity (A1) ranked first with a (D-R) value of 1.29, followed by conversion efficiency (A3), and reliability (A2), with scores of 1.18 and 0.29, respectively. All these barriers are related to PV technology and its performance, underscoring the importance of technology advancement to promote the development of community solar, particularly in nascent markets.

The results align with the findings of the questionnaire survey, which identified technical and economic barriers are the top two barriers affecting individuals' adoption in community solar projects. Respondents reached an agreement on the necessity of mature technology on the installation, operation, and maintenance of community solar projects. Concerns were raised that the immature technology could lead to high investment, potentially deterring individuals from participating in community solar projects. Additionally, worries were expressed about the potential new issues related to the reliability of the entire project due to immature technology. These findings underscore the necessity of mature technology related to community solar during the promotional period as it significantly influences the confidence and interests of individuals in community solar adoption. Therefore, developers are encouraged to advance their technologies and demonstrate their ability to successfully implement sustainable community solar projects, while official offices are encouraged to issue related policies to promote technological innovation and market acceptance.

From the perspective of developers, immaturity (B1), weather (B6), and lack of knowledge (B15) show strong driving power, as evidenced by their placement at the bottom levels of the ISM-based model. This suggests the need for advancements in PV technologies within the entire PV industry to support sustainable development. Mature solar technologies related to solar PV project installation, operation, and management can significantly enhance developers' confidence and interests in community solar projects. Furthermore, the impact of weather on project performance, particularly in terms of electricity generation following project launch, underscores the importance of selecting suitable sites for community solar projects. Additionally, the lack of knowledge about developing or managing community solar projects emerges as a significant barrier for developers, highlighting the necessity for a greater number of professionals to successfully implement new projects. While the results of the ISM method bring attention to various aspects for removing barriers to community solar adoption, they do not, however, indicate the priority of each barrier.

In comparison, the DEMATEL method yields insights into the intensity of the relationship between barriers. According to the results from the view of developers, immaturity (A1) ranked first, followed by weather (A3) and reliability (A2). These barriers represent the initial three obstacles that developers must address to effectively implement community solar projects, and are closely associated with technology and project performance. These findings keep consistence with the results of the questionnaire survey. As some respondents expressed that technical issues could lead to various challenges, such as increased upfront investment and inadequate supervision.

The findings from the perspectives of customers and developers exhibit both differences and similarities. Notably, immaturity emerges as the most significant barrier from the viewpoints of both customers and developers. This underscores the need to advance related technologies in community solar, requiring industry-wide efforts to demonstrate the market's capability to effectively implement sustainable community solar projects. Moreover, customers place greater emphasis on policy support, conversion efficiency, and reliability. Given that community solar represents a relatively new technology in the energy transition of Hong Kong, the transition from conceptualization to actual operation is anticipated to be a protracted process. The support from the government is perceived to significantly influence decision-making, as indicated by some respondents. Furthermore, the factors of conversion efficiency and reliability are closely linked to project performance, exerting an impact on public trust and interest. Conversely, developers regard weather, lack of information, and reliability as important barriers, which are more closely associated with project implementation. As articulated by some respondents, solar radiation can vary over time and across geographical locations, underscoring the significance of weather-related considerations. Additionally, the lack of information and concerns regarding reliability are pertinent to the successful execution of community solar projects.

4.4 Summary of the Chapter

This Chapter aims to identify key barriers to the adoption of community solar and categorize these factors based on their importance and relevance from the perspectives of different stakeholders to achieve objective 1. To this end, research methods including ISM-DEMATEL, literature review, questionnaire survey, and expert interview are introduced to present the research design of this chapter. This research design includes crucial barriers to community solar adoption for both customers and developers identified through a literature review and expert interviews. Subsequently, a hybrid ISM-DEMATEL approach is adopted to comprehensively understand the causal and hierarchical relationships among barriers to community solar adoption. Following the research design and data analysis, the results on key barriers to community solar adoption and their relative importance are obtained. The results show that immaturity is the most important barrier from the perspectives of customers and developers. Furthermore, customers pay more attention to policy support, conversion efficiency, and reliability, while developers focus more on weather, lack of information, and reliability as they affect the successful implementation of community solar projects. Finally, the results of the ISM-DEMATEL analysis were compared with the results of a questionnaire survey, and consistency is found in terms of technical and economic barriers. The findings underscore the importance of technology advancement and policy support in driving the adoption of community solar. Despite consistency, the ISM method, as visualized in the ISM levels plot, organizes criteria into a limited number of discrete levels, emphasizing structural interdependencies. However, this approach does not account for intra-level prioritization of criteria or quantify the magnitude of causal linkages between them. In contrast, the DEMATEL method employs a quantitative framework to rank criteria and measure relationship intensities, thereby enabling a granular assessment of causal dynamics. This reveals heterogeneity in the strength of interdependencies, demonstrating that relational intensities within the system are not uniformly distributed.

The contribution of this study is threefold. Firstly, this study explores key barriers to community solar adoption and categorize these factors based on their importance and relevance, serving as a reference for addressing barriers in a nascent market and lays the groundwork for future research on community solar adoption in various countries. Secondly, this study identified and compared key barriers to community solar adoption from the perspectives of different stakeholders, providing an effective analysis for understanding how to successfully implement community solar projects. Lastly, by integrating top-down and bottom-up analyses, the study further our understanding on the barriers to community solar adoption and provides constructive guidance for the development of community solar projects.

Chapter 5 Economic Performance of Community Shared Solar Projects in a Current Market (Techno-economic feasibility)

5.1 Introduction

In response to climate impacts, low-carbon energy transition and renewable energy technologies are rapidly developing and being widely adopted in different industries worldwide (Balta-Ozkan et al., 2015; Hong et al., 2017). A CSS project can be adopted to maximize the benefits of energy transitions, as it can create benefits for both individuals and communities while allowing for greater engagement and local preference (Beck et al., 2020; Fontaine & Labussière, 2018; Joshi & Yenneti, 2020). Since financial challenges have been broadly listed as impediments to the adoption of CSS projects, previous studies have explored the financial feasibility of CSS projects under different contexts. Despite these efforts, the techno-economic feasibility of CSS projects in emerging markets remains uncertain, highlighting the need for the development of robust business models and financial frameworks for CSS projects in niche markets.

A number of research gaps remain. First, no study has proposed a method to explore CSR dynamics under assumed financial performance goals in understanding the economic feasibility of a CSS project. CSR can serve as a benchmark for decision-makers to effectively respond to a CSS project, necessitating a generalized financial model with flexibility and adaptability to be expanded and adapted to fit different market contexts. Second, existing studies lack investigation into balancing the tradeoffs between economic benefits for the developer and subscribers of CSS projects. This conflict underscores the importance of achieving a balance that satisfies both parties for the successful establishment of CSS projects. Third, while there have been studies on CSS projects in established markets, the potential for implementing community solar initiatives in emerging markets remains largely unexplored. The uncertainty of CSS projects in nascent markets may hinder their broader adoption. To address these research gaps, this study aims to develop a generalized financial model of CSS projects with flexibility and adaptability to determine and optimize CSRs for a sustainable CSS project in nascent markets. Hong Kong is in its early stages of deploying solar PV systems with its over 50 government-funded solar PV projects, and can serve as a valuable case study for CSS projects in a nascent market. To this end, this study addresses the following research questions: (1) What is the optimal level of CSRs that enables developers to meet their target financial goals for a CSS project in Hong Kong? The CSR can serve as a benchmark, providing the boundary conditions that enable benefits for subscribers (e.g., a condition where CSRs become lower than the retail electricity price) and a break-even point for developers (e.g., a condition where a CSS project reaches its break-even point/payback period) in decision-making, which is critical in facilitating the establishment of a CSS project in a new market (An et al., 2022a). According to the optimal CSRs calculated, (2) is a CSS project economically attractive and viable for both the developer and subscribers in Hong Kong? The balanced economic feasibility of a CSS project is proven to effectively increase the participation of stakeholders, which is a critical challenge in nascent markets and is rarely considered in previous studies (Beck et al., 2020; Chan et al., 2018). Additionally, if the optimal CSRs for developers in the current Hong Kong market are calculated to be higher than retail electricity prices, this would make CSS projects less attractive to subscribers and necessitate additional subsidy to balance the economic viability for both the developer and subscribers. This raises a new question in addition to the second one: (3) What is the minimum level of subsidy that enables developers to meet their target financial goals for a CSS project in Hong Kong? To promote the development of CSS project in an emerging market, this study explores the minimum amount of extra subsidy needed, and the results are expected to provide references for the government in designing subsidies for CSS projects at an early stage.

To achieve this, a research design is developed as illustrated in Figure 5.1. Firstly, this study proposes a business model for a CSS project in Hong Kong to present its operational structure, basic characteristics, and participant information, providing insights into the functioning of a CSS project. Secondly, scenario analysis is applied to explore the attractiveness of CSS projects under different conditions, considering changes in subscriber combination, expected payback period, and subsidy. Thirdly, a financial model is developed based on life cycle cost analysis to analyze the CSRs and evaluate the techno-economic performance of a CSS project across various financial metrics (e.g., payback period (PP), IRR, etc.). Consequently, the CSRs will be compared with the retail electricity price, while the techno-economic performance will be compared with expected financial goals to explore the attractiveness of the CSS project to both the developer and subscribers. The findings are expected to provide a comprehensive understanding of the techno-economic feasibility and attractiveness of CSS projects in Hong Kong, as well as design suitable CSRs that provide benefits to both the developer and subscribers, to promote distributed solar generation through community solar adoption.

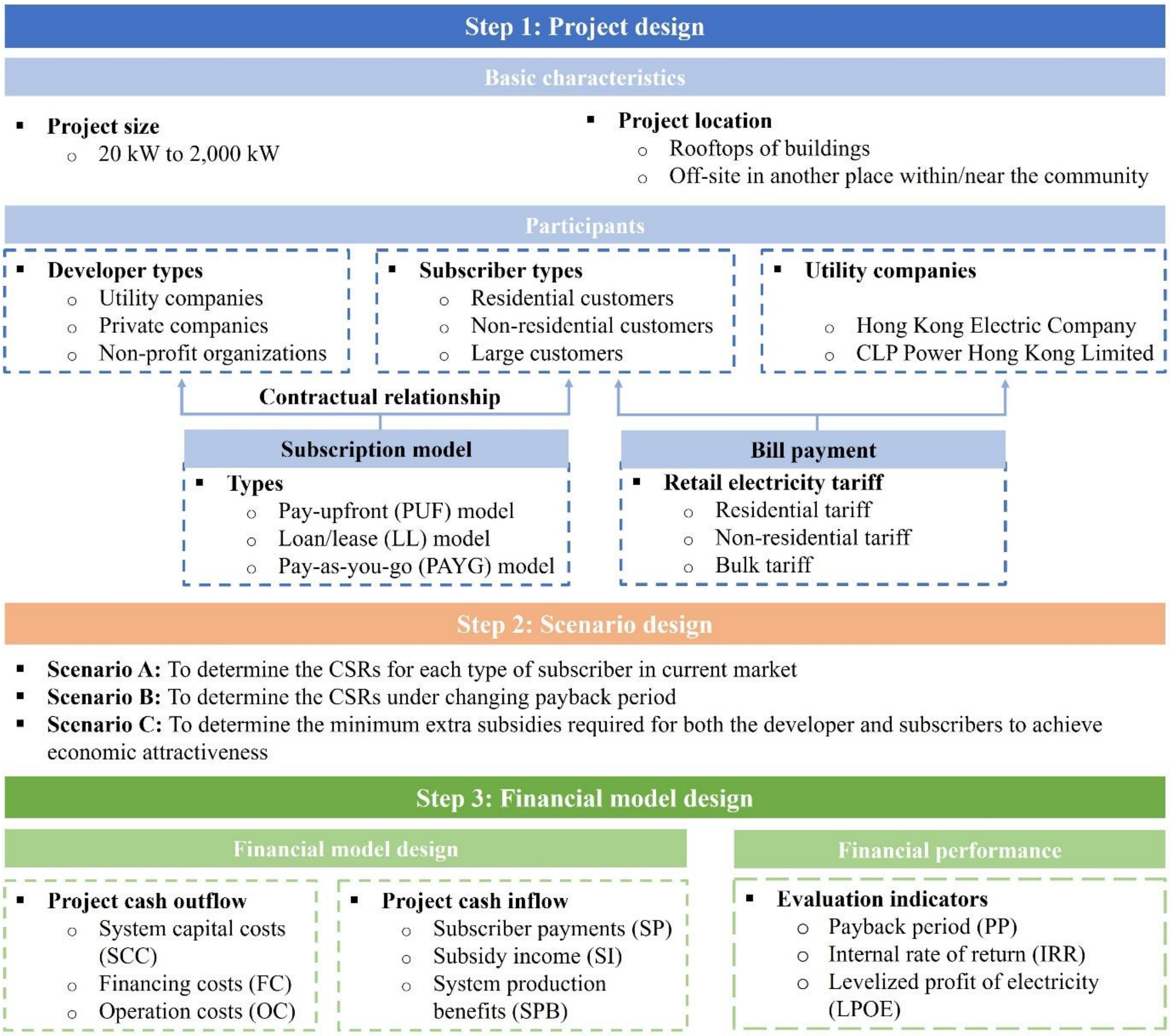


Figure 5.1 The research design of this chapter.

5.2 Community Shared Solar Project design

5.2.1 Target Region

This study selected Hong Kong as the target region for the CSS project due to its high suitability for exploring the adoption of such projects. Hong Kong, located in southern China, is a densely populated and energy-extensive city with high PV potential (EMSD, 2019). The geographical location of Hong Kong and its long-term global horizontal irradiation in China are illustrated in Figure 5.2 (a) (Solargis, 2024). As the CSS projects are primarily targeted for development in urban areas near the subscribers, the solar radiation data from the King's

Park Meteorological Station was utilized to represent the PV potential of the urban setting. This station provides daily data for single element (e.g., global solar radiation) in Hong Kong, with a latitude and longitude of 22°19'N and 114°10'E, respectively, as shown in Figure 5.2 (b). Appendix IV presents specific values of Hong Kong's daily global solar radiation (MJ/m^2) observed by the King's Park Meteorological Station (HKO, 2022). However, Hong Kong faces multiple challenges in installing and disseminating PV systems due to its building-intensive nature, limited rooftop access, and high installation costs (Yang et al., 2020). In this context, CSS projects offer a promising solution to overcome these challenges and provide opportunities for various consumer groups (e.g., tenants, apartment dwellers, and low-income households) to participate in and benefit from renewable energy generation (Brummer, 2018; Lo et al., 2018).

Despite the significance of CSS projects, their development in Hong Kong still lags behind. Although the Hong Kong government has announced the Hong Kong Climate Action Plan 2030+ in 2017 (EEB, 2017) and has undertaken some initial efforts to deploy PV systems with over 50 government-funded projects (EMSD, 2023), progress in CSS implementation has been limited. The "Solarizing Communities" project, which commenced in June 2016 with a total capacity of 6 kW, remains the only CSS project in Hong Kong. It should be noted that this project differs somewhat from the typical CSS project commonly observed in practice (Kong, 2017). Therefore, there is significant untapped potential for further development of CSS projects to enable broader community participation in Hong Kong's energy transition.

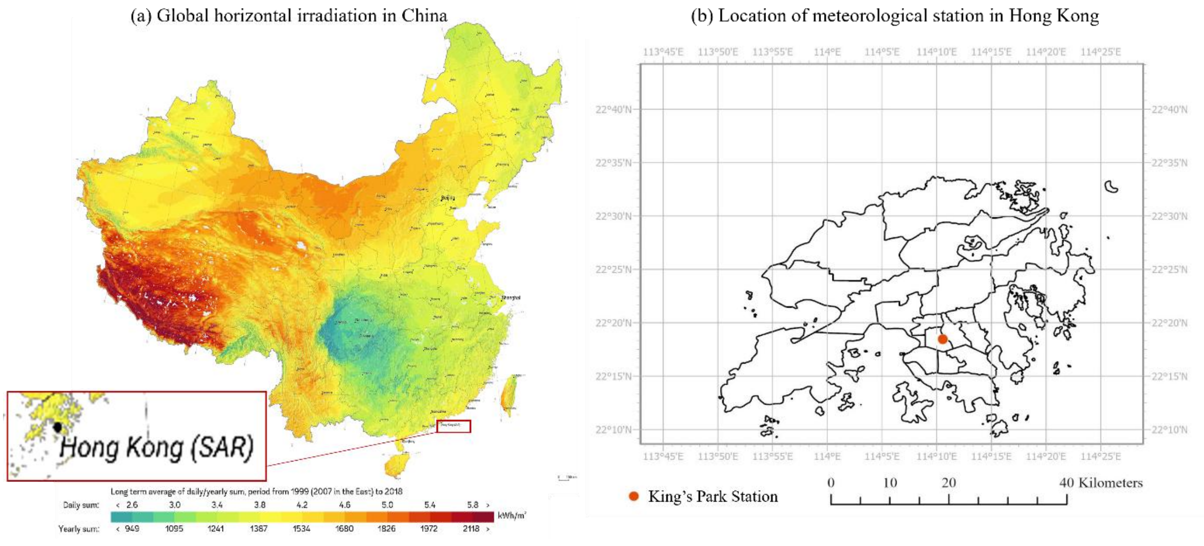


Figure 5.2 (a) China's global horizontal irradiation (Solargis, 2024) and (b) Location of King's Park Meteorological Station in Hong Kong

5.2.2 Project Information

5.2.2.1 Schematic Architecture of the Project

The schematic representation of both the existing and proposed energy-shared CSS projects is demonstrated in Figure 5.3. Figure 5.3 (a) shows the existing CSS project in Hong Kong where the "developers" do not practically exist. Instead, PV systems are installed on households' rooftops within a specific area (i.e., a chosen community), and all PV-generated electricity can optionally be used as an alternative energy source to traditional electricity or sold to the utility companies under the FiT scheme. The FiT scheme allows people who install solar energy generation systems at their premises to sell the electricity generated to the utility companies at a FiT rate. Currently, the FiT rate (i.e., 3 HKD/kWh for generating capacity more than 200 kW) is much higher than the retail electricity tariff rate (i.e., 1.3 HKD/kWh on average) in Hong Kong to incentivize electricity generation from clean energy sources. In addition, direct electricity trading among households is not allowed in existing CSS projects in Hong Kong (Standard, 2022). Other customers (e.g., residential or non-residential sectors) who wish to purchase PV-generated electricity, are only allowed to do so through the REC scheme at a price which is higher than the retail electricity price (i.e., a 0.5 HKD/kWh premium on top of the retail electricity price) (GovHK, 2022). Currently, the FiT scheme is considered as an effective and efficient means to promote solar PV projects by providing relatively high incentives for the private sector to invest in renewable energy systems, although the current rate may not be sufficient to cover the investment cost of solar panels in Hong Kong (Dato et al., 2021). Nonetheless, the FiT scheme is regarded as an incentive-driven initiative voluntarily implemented to promote PV adoption, and will expire in 2033 in Hong Kong (Dato et al., 2021). Therefore, proposing a more sustainable electricity trading mechanism is critically important to Hong Kong's renewable energy policy reform.

In this regard, this study proposes a new business model of CSS project based on the existing project model, as illustrated in Figure 5.3 (b). In this business model, PV systems are financed and installed by the developer, and the PV-generated electricity can be directly sold from the developer to different types of customers (e.g., residential or non-residential sectors) at CSRs through a PAYG subscription model. Under the PAYG model, from the subscribers' perspective, customers (i.e., subscribers) subscribe to a CSS project, prioritize their electricity consumption based on the PV-generated electricity they receive in kWh, and make regular payments at CSRs (currency/kWh) based on their usage. If there is any unmet electricity demand, subscribers can purchase additional electricity from the utility companies at retail electricity price. In such circumstances, consumers may opt to procure electricity from the grid when CSR significantly exceeds the retail electricity price. From the developers' perspective, some PV-generated electricity might remain unsubscribed due to various reasons such as insufficient subscribers and load mismatch. This study assumes that the CSS project is connected to the grid and such unsubscribed energy is fed back into the grid at a price equivalent to the cost of traditional electricity. In addition, Developers may choose to supply electricity to the grid through the FiT scheme rather than directly to consumers through CSS projects if the CSR is substantially lower than the FiT rate. Therefore, it is essential for CSR to be set at a reasonable level to effectively balance the benefits for both subscribers and developers.

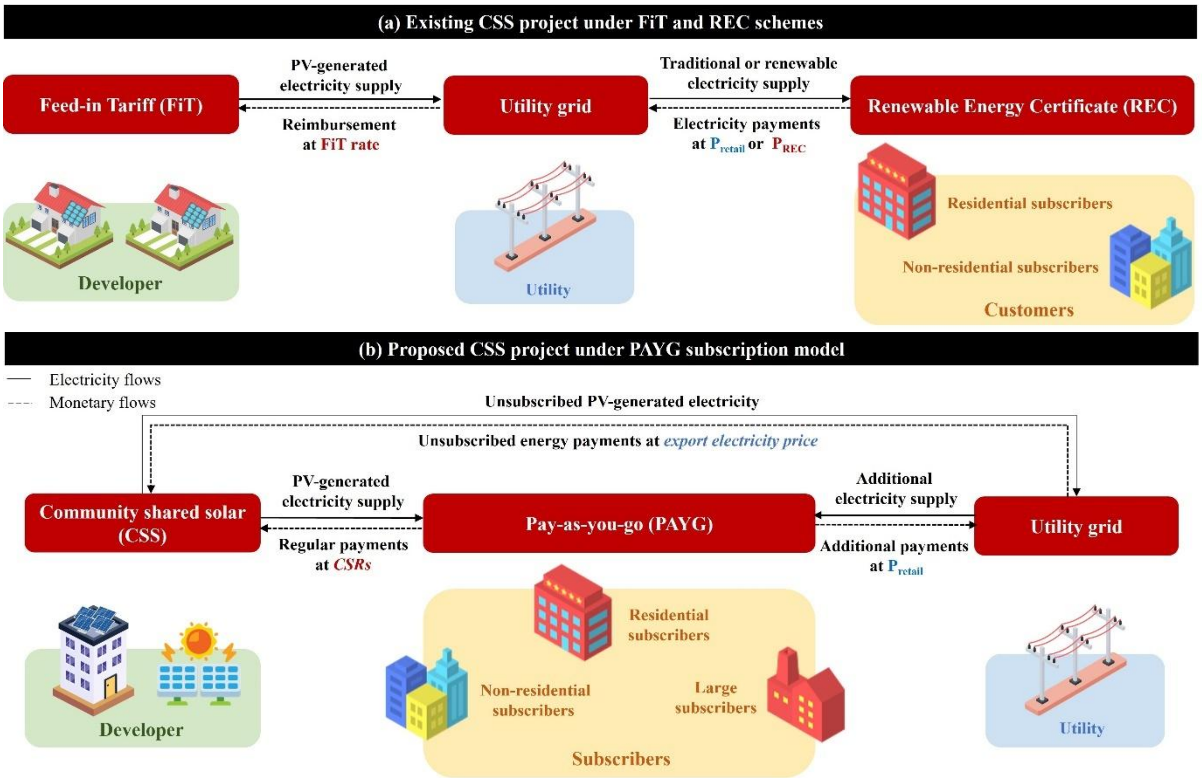


Figure 5.3 Schematic representation of (a) the existing CSS project under FiT and REC schemes in Hong Kong; and (b) the proposed energy-shared CSS project under PAYG subscription model

5.2.2.2 Project Size and Location

The size of CSS projects can vary significantly depending on a number of factors such as location, available space, and the number of participants. According to literature review, the installed capacity of most existing CSS projects is generally smaller than the utility-scale solar projects but larger than typical residential solar projects (Vignesh et al., 2022), typically ranging from 20 kW to 2,000 kW (EPA, 2016). Based on the available evidence, this study considers an average value of 1,000 kW as the size of proposed CSS project for analysis.

The installation location of solar PV projects varies across projects, encompassing building rooftops as well as open ground spaces. According to the list of solar PV projects in Hong Kong (Net, 2006), the installation locations can include rooftops of different types of buildings, such as governmental buildings, hospitals, police stations, blocks, campus greenhouse, and main school buildings, as well as various types of grounds, such as island, park, garden, and sewage treatment works. In general, residential and commercial PV systems are usually installed on rooftops, whereas utility-scale PV systems are typically installed on the ground since they require a larger space to accommodate hundreds of panels. As for the CSS projects, since their size is more flexible compared to residential and utility-scale PV systems, the installation locations can also be either rooftop or ground, depending on the specific project. Therefore, this study selects building rooftops as the installation location for the proposed CSS project, considering the limited availability of land resources in Hong Kong. In addition, Hong Kong has significant potential for rooftop solar PV installation, considering the high building density (Peng & Lu, 2013).

5.2.2.3 Participant Type and Subscription Models

As shown in Figure 5.4, in a CSS project, main participants are the developer and subscribers. The developer works as a project leader and is responsible for the entire CSS project lifecycle, including installation, operation and maintenance, which can be undertaken by a single entity or multiple types of entities, such as utility companies, private companies, or non-profit organizations. In the operation phase, the main role of the developer is to acquire and engage subscribers as well as provide technical services with them.

On the other hand, the main role of subscribers in a CSS project is to subscribe to PV-generated electricity. This study considers three types of subscribers in CSS projects according to customer types of two major utility companies in Hong Kong (i.e., Hongkong Electric Company, Limited (HK Electric) and CLP Power Hong Kong Limited (CLP)). *Residential subscribers* refer to those individuals or households who subscribe to a CSS project and utilize electricity exclusively for residential purposes. *Non-residential subscribers* include those entities or establishments that subscribe to a CSS project and consume electricity solely for non-residential purposes. Subscribers whose expected monthly consumption is not less than 20,000 units (kWh) are regarded as *large subscribers*.

To understand the contractual relationship between the developer and subscribers, subscription models are adopted. As mentioned in the Introduction, PUF, LL, and PAYG are commonly employed subscription models for CSS projects (Beck et al., 2020). In the PUF model, the subscriber pays for the entire subscription upfront. This offers a predictable revenue stream for the developer and proves advantageous for the financial planning of CSS projects. Adopting the PUF model can lead to a higher level of customer commitment; however, some subscribers may hesitate to commit to a long-term subscription if they are uncertain about their future needs. On the other hand, in the LL model, the subscriber either takes out a loan or obtains a lease in a way that enables the subscriber to spread the subscription cost over a longer period, making it more affordable and accessible, particularly for those who are unable to make an upfront payment. Nonetheless, qualifying for a loan or lease under the LL model may involve credit checks, which could dissuade prospective subscribers. In the PAYG model, subscribers are billed based on their actual usage of the service or product, offering a higher financial flexibility and a lower financial burden. However, this flexible transaction and financing may expose developers to risks related to payment collections from subscribers (e.g., payment failure) and increased competitive pressure from peers (e.g., price pressure, loyalty of subscribers, etc.), potentially affecting cash flow and profitability. Despite these challenges, customer acquisition remains a critical hurdle for the adoption of CSS projects, particularly in emerging solar markets (Beck et al., 2020; Mah et al., 2018; Thakur & Wilson, 2022). The PAYG model, which is expected to boost the participation rate by enhancing financial availability and flexibility (Chan et al., 2017; Chan et al., 2018; Chang et al., 2017), is especially appropriate for CSS projects in new markets. Therefore, this study adopts PAYG model as the subscription model.

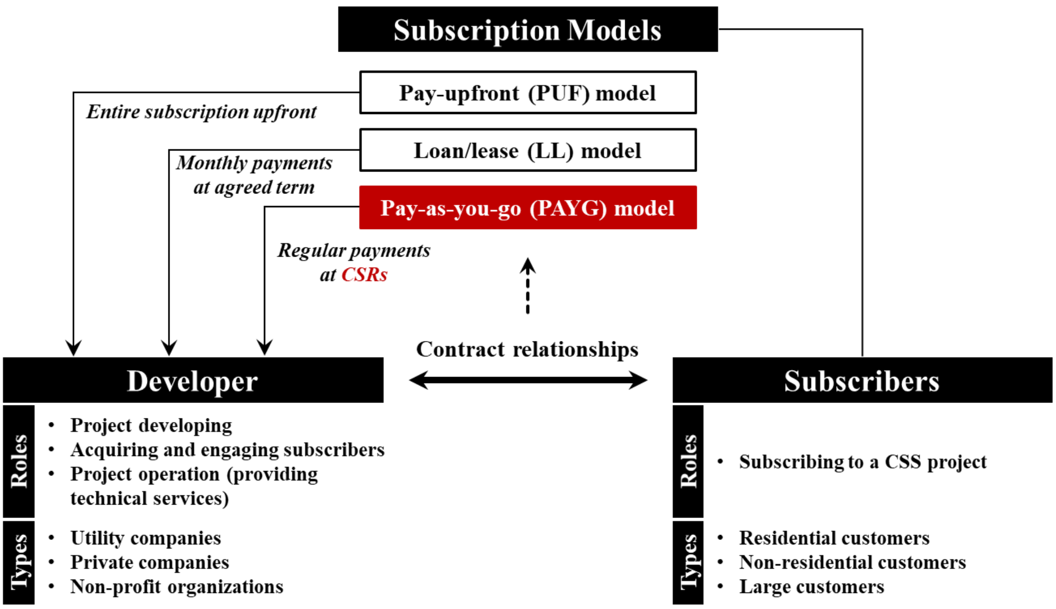


Figure 5.4 Three subscription models according to the contractual relationships between the two key participants (i.e., a developer and subscribers) in a CSS project

5.3 Scenarios Design

This study aims to explore the CSR for each type of subscriber under expected financial goals of the developer in current market conditions. The results of CSR will be compared with the retail electricity price in Hong Kong to investigate the attractiveness of a CSS project from the perspectives of both subscribers and developer. Towards this end, this study bases its analysis on the current cost data and retail electricity prices in Hong Kong, assuming the implementation of a CSS project from 2021. To enhance the comprehensiveness and robustness of the analysis, three different scenarios are proposed to determine CSRs, PP, and financial incentives, respectively, that ensure a financially sustainable and attractive CSS project for both subscribers and developers, as below. A summary of these three scenarios is also presented in Table 5.1.

Table 5.1 Summary of three scenarios considered in this study.

Scenario	Project life	Subscription rate		Financial goals		Outcome		
		Single subscriber type[a]	Multiple subscriber types[b]	PP	CSR	CSR	PP	Subsidy
A	25 years (2021-2046)	Residential: 100% Non-residential: 100% Large: 100%	Residential: 50% Non-residential: 25% Large: 25%	8 years		√		
B				8-25 years		√		
					Retail price[c]		√	
C				8 years	Retail price[c]			√

Note: [a] subscription rates for a single CSS project, respectively; [b] subscription rates for a single CSS project, collectively; and [c] Equivalent to the retail electricity price.

- Scenario A: This scenario aims to determine the CSR for each type of subscriber under expected financial goals. The expected financial goal assumes that the PP for the developer falls within 8 years based on Mah et al. (2018). According to Mah et al. (2018), a long PP is identified as a major concern for potential PV adopters, and thus, interviewees expressed high interest in installing PV if PP can be reduced to 8 years, which has already been achieved in some places like Seoul, certain states in the United States (U.S.), and Australia (Burtt & Dargusch, 2015; Mah et al., 2018). To explore the CSR under this financial goal, it is necessary to make assumptions on customer acquisition. This study considers the combination of different subscriber types involved in a CSS project to represent the volatility of communities and the adaptability of the proposed financial model. Therefore, in addition to the scenario where only a single subscriber type is involved, this study also examines situations with multiple subscriber types participating in the CSS project. When a single subscriber type is engaged in a CSS project, a 100% subscription rate is assumed for that type of subscriber to calculate their CSR. This means that all PV-generated electricity from the CSS project will be subscribed to by that single subscriber type, whether residential, non-residential, or large subscribers. When different types of subscribers are involved in a CSS project, the financial model proposed in this study is adaptable to various subscriber compositions according to market contexts. In this study, the subscription rates for residential, non-residential, and large subscribers are assumed to be 50%, 25%, and 25%, respectively, according to the customer segments of the U.S. solar market in 2021 (Galen et al., 2022). Consequently, 50%, 25%, and 25% of the total PV-generated electricity from the CSS project will be subscribed by residential, non-residential, and large subscribers, respectively.

- Scenario B: This scenario is proposed in case the CSRs determined in Scenario A are higher than the retail electricity price due to the high upfront cost of PV systems in Hong Kong compared to other regions or countries (WAI, 2014). In such a case, subscribers are unlikely to be interested in the project, making CSS projects infeasible. To lower CSRs, this scenario assumes that PP can be much longer and aims to find the specific PP, especially the one when CSR is equal to the retail electricity price for each type of subscriber. The results are expected to provide references for developers investing in a new CSS project. The assumptions on subscription rates are the same as in Scenario A.
- Scenario C: This scenario aims to explore the minimum amount of extra subsidy needed for the developer to keep CSRs at a reasonable level while achieving the expected financial goal in Scenario A. This scenario is proposed in case the CSRs determined in Scenario A are higher than the retail electricity price, and the PPs determined in Scenario B are not short enough to attract developers to initiate a CSS project. In a such case, neither subscribers nor developers are likely to show interest in the project, making CSS projects unlikely to be implemented. To promote the development of CSS project in a new market, this scenario explores the minimum amount of extra subsidy needed, and the results are expected to provide references for the government in designing subsidy for CSS projects at an early stage. In this scenario, CSRs are assumed to be equal to the retail electricity prices for each type of subscriber, while the PP for the developer is assumed to be within 8 years. To balance the cashflow in the beginning of a CSS project, this scenario assumes that each subsidy for the project will be split out in the first five years. Five years is referred to CSBC tool (Elevate, 2017) where five years are pre-populated for the subsidy in the

U.S. based on the industry averages. The assumptions on subscription rates are the same as in Scenario A.

5.4 Financial Model Design

Based on the research aim and scenario design, this study developed a financial model for CSS projects using life cycle analysis. The CSR determined by this financial model represents the price at which electricity generated by a CSS project is offered to subscribers. This electricity corresponds to the amount of PV-generated energy that subscribers commit to in their subscription contracts with the CSS project. Consequently, the determination of CSR is conducted based on the subscription rate, independent of the actual hourly electricity consumption by subscribers. Moreover, this model is designed to be concise and practical, facilitating quick and effective decision-making in a nascent community solar market by avoiding complex business structures, time-consuming processes, and the need for extensive data. This model thereby consists of two parts: project cash outflow, which encompasses an exhaustive compilation of all financial expenditures incurred throughout the entire duration of the CSS project's existence, and project cash inflow, which refers to the revenue throughout the lifetime of a CSS project. The specifications of the research model are presented in Table 5.2.

Table 5.2 Specifications of research model and data used in this study

Cashflow	**Category**	**Sub-category**	**Data**
CO	SCC	UIC	29,200 HKD/kW
		UAC	Residential subscribers: 10.89% of SC+P Non-residential subscribers: 9.93% of SC+P Large subscribers: 5.37% of SC+P
	FC	D	50% of UIC
		DIP	IPMT function with 5% interest rate
		DPP	PPMT function with 5% interest rate

Cashflow	Category	Sub-category		Data
	OC	OTC	YSAC	0.0549% of UIC per subscriber
			YSMC	0.443% of UIC per subscriber
		OMC		1% of UIC
		SLP		Zero
		SRC		5% of UIC
		Ins		0.25% of UIC
		TE		Eq. (5.5)
CI	SP	S_e		Eq. (5.8)
		CSR		Objective function
	SI	ITF		90% of CO or 5 million HKD, whichever is less
		EPF		2,818,800 HKD
	SPB	UEP		0.088*Amount of unsubscribed energy
		SV		Zero

Note: SC+P refers to the combined soft cost and profit.

5.4.1 Financial Model

5.4.1.1 Project Cash Outflow (CO)

CO considers all expenses throughout the project lifetime, including system capital costs, financing costs, and operation costs. The CO of a CSS project in year t can be calculated using Eq. (5.1):

$$CO_t = SCC_t + FC_t + OC_t \tag{5.1}$$

Where CO_t refers to the cash outflow of a CSS project in year t (currency), SCC_t refers to system capital costs of CSS projects in year t (currency), FC_t refers to financing costs of CSS projects in year t (currency), and OC_t refers to the operation costs of CSS projects in year t (currency). The specific calculations of each component are explained as follows. In this analysis, the year is t and the ending year is T, where t refers to the year of PV installation (e.g., t = 0 represents the year of installation, t = 1 represents the first year after installation, and so on), and T refers to the year when the system is at the end of its service life (i.e., 25 years).

5.4.1.2 System Capital Costs (SCC)

SCC are costs that will be incurred prior to the occupation of the facility, including upfront administrative costs and upfront installation costs of a PV system (Vignesh et al., 2022). SCC in year t can be calculated by Eq. (5.2):

$$SCC_t = UIC_t + UAC_t \tag{5.2}$$

Where UIC_t is the upfront installation cost in year t (currency), including the cost of PV module, inverter, other hardware, and soft costs and profits (Vignesh et al., 2022). Other hardware includes costs of cable, cable connection, steel support, switches, combiner boxes, monitor system, etc. (Yang et al., 2020). Soft costs and profits include labor costs, project coordination fees, operating overhead, supply chain costs, permitting, interconnection and inspection costs, and contractor profits (Zhang, 2016). UIC is set to the installation cost of monocrystalline (Mono-Si) solar panels in Hong Kong, which was reported as 29.2 HKD/W in Yang et al. (2020) as shown in Table 5.3. UAC_t is the upfront administrative cost in year t (currency), including marketing and communications, customer acquisition setup, outreach setup, admin setup, and subscriber management costs. Due to the absence of typical CSS projects and an established UAC in Hong Kong, this study referred to the percentage of UAC to UIC observed in existing markets. According to the report on solar project costs from NREL (Vignesh et al., 2022), the UAC_t for residential, non-residential, and large subscribers are 10.89%, 9.93%, and 5.37% of the combined soft cost and profit, respectively.

Table 5.3 Assumption on the installation and administrative costs of a CSS project in Hong Kong (HKD/kW)

Subscriber type		Residential	Non-residential	Large
UIC (Yang et al., 2020)	PV module (Mono-Si)		2,800	
	Inverter		1,400	
	Other hardware		10,000	
	Soft cost and profit		15,000	
	Total		29,200	
UAC (Vignesh et al., 2022)		1,663.5	1,489.5	805.5

5.4.1.3 Financing Costs (FC)

FC are the cost of finances involved in the borrowing of money to build or purchase assets for CSS projects. FC includes debt, debt interest payment, and debt principal payment, which can be calculated by Eq. (5.3):

$$FC_t = D_t + DIP_t + DPP_t \tag{5.3}$$

Where D_t refers to the debt of the project in year t (currency). DIP_t refers to interest payment in year t (currency). According to the 2021 annual report of Hong Kong monetary authority (HKMA, 2021), the average interest rate in Hong Kong is 5%, which will be referred to as the debt interest rate in this study. DPP_t refers to debt principal payment in year t (currency).

5.4.1.4 Operation Costs (OC)

OC associated with a CSS project encompass various essential aspects that are recurrent in its daily operations. OC consists of transactional costs, operations and maintenance costs, site/land lease payments, insurance, profit tax, and the system removal costs, which can be calculated by Eq. (5.4):

$$OC_t = OTC_t + OMC_t + SLP_t + SRC_t + Ins_t + TE_t \tag{5.4}$$

Where OTC_t refers to ongoing transactional cost in year t (currency), which consist of yearly subscription acquisition costs for new customers (YSAC) and yearly subscription management costs for existing customers (YSMC). YSAC covers outreach, sales, and sign-up transaction. YSMC covers customer service and billing administration. According to Community Solar Business Case Tool (Elevate, 2017), YSAC and YSMC account for 0.0549% and 0.443 % of UIC, respectively. OMC_t refers to operations and maintenance costs in year t (currency), which is 1% of UIC (An et al., 2022b). These costs are essential for ensuring the smooth and effective operation of CSS projects, encompassing general and administrative fees related to project management and operation, preventive maintenance scheduled at regular intervals (e.g., inspection, monitoring, module cleaning), and corrective maintenance to replace components (e.g., inverter replacement, module and component replacement) (Vignesh et al., 2022). SLP_t refers to site lease payment in year t (currency), which is the expense of using the site for CSS projects. As mentioned in section 2.3.1, this study assumes that the location of CSS project is the rooftop of buildings, and the developer has the right to access the rooftops. Thus, SLP is not considered in the data analysis. SRC_t refers to system removal cost in year t (currency), indicating the expense of removing the PV systems at the end of system service, which is 5% of UIC (Ouyang & Lin, 2014). Ins_t refers to insurance cost in year t (currency), showing the total property insurance premium, which accounts for 0.25% of UIC in this study (Vignesh et al., 2022). TE_t refers to tax expenses involved in a CSS project in year t (currency). According to the Land Revenue Department of Hong Kong, three common taxes in Hong Kong are profits tax, salaries tax, and property tax (IRD, 2023). Among them, the CSS project is eligible for profits tax only, and therefore, this study considers profits tax (PT_t) as TE_t (HKD) by using Eq. (5.5). It will be paid at the rate of 8.25% on assessable profits up to HKD2,000,000, and 16.5% on any part of assessable profits over HKD2,000,000.

$$TE_t = PT_t = \begin{cases} CI_t * 8.25\%, & CI_t \leq 2{,}000{,}000 \\ CI_t * 16.5\% - 165{,}000, & CI_t > 2{,}000{,}000 \end{cases} \tag{5.5}$$

Where CI_t refers to the cash inflow of a CSS project in year t (HKD).

5.4.1.5 Project Cash Inflow (CI)

CI is another part of the financial model, which refers to the revenue throughout the lifetime of a CSS project. CI in year t can be calculated by Eq. (5.6), which includes subscriber payments, system production benefits, and subsidy income.

$$CI_t = SP_t + SPB_t + SI_t \tag{5.6}$$

Where SP_t refers to subscriber payments of a CSS project in year t (currency), SPB_t refers to total system production benefits in year t (currency), and SI_t refers to subsidy income of a CSS project in year t (currency). The specific calculations of each component are explained as follows.

5.4.1.6 Subscriber Payments (SP)

SP is the total revenue of a CSS project, including payments from multiple subscriber types, which can be calculated by Eq. (5.7):

$$SP_t = \sum_t (S_e^r * CSR_r + S_e^n * CSR_n + S_e^l * CSR_l) \tag{5.7}$$

Where S_e^r, S_e^n, and S_e^l refer to the total cumulative subscribed electricity of residential, non-residential, and large subscribers in each year (kWh), respectively, which can be calculated by Eq. (5.8); CSR_r, CSR_n, and CSR_l refer to CSRs for residential, non-residential, and large subscribers (HKD/kWh), respectively.

$$S_e = NP/TNP * E \tag{5.8}$$

Where NP refers to the total number of panels subscribed by each type of subscriber. TNP refers to total number of panels in a CSS project. E is the annual solar PV electricity generation of the CSS project (kWh), the calculation of which is based on daily PV system electricity generation as expressed by Eq. (5.9) (Vakili et al., 2022; Zhang, Lee, Zhao, et al., 2023):

$$E = H * A * \gamma * PR \tag{5.9}$$

Where H is the average daily global radiation ($MJ/m^2/day$), data on which can be obtained from Hong Kong Observatory (HKO, 2022). A is the total area of solar panels (m^2); γ is the solar panel yield (%), which is the amount of energy harvested from the solar panels. γ is subjected to external factors such as orientation, wind speed, shade, ambient temperature, and dust deposition. γ is taken as 18.7 % for a 305 W Mono-Si PV module with a unit solar panel area of 1.64 m^2 (Yang et al., 2020). PR is the performance ratio, measuring the efficiency of energy output and thus considers the possible internal losses during the conversion of solar energy into electricity (i.e., inverter losses and cable losses) by the PV system, which is assumed to be 0.75 (Lu, 2013). Figure 5.5 shows the monthly solar power generation per unit installed capacity in this project.

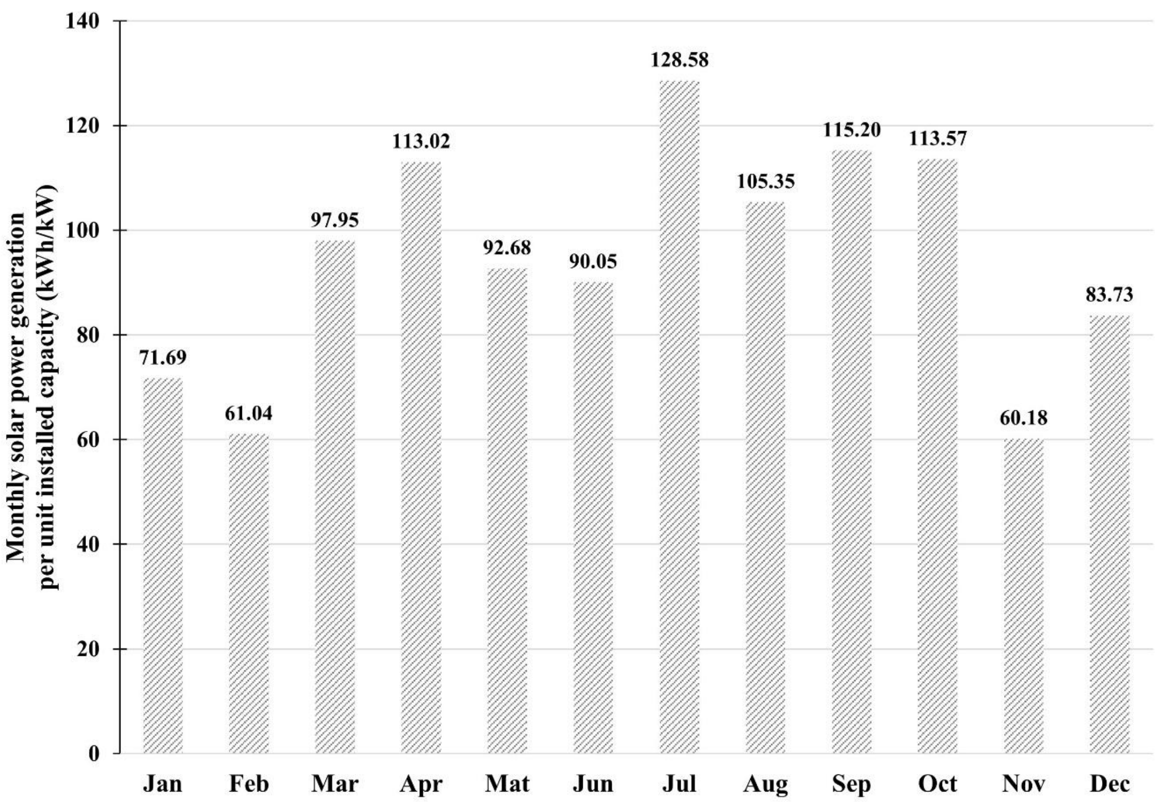


Figure 5.5 Monthly solar power generation per unit installed capacity for a CSS project in Hong Kong.

5.4.1.7 Subsidy Income (SI)

SI are revenues provided by governments or utilities to support the implementation and operation of a CSS project. In Hong Kong, most renewable energy policies are not specifically tailored for CSS projects in terms of the sponsoring target. However, the Innovation and technology fund for better living provided by Innovation and Technology Commission of Hong Kong is an appropriate subsidy for a CSS project, since this fund is designed to support innovation and technology projects that enhance the convenience, comfort, safety, or address the specific needs of community groups (ITC, 2022). Maximum funding support is either 90% of the total eligible costs of the project or HKD 5 million, whichever is less. In addition, with effect from the year of assessment 2018/19, a full deduction is allowed during the basis period in which the expenditure is incurred for procuring environmental protection facilities (IRD, 2023). This is another subsidy for a CSS project in Hong Kong. SI in year t can be calculated by Eq. (5.10):

$$SI_t = ITF_t + EPF_t \tag{5.10}$$

Where ITF_t refers to total amount of the Innovation and Technology Fund for better living in year t (HKD); EPT_t refers to expenditure on environmental protection facilities in year t (HKD).

5.4.1.8 System Production Benefits (SPB)

SPB are total system production benefits, including the salvage value of a CSS project and revenue from unsubscribed energy, which can be calculated by Eq. (5.11):

$$SPB_t = UEP_t + SV_t \tag{5.11}$$

Where UEP_t refers to unsubscribed energy payments in year t (currency). This study assumes that the CSS project is connected to the grid and unsubscribed energy can be sold to the grid at export electricity price (i.e., a price equal to the cost of traditional electricity). According to the financial and electricity data (i.e., generation cost, operation cost, fuel cost, and amount of electricity generation) published by HK Electric Corporate Information (HKE, 2014, 2021), the cost of electricity from traditional sources (i.e., mixed fuel) was calculated as 0.688 HKD/kWh in 2021. SV_t refers to the salvage value of a CSS project in year t (currency). Since Hong Kong is still in its nascent stage of solar PV adoption, with renewable energy accounting for only 0.4% of the city’s total electricity consumption in 2020 [55], there is insufficient evidence to establish a reliable salvage value. Therefore, this study takes a conservative approach by assuming a salvage value of zero.

5.4.2 Financial Performance Evaluation

The results of the life cycle cost analysis-based financial model can be presented in various financial indices. Financial performance evaluations for the developer used in this study are shown as follows:

- PP represents the number of years required for the cumulative after-tax cash flow to cover the initial equity investment in the project, and can be calculated using Eq. (5.12) (Chang & Starcher, 2019):

$$\sum_{t=1}^{Y} \frac{CI_t - OC_t - FC_t}{(1+i)^t} = SCC_t \qquad (5.12)$$

  Where the minimum value of Y represents the expected value of PP and i is the discount rate (%), which is set as 2.75%, according to the average rate provided by the Hong Kong Monetary Authority (HKMA, 2021).

- IRR evaluates the expected return on investment (%), expressed as a percentage. When the discount rate is less than the IRR, the investment is profitable. According to Yan et al. (2019), a solar project is very profitable when IRR is equal to 16%, which is used in this study. The calculation of IRR is the discount rate needed for NPV to equal zero, and can be expressed by Eq. (5.13) (López Prol & Steininger, 2020; Zhang & Lee, 2023):

$$NPV(IRR) = \sum_{t=1}^{T} \frac{CI_t - CO_t}{(1+IRR)^t} = 0 \qquad (5.13)$$

- Levelized profit of electricity (LPOE) is adopted to measure the net profit of a CSS project per unit of electricity generated (HKD/kWh) and can be calculated by Eq. (5.14) (Yan et al., 2019; Zhang & Lee, 2023). It is the discounted net benefit divided by the discounted net power generation, where the discounted net benefit includes the discounted net incomes and net costs. LPOE $\geqslant$ 0 means this project could reach net profit status by installing a CSS project (Yan et al., 2019).

$$LPOE = \frac{\sum_{t=1}^{T} \frac{CI_t - CO_t}{(1+i)^t}}{\sum_{t=1}^{T} \frac{S_e\,(1-r)^{t-1}}{(1+i)^t}} \tag{5.14}$$

Where r is the degradation rate of the PV system (%), which takes a median degradation rate of about 0.5% per year published by NREL (NERL, 2018).

5.5 Results and Discussion

5.5.1 Community Solar Rate for Subscribers under Scenario A

Figure 5.6 shows the CSRs determined for each type of subscriber under Scenario A. It is revealed that when only a single subscriber type (i.e., 100% subscription rate for each type of subscribers) is involved in a CSS project, the CSRs for residential, non-residential, and large subscribers are 3.12 HKD/kWh, 3.09 HKD/kWh, and 3.01 HKD/kWh, respectively. The variation in CSRs can be attributed to the different level of UAC and OTC associated with each subscriber type. A lower UAC leads to a lower CSR, while a higher number of subscribers results in a higher OTC and CSR since OTC is imposed on a per-subscriber basis and thus its total cost is affected by the total number of each subscriber types. Notably, the determined CSRs of all three subscribers are nearly double or triple the prevailing retail electricity price in Hong Kong, thereby signaling the infeasibility of CSS projects concerning subscriber benefits in the present market context. Furthermore, all CSRs are found similar to the current FiT rates (i.e., 3 HKD/kWh for generating capacity more than 200 kW) in Hong Kong. This minimal difference between CSRs and FiT rates may reduce the likelihood of developers shifting from the well-established practice of selling PV-generated electricity through the FiT scheme to selling such electricity at CSRs through CSS projects, further weakening the economic appeal of CSS projects for developers. Meanwhile, when multiple subscriber types (i.e., 50% residential, 25% non-residential, and 25% large subscribers) are engaged in a CSS project, CSRs of 3.14 HKD/kWh, 3.07 HKD/kWh, and 2.98 HKD/kWh are determined for residential, non-residential, and large subscribers, respectively, as shown in Figure 5.6. Similar to the case involving only a single subscriber type, residential subscribers show the highest CSR, whereas large subscribers show the lowest CSR due to the difference in UAC and OTC across different subscriber types. The higher burden on UAC of residential subscribers due to marketing and communications, customer acquisition setup, outreach setup, admin setup, and subscriber management costs, leads to a higher CSR. In addition, the types of subscribers also influence OTC involved in OC. The larger customer pool of residential subscribers contributes to significant YSAC and YSMC, thereby resulting in a higher CSR. However, it should be noted that changes in subscriber rates may alter CSRs and the explanatory factors of CSR, which further needs to be validated in practice. Nevertheless, similar to the case involving only a single subscriber type, CSRs remain approximately double or triple the retail electricity price in Hong Kong, even with multiple subscriber types, indicating the infeasibility of CSS project in the current market. In contrast, CSRs in the U.S. with mature solar markets average a range from a 13% discount to a 15% premium of average state-wide retail rates, with an average close to average retail rates (Mackenzie & Research, 2018). In certain states, such as California, Florida, and Michigan, the majority of customer segments experience bill savings from community solar and are projected to achieve 40%-50% reductions in customer bills by 2030 (Mackenzie & Research, 2018). This is attributed to the relatively low level of SCC and OC due to scale, operational efficiencies, and advanced technologies in mature markets in the U.S. (Mackenzie & Research, 2018).

Despite the findings indicating significantly higher CSR compared to the retail electricity price but at a similar level to the FiT rate, which suggests a less favorable investment environment for both customers and the developer in Hong Kong's current market. The CSS project still holds potential to overcome economic barriers from a long-term perspective due to the following reasons. First, the upfront installation cost of PV systems is declining worldwide because of technological advancements, scale economies, and project management practices (IREAN, 2020). According to *Renewable Power Generation Costs* published by the International Renewable Energy Agency in 2020, the global median installed cost of residential PV systems decreased by 77% from 2010 to 2018, while the median installed cost of commercial and industrial PV systems decreased by 78% over the same period (IREAN, 2019). Additionally, it is widely acknowledged that the global solar PV industry has been developing for several decades and has already reached a level of maturity, whereas Hong Kong's solar PV market is still in a relatively early stage of development (Mah et al., 2018). As the solar market in Hong Kong matures over time, the upfront installation cost of PV systems is expected to follow the same decreasing pattern observed globally, which would consequently lead to a lower CSR required to achieve the expected financial goals. Second, the retail electricity price is expected to be increased steadily since it has increased with an annual rate at 2.76% in the past five years (CLP, 2022). Thus, the gap between CSRs and retail electricity price are expected to decrease in the coming years. As this gap narrows, eventually reducing the CSR below the retail electricity price, the CSS project will become economically attractive to subscribers.

Furthermore, the financial model developed in this study can provide insights into CSS project's financial performance for the developer, such as PP, IRR, 25-year cost, and 25-year revenue. Table 5.4 summarizes the specific results of financial performance of a CSS project under Scenario A. It can be concluded that the CSS project show overall high financial performance with a high IRR of 16% and a low PP of 8 years when CSRs are two to three times higher than retail electricity price. According to Yan et al. (2019), a solar project fails to be financially viable if the IRR is below 8.5%, while it is very profitable when the IRR exceeds 16%. The findings of this study indicate a higher IRR (i.e., 16%) compared to the IRR of 11.33% observed in a base CSS project in Texas, which entailed a 1 MW project with 100% subscriber participation, due to much higher CSRs calculated in this study.

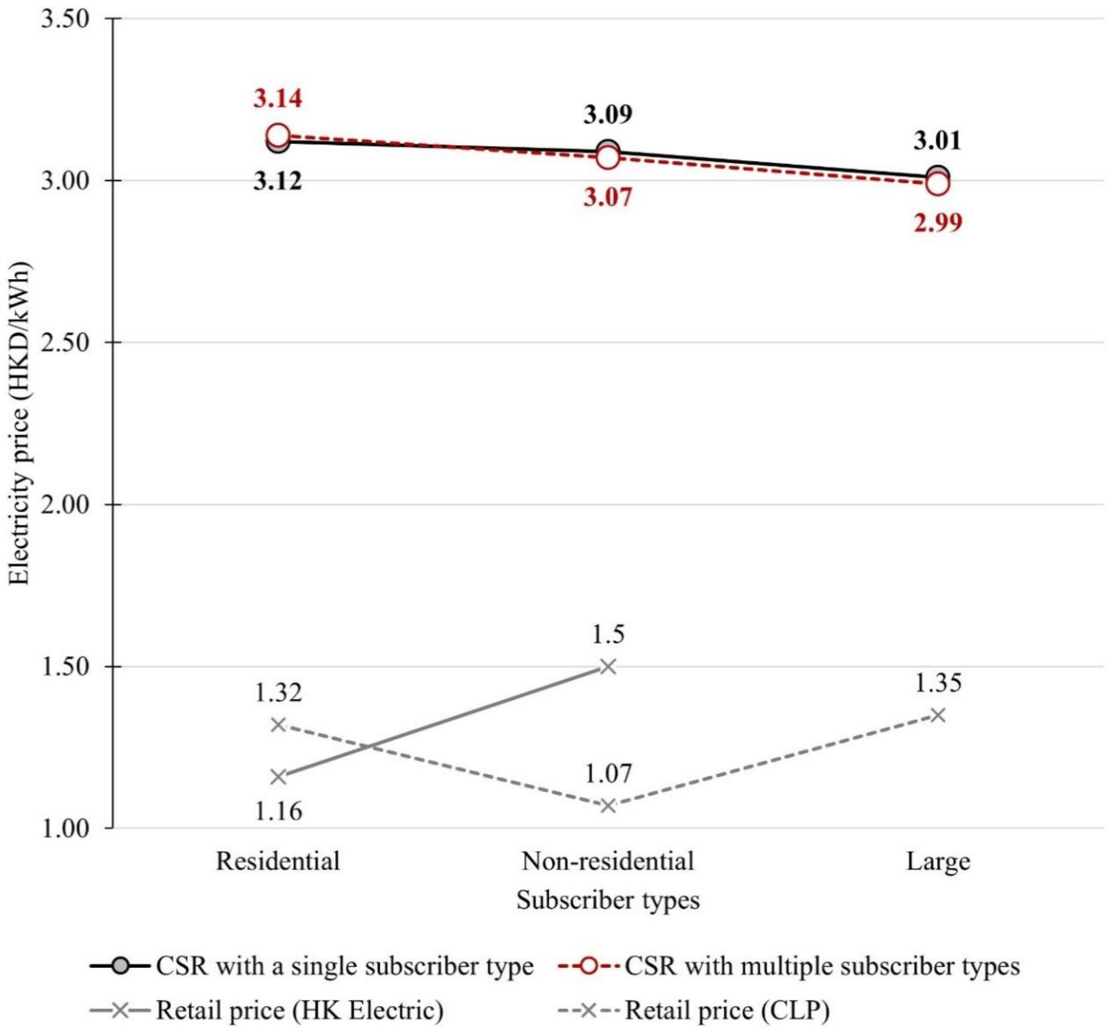


Figure 5.6 CSRs and retail prices for each subscriber type under Scenario A

Table 5.4 Financial performance of a CSS project for the developer under scenario A

Indices		**Total value (Million HKD)**	**Unit value (HKD/Watt)**
Cash flow	25-year costs	-54.6	-54.58
	25-year revenues	96.9	96.97
	25-year net benefits	42.3	42.31
	25-year NPV	28.9	28.93

Indices	Total value (Million HKD)	Unit value (HKD/Watt)
IRR	16%	
PP	8 years	

5.5.2 Payback Period for the Developer under Scenario B

Figure 5.7 demonstrates the changes to CSRs as PP extends beyond 8 years and the specific PP at which the CSR equals the retail electricity price under Scenario B. It can be seen that as PP increases, CSRs for all types of subscribers steadily decline with a similar trend when there is only a single subscriber type in a CSS project. Additionally, CSRs differ in relation to the retail electricity price for each customer type. As shown in Figure 5.7, CSRs for residential and large subscribers consistently exceed the retail electricity price even though the PP reaches as long as 25 years. This indicates that the PP is longer than the lifetime of a CSS project, making it economically infeasible and unappealing in the current market. Regarding non-residential subscribers, it is observed that all CSRs surpass the retail electricity price for CLP customers, which indicates that the PP is longer than the lifetime of a CSS project, thus, the CSS project is regarded infeasible. However, for HK Electric customers, CSRs for non-residential subscribers become lower than the retail electricity price once the PP exceeds 23years, demonstrating the potential for a CSS project in the current market. Nonetheless, its economic attractiveness to the developer can be still relatively low due to the long PP. As for the specific PP when CSR is equal to the retail electricity price for each type of subscriber, it can be concluded from Figure 5.7 that PP significantly exceeds eight years.

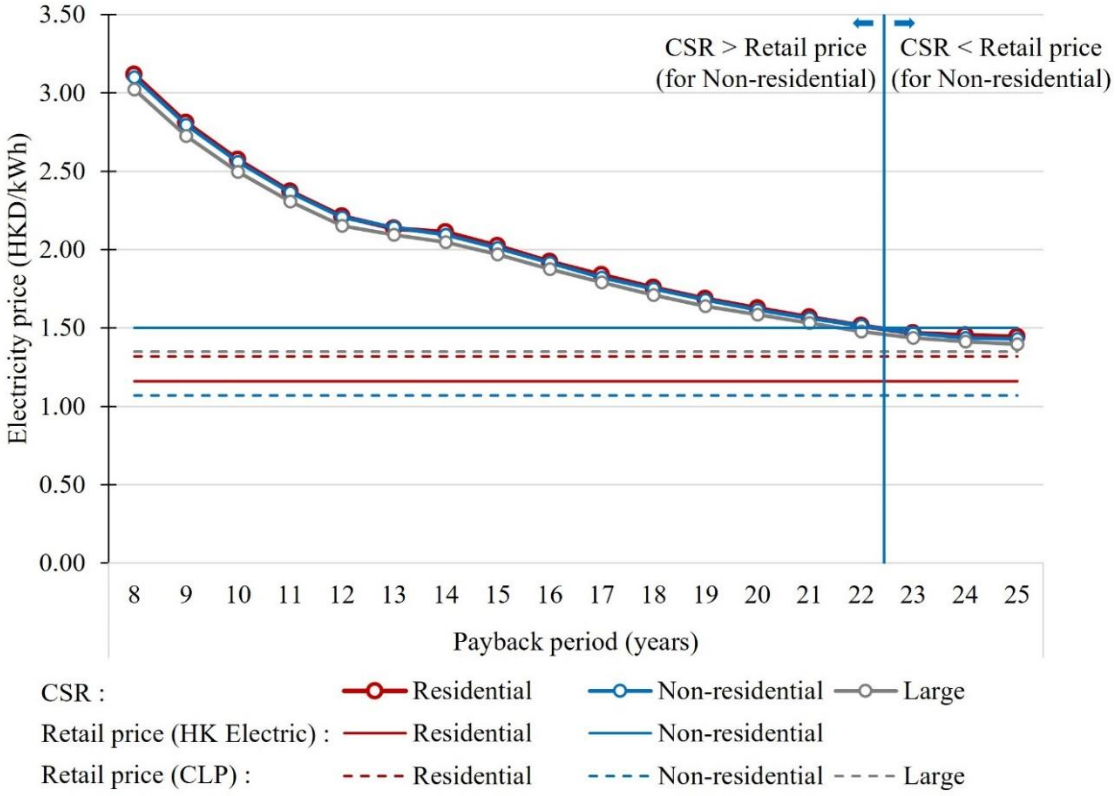


Figure 5.7 CSRs and retail prices for each subscriber type under scenario B (only a single subscriber type in a CSS project)

Figure 5.8 displays the results of PP in the context of a CSS project with the participation of multiple subscriber types. Similar to the case when only a single subscriber type is involved in a CSS project, the result demonstrates clear trends of declining CSRs for all types of subscribers as assumed PP extends. Notably, irrespective of the PP, the CSR for large subscribers consistently remains the lowest among the three types; whereas residential subscribers exhibit the highest CSR in most cases, with the exception being when the PP is set at 17 years. This disparity can likely be attributed to the administrative and transactional costs associated with operating a CSS project. Typically, the transactional costs are related to the number of subscribers involved. Given the broader customer pool of residential subscribers, YSAC covering outreach, sales, and sign-up transaction, as well as YSMC covering customer service and billing administration contribute to a larger burden of these costs, resulting in an increased total share and subsequently a higher CSR. Conversely, for large subscribers, the allocation of costs come from a smaller pool of customers. Moreover, the administrative cost for large subscribers has the lowest level compared among all three types of subscribers due to lower marketing and communications, customer acquisition setup, and subscriber management costs. Consequently, the total amount of these costs is lower, leading to a lower CSR for this particular subscriber type.

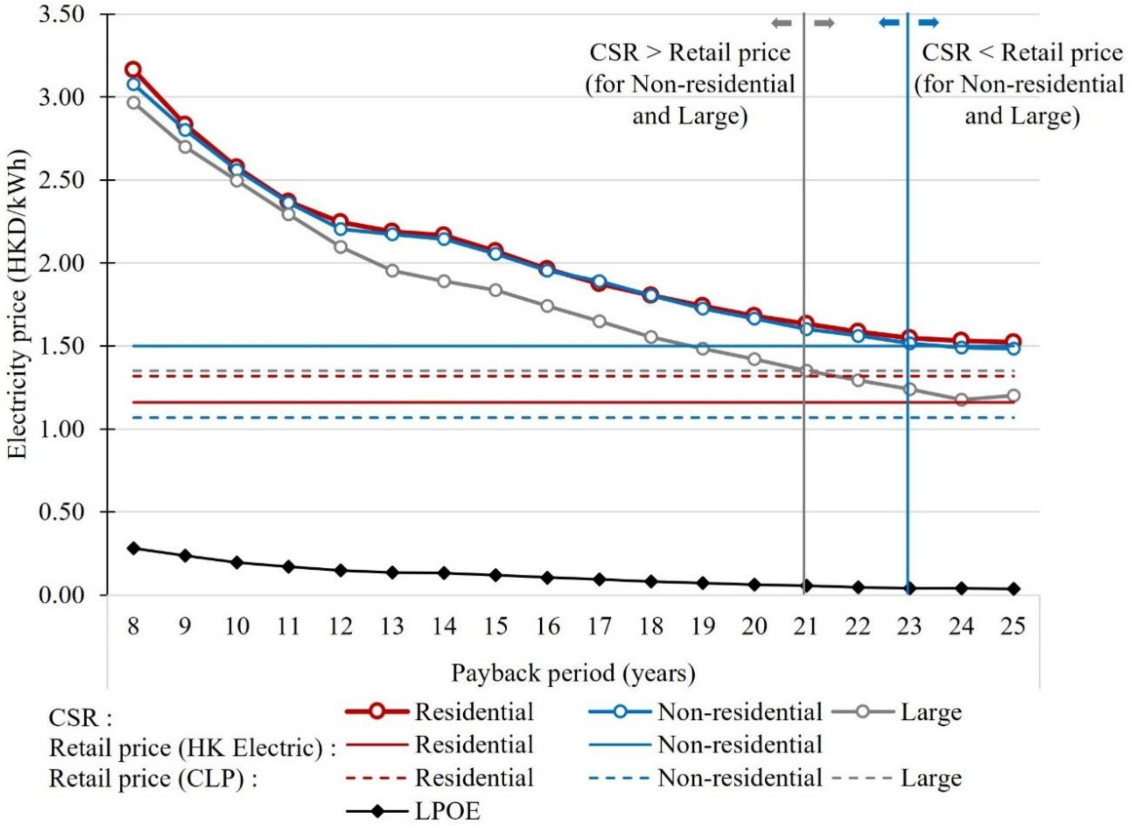


Figure 5.8 CSRs and retail prices for each subscriber type under Scenario B (multiple subscriber types in a CSS)

In addition, Figure 5.8 provides insights into the relationship between CSRs and PP when a CSS project involves multiple subscriber types. Similar to the case when only a single subscriber type is involved in a CSS project, the result demonstrates that CSRs for different subscriber types mostly exceed the retail electricity price until the PP reaches as long as 21 to more than 25 years, indicating that the CSS project has lower economic feasibility and attractiveness in the current market. Moreover, it is not feasible for the CSRs of all three subscriber types to be lower than their respective retail electricity prices at the same time. For instance, in the case of CLP large customers, the CSR can be lower than retail electricity price when the PP is 21 years, whereas CSRs for both residential and non-residential subscribers continue to surpass their retail electricity prices. Such an outcome is deemed unacceptable within the context of a CSS project involving multiple subscriber types. In summary, the analysis reveals that a CSS project with multiple subscriber types faces challenges in ensuring that CSRs for all subscriber categories are simultaneously lower than their respective retail electricity prices. This fact, along with the long PP required for the customers' grid parity, contributes to the overall low feasibility and attractiveness of such a project in the current market. This finding is consistent with the results of a study on regular solar projects by (Dato et al., 2021), which revealed that the current FiT leads to a minimum PP of 50 years for regular solar projects in Hong Kong, highlighting the necessity for extra subsidy or a higher selling price of PV-generated electricity to assist in recovering the costs of investment in renewable energy systems and generation.

Moreover, LPOE, which represents the net profit per unit of electricity generated from a CSS project, differs when PP changes. Figure 5.8 illustrates that as PP increases, LPOE steadily decreases. The highest LPOE value of 0.28 occurs when PP is 8 years, while the lowest value of 0.0375 is observed when PP reaches 25 years. According to Yan et al. (2019), an LPOE $\geqslant$ 0.20 indicates a high level of profitability. The results in this study show that when PP is less than 11 years, LPOE can exceed 0.20, implying developers would be more interested in a CSS project when PP $\leqslant$ 10 years. This observation aligns with a study on financial analysis of regular PV systems in Hong Kong (Zhang, Lee, & Huang, 2023), which revealed that it takes a minimum of 12 years for a developer to achieve LPOE $\geqslant$0.20 without a FiT scheme. However, with the support of the FiT scheme, the LPOE can reach a high value of 1.73 in 5 years and can sustain economic profitability until the FiT scheme expires. This underscores the notion that adequate incentives for developers can stimulate the advancement of PV systems. In summary, shorter PP can lead to higher net profits per unit of electricity generated, ultimately enhancing the attractiveness of CSS projects for developers. However, when PP is short, CSRs for all types of subscribers exceed their respective retail electricity prices, thus diminishing the attractiveness of CSS projects for subscribers. To satisfy the benefits of both developer and subscribers, it is necessary to meet the desired PP (i.e., shorter PP) with an appropriate CSR (i.e., lower CSR) in the current market, which would require additional subsidy to promote the development of CSS projects in their early stages.

5.5.3 Extra Subsidy for the CSS project under Scenario C

Figure 5.9 provides an overview of the minimum extra subsidy required for developers under Scenario C, where CSRs are equal to retail prices of each type of subscriber of CLP and the PP for the developer is eight years. According to the results, when there are only residential subscribers involved in a CSS project, developer would require an additional subsidy of approximately 3,355.45 HKD/kW/year for a period of five years, which accounts for roughly 11.5% of the total upfront installation cost of PV systems in Hong Kong. Likewise, for a CSS project with only non-residential subscribers, a developer would need an extra subsidy of about 3,827.96 HKD/kW/year for five years, representing 13.1% of the total upfront installation cost. CSS projects with only large subscribers, on the other hand, would require the lowest level of additional subsidy, amounting to approximately 3,330.33 HKD/kW/year for five years, constituting 11.4% of the total upfront installation cost. The levels of required additional subsidy vary when involving different types of subscribers. The subscriber type with higher CSRs enhances the cash inflow of a CSS project, making it financially feasible. Consequently, this allows for a lower level of extra subsidy needed to fulfill the desired financial goals. Notably, large subscribers possess the highest level of retail electricity price at 1.35 HKD/kWh, compared to residential and non-residential subscribers, leading to the lowest level of extra subsidy needed for a developer.

In addition, when multiple subscriber types are involved in a CSS project, the calculated amount of extra subsidy needed for the developer is calculated as 3,387.63HKD/kW/year for five years. This value falls between the extremes observed in the cases when there is only a single subscriber type, implying that the combination of subscribers can have a significant impact on the required level of additional subsidy. However, noteworthy variations arise when only large or residential subscribers are present. In these cases, the required extra subsidy is found to be lower compared to the other cases, which may enhance the feasibility of funding and implementing a CSS project. To summarize, the findings demonstrate that by providing the appropriate level of extra subsidy, it is possible to establish CSR rates that align with the retail electricity prices for each subscriber type, resulting in a PP as short as eight years. This optimal scenario serves the interests of both developers and subscribers, overcoming the limitations observed in the first two scenarios (e.g., high CSRs and long PP).

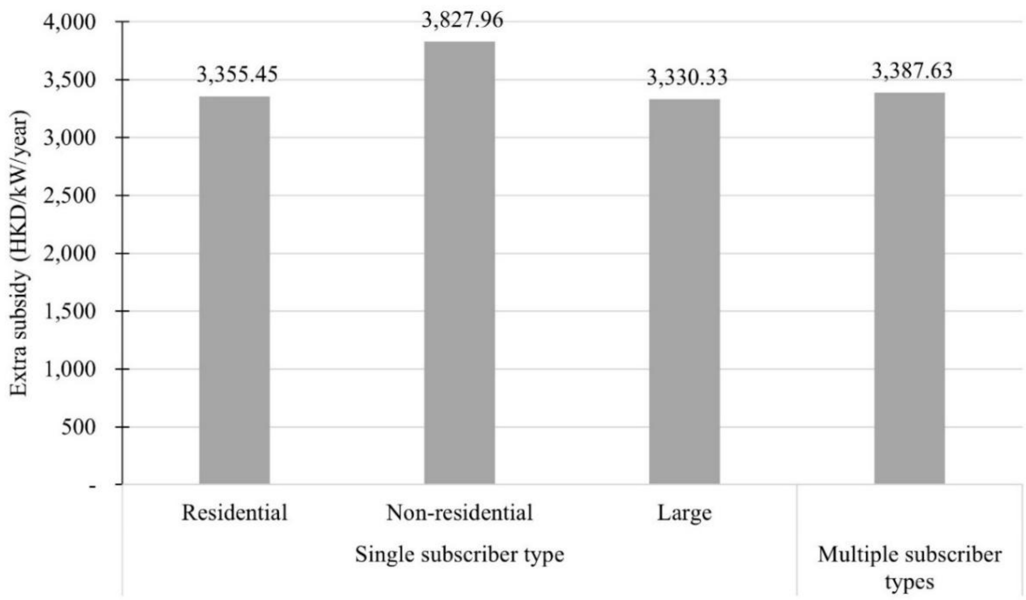


Figure 5.9 Extra subsidy required for a CSS project under Scenario C

5.6 Summary of the Chapter

To explore attractiveness of CSS projects to both investors (i.e., developers) and customers (i.e., subscribers) in nascent markets (e.g., Hong Kong) and achieve Objective 2, this chapter firstly proposes a new business model for CSS projects in niche markets where CSS projects face uncertainties and challenges regarding their operation, financial performance, and pricing strategies. The proposed business model for CSS projects offers an innovative approach which enables direct selling of PV-generated electricity to end-users. Based on it, this chapter develops a financial model using life cycle cost analysis to evaluate the economic performance of CSS projects under different scenarios. Specifically, the model is employed to determine the appropriate price of CSS-generated electricity, the expected payback period, and the necessary subsidies considering the benefits to both developers and subscribers in the current Hong Kong market. The major findings are elaborated below:

- The CSRs for each type of subscriber are nearly two to three times higher than its retail electricity price, revealing that CSS projects are financially infeasible under current market conditions in Hong Kong. Nonetheless, the CSRs proposed in this study can serve as a benchmark value for both the developer and subscribers to effectively respond to a CSS project as Hong Kong's solar PV market matures.
- The estimated PPs for CSS projects require at least over 20 years to achieve acceptable financial performance, with CSRs no greater than retail electricity prices, which greatly exceed the desired payback period of eight years.
- The minimum amount of extra subsidy required for the developer to ensure the financial sustainability and attractiveness of a CSS project accounts for around 11% of the total upfront installation cost of PV systems.

In addition, the contribution of this study is threefold:

- In terms of the CSS project design, this study proposes a new business model for niche markets (e.g., Hong Kong) where CSS projects face uncertainties and challenges regarding their operation, financial performance, and pricing strategies. The proposed business model for CSS projects offers an innovative approach which enables direct selling of PV-generated electricity to end-users, and it can serve as a valuable reference for future community solar adoption in various solar markets, and can be further expanded and adapted to fit different market contexts.
- In terms of the financial model, this study develops a heuristic financial model specifically customized for CSS projects. This model is designed to avoid complex business structures, time-consuming processes, and the need for extensive data, thereby making it practical for quick and effective decision-making in nascent community solar markets. This financial model can be used not only to analyze the techno-economic performance of CSS projects under different scenarios, but also to determine and optimize favorable CSRs to achieve desired financial performance. The CSRs can be automatically adjusted in response to changes in key parameters of the financial model, such as desired financial performance or other relevant factors. This flexibility allows the financial model to be expanded and adapted to suit different market contexts, accommodating various tax types, subsidy types, and other financial incentives.
- In terms of analysis, this study provides an exploratory analysis of the determination and optimization of CSRs for CSS projects. The analysis of CSRs and other financial performance metrics (e.g., PP and subsidy) provides insights into designing appropriate pricing and subsidy strategies to promote community solar adoption. Although the analysis and financial model incorporates numerous Hong Kong-specific parameters, the financial model's design allows it to be adapted to various market contexts, making it applicable beyond the specific case of Hong Kong. Overall, this study makes significant

contributions to the CSS project domain by introducing a novel business model, developing a dedicated financial model, and providing insights into CSR dynamics. These contributions pave the way for further advancements in the field and offer practical guidance for promoting community solar adoption.

Nonetheless, since the financial model developed in this study only considered PAYG subscription model as it is proven to boost the participation rate most effectively by enhancing financial availability and flexibility, it is suggested that future studies improve the following aspects:

- Involve different types of subscription models to ensure the proposed model can be adopted and customized for effective analysis in diverse locations and contexts.
- Consider potential changes in market conditions (e.g., potential fluctuations in the upfront cost of PV systems, operation costs, and retail electricity prices) to inform the design of pricing and subsidy strategies for CSS projects over the longer term.
- Conduct a sensitivity analysis encompassing a broader range of factors affecting the CSRs of CSS projects, propose more scenarios related to key components affecting SCRs, and comprehensively explore the techno-economic performance.

Chapter 6 Economic Performance of Community Shared Solar Projects in the Future Market (Techno-economic feasibility)

6.1 Introduction

Renewable energy is widely considered as a vital alternative energy source that can mitigate carbon emissions and reduce reliance on fossil fuels (Balta-Ozkan et al., 2015). Significant efforts have been made to develop and implement renewable energy technologies across various industries worldwide. Community solar has emerged as a viable approach to harnessing solar energy, overcoming limitations such as improper orientation, insufficient roof space, and high upfront costs (Lo et al., 2018; Mah et al., 2018). In the conventional practice, a PV system is installed off-site in another facility or elsewhere in the community. Subscribed customers then receive benefits based on their share in the PV system (Siegrist et al., 2013). This model is typically implemented when the community location does not meet the necessary requirements for installing a PV system. Another community solar practice involves community members jointly funding the installation of PV systems on suitable rooftops. Investors in this practice receive a share of the profits based on the electricity generated by the installed systems (Coughlin et al., 2011). Community solar provides accessibility and affordability to solar power for individuals constrained by financial or location limitations to access solar power.

Since financial challenges have broadly been identified as impediments to the adoption of CSS projects, previous studies have evaluated various financial metrics to analyze the financial feasibility of CSS projects under different contexts. However, it is important to note that the assumptions regarding financial parameters in previous studies are often context-specific and may not account for the inherent variability and uncertainty of local conditions, potentially compromising the accuracy and predictability of economic analysis results for CSS projects. Among the various financial metrics used in the economic analysis of CSS projects, the price of electricity generated by a CSS project (CSR) is of particular importance as it has an impact on the willingness of customers to adopt CSS projects and ultimately on the success implementation of CSS projects. Two types of pricing model are commonly used for financial viability exploration in existing studies: variable pricing model and fixed pricing model. However, they are associated with complex business structures, time-consuming processes, and the need for extensive data, which renders them impractical for facilitating quick and effective decision-making in a nascent community solar market. Additionally, while various pricing models have been applied in community solar business models, which tie the CSR to the market price of electricity (Lee et al., 2021; Mehta & Tiefenbeck, 2022; Mirzania et al., 2020), they do not provide a method to determine the specific CSR or differentiate it based on different subscription models. Investigating CSR is crucial for a new CSS project, particularly in a new market, considering that CSR is of great importance to indicate the attractiveness for both developers and subscribers. Benefits of these two stakeholders involved in a CSS project are usually contradictory to a certain extent.

Even though existing studies offer insights into the economic analysis of community solar, several research gaps can be identified in the following aspects. Firstly, no studies have determined a specific CSR to assess the economic feasibility of a CSS project in a new market. Secondly, factors influencing CSRs have not been thoroughly explored in previous studies. Thirdly, existing studies lack investigation into the economic benefits under different market conditions considering market dynamics. To fill these research gaps, this study aims to develop a financial model for CSS projects and explore CSRs for CSS projects under both current and future market conditions. To this end, this study addresses the following research questions: (1) What are the CSRs for a sustainable CSS project in the current and future market considering the profitability for main stakeholders?; (2) What is the minimum subscription rate for a sustainable CSS project considering the profitability for main stakeholders?; and (3) How do the revenue and cost components determining CSS projects affect the financial performance of a CSS project? The findings of this study contribute to a comprehensive understanding of the economic feasibility and attractiveness of CSS projects, as well as the design of suitable CSRs for a CSS project in different market conditions, ultimately promoting community solar adoption in new markets.

6.2 Methodology

To understand the economic feasibility and practicability of a CSS project, this study explores appropriate CSR and minimum subscription rate for each type of subscriber under expected financial goals in both current and future markets. Toward this end, a three-step research approach was undertaken, as depicted in Figure 6.1. The first step involves the development of a business model for CSS projects, which encompasses the operational structure, fundamental characteristics, and subscriber details of a CSS project. The second step focuses on the formulation of scenario designs and corresponding financial models, which are utilized to ascertain the economic performance and feasibility of the CSS project. The scenario designs encompass various cases where some local market conditions change, providing insights into the potential implications on the CSS project. The financial model is developed based on LCCA and the proposed business model of a CSS project, which is established to calculate the CSR and subscription aligned with the expected financial goals. The third step entails conducting sensitivity analysis to identify the key revenue and cost components that significantly impact the financial performance of the CSS project. By providing these insights, developers are equipped with valuable references to inform the development of effective pricing strategies. The research design proposed in this study can be adopted in any new solar market and is validated in the context of Hong Kong which is still in its nascent stage of solar PV adoption.

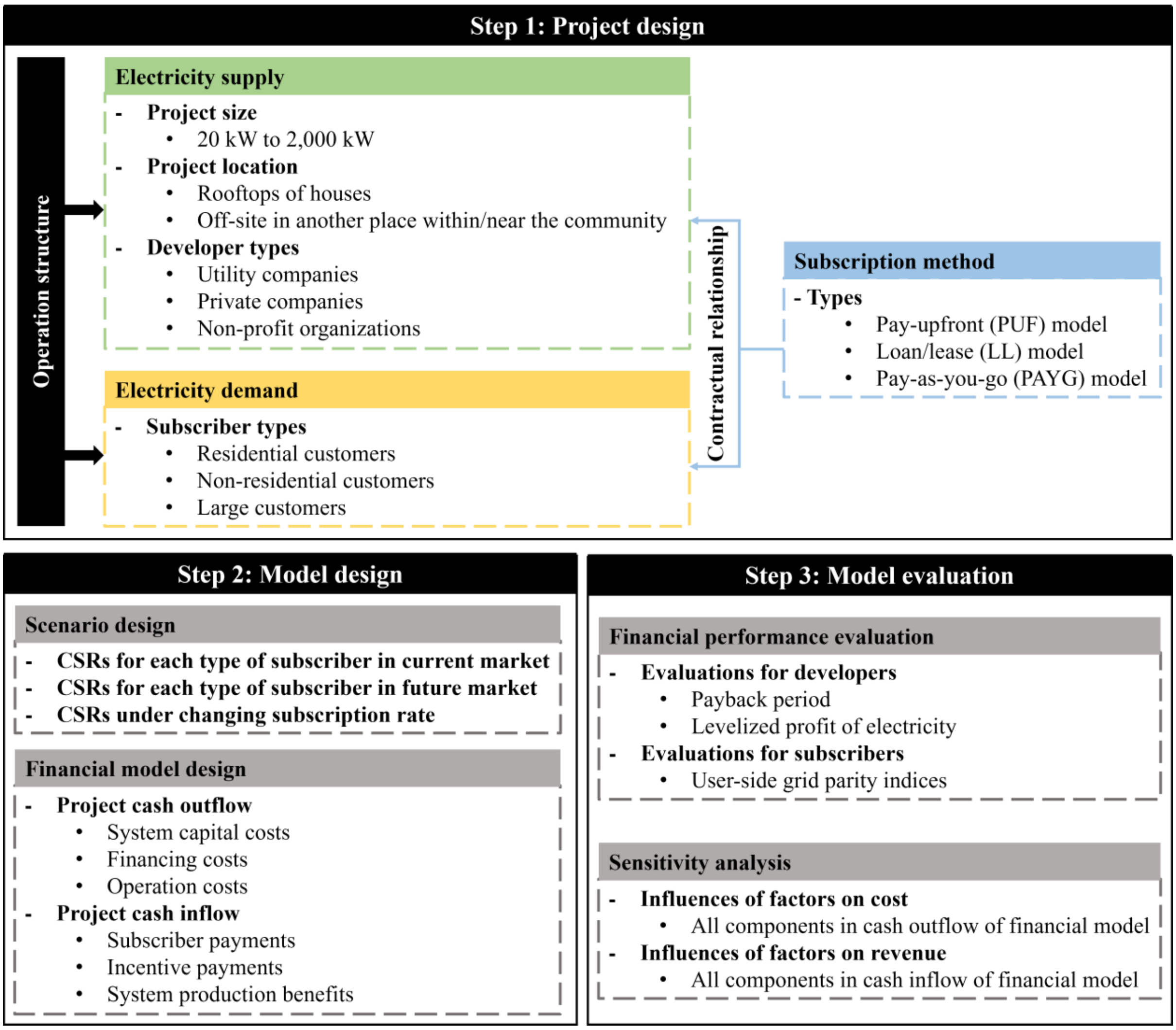


Figure 6.1 The research design of this chapter.

6.2.1 Community Solar Project Design

Solar initiatives, particularly in the form of CSS projects, involve a collective effort by a group of individuals with shared interests in energy-related activities within a specific location. Based on the existing CSS project in Hong Kong where PV-generated electricity can either be used by the owner or sold to the grid through the FiT scheme (Kong, 2017), this study proposes a new business model of the CSS project that enables the direct purchase of

PV-generated electricity by various types of subscribers through a subscription method at CSRs. Subscribers also have the option to purchase electricity from the grid to meet higher demand. The responsibility for the entire lifecycle of the CSS project, including installation, operation, and maintenance, lies with the developer who works as a project leader and can be utility companies, private companies, or non-profit organizations. Figure 6.2 illustrates the schematic architecture of a CSS project, which consists of two sides: electricity supply and electricity demand.

The electricity supply part is crucial in a CSS project as it involves converting solar energy into electricity for immediate sale. The capacity of electricity generation depends on the size of a CSS project, which can vary from project to project. Generally, CSS projects benefit from economies of scale compared to residential and small commercial solar projects, which typically range in size from 20 kW to 2,000 kW (EPA, 2016). As such, this study adopts an average size of 1,000 kW as the installed capacity for analysis purposes. Regarding the location for project installation, according to various solar practices, PV systems in a CSS project can be installed on the rooftops of houses or off-site in another place within or near the community, depending on project-specific situations. This study therefore selects building rooftops as the installation location considering two aspects: (i) limited availability of land resources in Hong Kong; and (ii) significant potential for rooftop solar resources (i.e., 14.2% of the annual energy yield to the total electricity used in Hong Kong in 2011) (Peng & Lu, 2013).

In addition to electricity supply, the electricity demand part is another essential component for a CSS project since it significantly affects the effectiveness and success of a CSS project. In this part, the type of subscribers and the subscription methods determining the way for subscribers to subscribe to a CSS project, should be paid much attention, as subscribers are the end-users for generated electricity and their intensions to a CSS project greatly influence the successful implantation of a CSS project. Different project may attract various types of subscribers to meet their specific needs and maximize their benefits. In this study, subscriber type refers to three types of customers categorized by two utility companies in Hong Kong (i.e., HK Electric and CLP): (i) residential subscribers; (ii) non-residential subscribers; and (iii) large subscribers (i.e., those with an expected monthly consumption of not less than 20,000 units (kWh)) (CLP, 2023; HK Electric Company, 2023).

The subscription method serves as a crucial link between electricity supply and demand. In practice, the PUF, the LL, and the PAYG are commonly employed subscription models for CSS projects to establish the contractual relationship between developer and subscribers (Beck et al., 2020). PUF requires customers to pay the upfront cost for solar capacity and offers a monthly bill credit for the agreed term. This model provides a predictable revenue stream and proves advantageous for the financial planning of CSS projects. However, some subscribers may hesitate to commit to a long-term subscription if they are uncertain about their future needs. LL allows customers to spread the subscription cost over a longer period by settling monthly payments based on the amortized upfront cost of solar capacity. This makes it more affordable and accessible, especially for those unable to make an upfront payment. Nonetheless, qualifying for a loan or lease under LL may involve credit checks, which could deter prospective subscribers. PAYG enables subscribers to pay for solar electricity at a certain rate based on their actual usage without any upfront payments, offering a higher financial flexibility and a lower financial commitment. Consequently, PAYG is expected to increase the participation rate by enhancing financial availability and flexibility (Chan et al., 2017; Chan et al., 2018; Chang et al., 2017). Furthermore, PAYG is particularly appropriate for CSS projects in a new market as it can efficiently improve customer acquisition, which is considered a critical challenge for the adoption of CSS projects (Mah et al., 2018; Thakur & Wilson, 2022). Therefore, this study adopts PAYG as the subscription method.

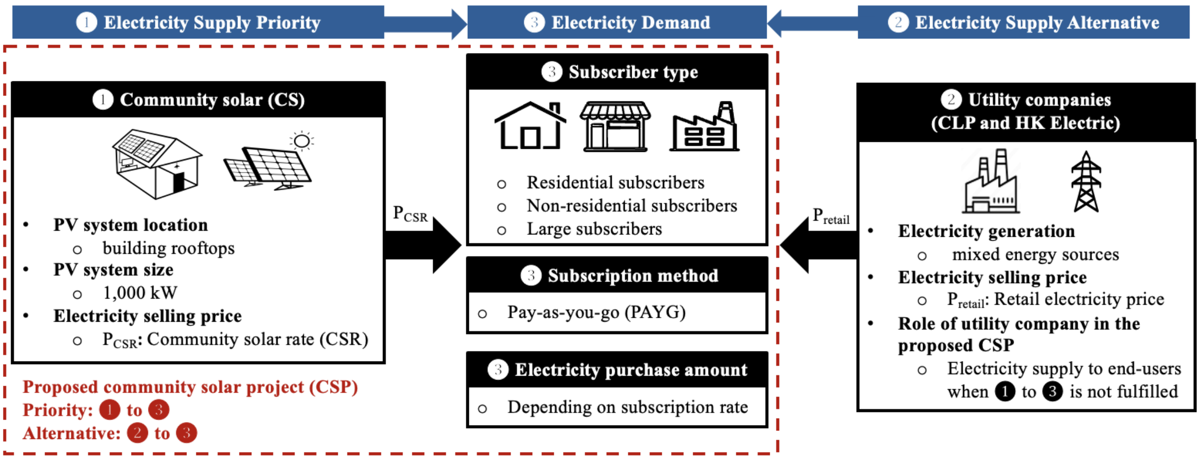


Figure 6.2 Schematic representation of proposed community shared solar project.

6.2.2 Scenario Design

This study aims to determine and compare the CSR for each type of subscriber across different markets for a comparative analysis. Towards this end, this study firstly bases its analysis on the current cost data in Hong Kong, assuming the implementation of a CSS project commences from 2021. The results of CSR will be compared with the REP in Hong Kong to evaluate the attractiveness of a CSS project from the perspectives of both subscribers and developer in the current market. Secondly, this study bases its analysis on the future cost data in Hong Kong, the results of which will also be compared with the corresponding REP to assess the attractiveness of a CSS project in the future market. To enhance the comprehensiveness and robustness of the analysis, a scenario involving a changing subscription rate is subsequently proposed to determine lowest subscription rate that ensures a financially sustainable and attractive CSS project for both subscribers and developers. All three scenarios are presented below, and Table 6.1 provides a summary of these scenarios considered in this study.

- Scenario A: This scenario aims to determine the CSR for each type of subscriber under expected financial goals of the developer in the current market and compare it with the current REP. The expected financial goal assumes that PP for the developer falls within 8 years based on Mah et al. (2018). According to Mah et al. (2018), a long PP is a major concern for potential PV adopters, and interviewees expressed high interests in installing PV if PP can be reduced to 8 years, which has already been achieved in some places like Seoul, certain states in the U.S., and Australia (Burtt & Dargusch, 2015; Mah et al., 2018). To explore the CSR under this financial goal, assumptions on customer acquisition are made, as CSR may differ for each type of subscribers. When a single subscriber type is engaged in a CSS project, a 100% subscription rate (i.e., all PV-generated electricity is subscribed by this type of subscriber) is assumed for that type of subscriber to calculate their CSR. When multiple subscriber types are involved in the same CSS project, the subscription rates for residential, non-residential, and large subscribers are assumed to be 50%, 25%, and 25%, respectively, according to the customer segments of the U.S. solar market in 2021 (Galen et al., 2022).
- Scenario B: This scenario aims to determine the CSR for each type of subscriber under expected financial goals of the developer in the future market and compare it with the projected REP, to provide insights for developers regarding the optimal timing to invest in a CSS project within a new market. This scenario has been proposed to facilitate a clear comparison of the economic attractiveness of a CSS project between the current and future markets considering evolving market dynamics (e.g., fluctuations in PV installation prices and REPs). It is evident that the average installation costs of PV systems have been decreasing globally (IREAN, 2022), while REP has shown a steady increase over the past decades (CLP, 2022). Consequently, it

is expected that the gap between CSRs and REPs will gradually narrow over time. As this gap diminishes, the CSR will eventually fall below the REP, making the CSS project economically attractive to subscribers. The assumptions on the expected financial goal (i.e., PP) and subscription rates remain the same as in Scenario A, providing consistency in the scenario analysis.

- Scenario C: This scenario aims to investigate the impact of the change in subscription rate on the change in CSR, and explore the minimum subscription rate required for developers to maintain CSRs at a reasonable level while still achieving their financial goal. This scenario has been proposed to provide a more practical and realistic insights to developers of CSS projects, considering that achieving a 100% subscription rate is an extremely stringent condition and somewhat unrealistic. By understanding the potential limitations and exploring alternative scenarios, developers can make informed decisions and devise strategies that align with the changing market dynamics and subscriber acquisition uncertainties, optimizing the success and impact of their CSS projects. In this scenario, the subscription rate is assumed to range from 70% to 100% with a 1% interval, aiming to identify the minimum subscription rate at which the CSR equals the REP of each type of subscriber. The assumptions on the expected financial goal (i.e., PP) remain the same as in Scenario B.

Table 6.1 Summary of three scenarios considered in this study.

Scenario	Project life	Subscription rate		Financial goals		Outcome		
		Single subscriber type[a]	Multiple subscriber types[b]	PP	CSR	CSR	Starting year	Subscription rate
A	25 years (2021-2045)	(a) Residential: 100% (b) Non-residential: 100% (c) Large: 100%	(d) Total: 100% - Residential: 50% - Non-residential: 25% - Large: 25%	8 years		√		
B				8 years	Retail price[c]	√	√	
C		(a) Residential: 70% to 100% with a 1% interval (b) Non-residential: 70% to 100% with a 1% interval (c) Large: 70% to 100% with a 1% interval	(d) Total: 70% to 100% with a 1% interval - Residential: 50% of the total - Non-residential: 25% of the total - Large: 25% of the total	8 years	Retail price[c]			√

Note: [a] subscription rates for a single CS project, respectively; [b] subscription rates for a single CS project, collectively; and [c] Equivalent to the REP.

Regarding the installation cost of PV systems, the upfront installation cost of PV systems has been decreasing globally due to technology advancements, economies of scale, and efficient project management practices (IREAN, 2020). According to *Renewable Power Generation Costs* published by the International Renewable Energy Agency in 2020, the global weighted average total installed costs for PV decreased by 82.9% from 2010 to 2022 (IREAN, 2022). Furthermore, it is widely recognized that the global solar PV industry has reached a level of maturity over several decades, while the solar PV market in Hong Kong is still in its early stages of development (Mah et al., 2018). As Hong Kong's solar market matures over time, the upfront installation cost of PV systems is expected to follow the global decreasing trend, consequently resulting in a lower CSR required to achieve expected financial goals. Therefore. this study adopts the Learning Curve Case (LCC) method to estimate the total upfront installation cost of PV systems in the future Hong Kong. LCC, which represents the decreasing rate of PV system unit capital cost, is derived from the learning rate observed between 2010 and 2020 as the global PV market approaches maturity. LCC can be calculated based on Eqs. (6.1) and (6.2). Based on these calculations, a reliable estimate of future unit installation costs can be determined. It is estimated that the annual decreasing rate of PV system unit installation cost under LCC from 2021 onwards is around 6%. This rate reflects the long-term decline in PV system unit installation cost from the early stages to the mature phase of solar PV development. Consequently, the upfront costs of PV systems in subsequent years can be estimated, as illustrated in Figure 6.3 (a).

$$C_c = C_p\left(\frac{P_c}{P_p}\right)^{-\beta} \tag{6.1}$$

$$LR = 1 - 2^{-\beta} \tag{6.2}$$

Where C_c and C_p are the averaged global unit installation costs of the PV system (USD/kW) in 2020 and 2010, respectively, P_c and P_p are the cumulative solar PV installed capacity (MW) in 2020 and 2010, respectively, β is the slope of the function, and LR is learning rate, which represents the decreasing rate of PV system unit installation cost when the installed capacity doubles. LR has been calculated as 33.67% in this study (see Figure 6.3 (b)).

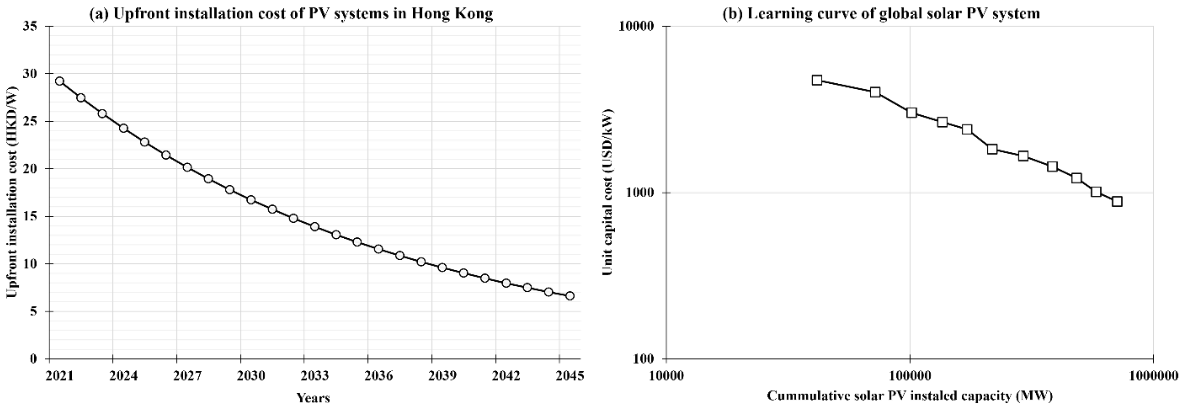


Figure 6.3 (a) Upfront installation cost of PV systems in Hong Kong in the future; and (b) Learning curve of global solar PV system from 2010 to 2020.

Regarding future REP in Hong Kong, this study firstly calculated REP for three types of customers in both CLP and HK Electric over a twenty-year period from 2003 to 2023 by utilizing historical data on electricity tariffs and average electricity consumption data obtained from Hong Kong Energy Statistics Annual Report (CSD, 2023). An example of the REP calculation for each customer type in 2021 and the calculated REP for all types of customers in the past twenty years are provided in Tables 6.2 to 6.4. The findings revealed overall consistent upward trends in REPs for all customer types over the past two decades. The study therefore projected future REPs for the period from 2021 to 2045, assuming a continuation of the historical increasing trend in electricity prices. Subsequently, this study calculated the annual rate of REP for each customer type every two years and used the average annual rate as the business as usual (BAU) rate for REP prediction. As a result, the average annual rates for residential, non-residential, and large customers in CLP were determined to be 3.89%, 3.88%, and 5.39%, respectively, while for residential and non-residential customers in HK Electric, the rates were 3.85% and 3.40%. To enhance the robustness of the analysis, instead of solely using a fixed BAU rate, the allowance is provided to project a flexible REP range and represent potential future trends in electricity prices. Henceforth, the maximum annual rate was utilized to estimate the upper bound of REP, which represent an optimistic trend against BAU. On the other hand, the minimum annual rate was adopted to predict the lower bound of REP, which stands for a pessimistic trend against BAU. Accordingly, the estimated future changes in various categories of REP in Hong Kong are depicted in Figure 6.4.

Table 6.2 Breakdown calculation of retail electricity price for CLP residential customers in 2021

Month	**Monthly electricity consumption per household (kWh)**	**CLP charge items (HKD)**		
		Energy charge (A)	**Fuel cost adjustment (B)**	**Final charge (A+B)**
Jan	270.33	489.23	151.93	641.16
Feb	270.33			
Mar	270.33	596.99	182.09	779.08
Apr	377.67			
May	377.67	704.75	215.27	920.02
Jun	377.67			
Jul	542.33	1048.78	319.98	1368.76
Aug	542.33			
Sep	542.33	791.43	277.75	1069.18
Oct	299.33			
Nov	299.33	547.46	215.52	762.98
Dec	299.33			
Total	4,469.00	-	-	5541.19
REP for CLP residential customers			**1.240 HKD/kWh**	

Table 6.3 Breakdown calculation of retail electricity price for HK Electric non-residential customers in 2020

Month	**Monthly electricity consumption per household (kWh)**	**HK Electric charge items (HKD)**		
		Energy charge (A)	**Fuel cost adjustment (B)**	**Final charge (A+B)**
Jan	4,502.33	4,937.16	783.41	764.04
Feb	4,502.33	4,937.16	783.41	
Mar	4,502.33	4,937.16	729.38	734.75
Apr	5,475.00	6,044.05	848.63	
May	5,475.00	6,044.05	815.78	1,331.66
Jun	5,475.00	6,044.05	865.05	
Jul	5,987.00	6,626.71	1,023.78	1,623.58
Aug	5,987.00	6,626.71	1,149.50	
Sep	5,987.00	6,626.71	1,335.10	1,311.17
Oct	4,747.00	5,215.59	1,219.98	
Nov	4,747.00	5,215.59	1,400.37	747.38
Dec	4,747.00	5,215.59	1,561.76	
Total	62,134.00	-	-	6,512.59
REP for HK Electric non-residential customers			**1.303 HKD/kWh**	

Table 6.4 Calculated REP for three types of customers in both CLP and HK Electric from 2003 to 2023 (HKD/kWh).

Customer types		**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Res	CLP	0.908	0.858	0.908	0.907	0.908	0.992	1.026	1.046	1.098	1.195	1.284	1.338	1.416	1.378	1.344	1.391	1.189	1.203	1.240	1.395	1.544
	HK Elec	0.808	0.826	0.899	1.017	1.056	1.154	1.238	1.234	1.308	1.408	1.459	1.406	1.388	1.326	1.052	1.063	0.920	0.927	1.153	1.480	1.630
Non-res	CLP	0.986	0.937	0.987	0.984	0.984	1.068	1.093	1.116	1.168	1.205	1.381	1.429	1.509	1.472	1.439	1.500	1.283	1.299	1.336	1.497	1.656
	HK Elec	1.008	1.028	1.177	1.290	1.332	1.454	1.528	1.529	1.611	1.762	1.834	1.764	1.756	1.696	1.421	1.442	1.295	1.303	1.374	1.703	2.033
Large	CLP	0.618	0.629	0.619	0.620	0.620	0.702	0.703	0.714	0.756	0.843	0.889	0.807	0.921	0.912	0.912	0.945	1.003	1.022	1.055	1.215	1.374

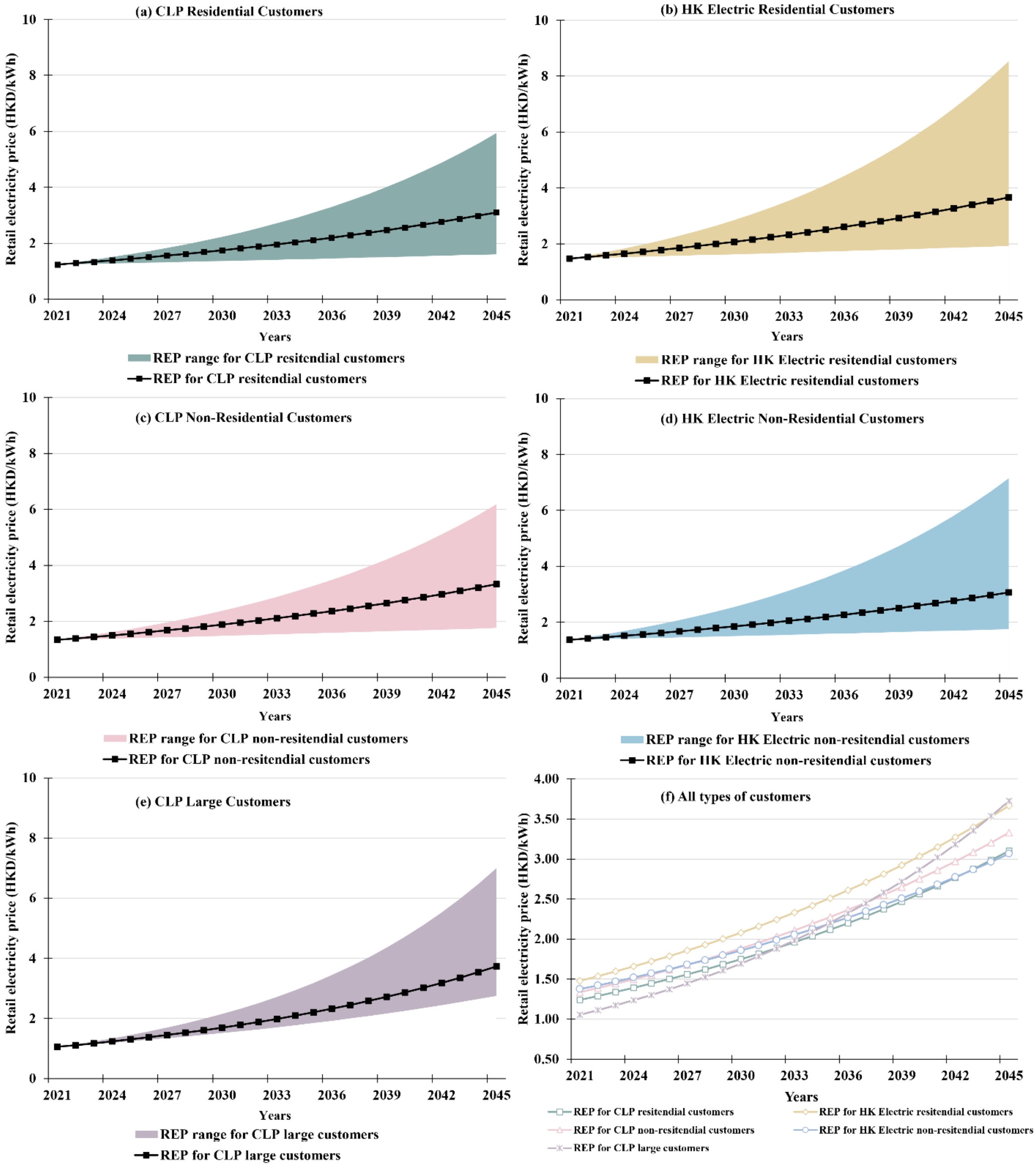


Figure 6.4 The estimated changes in the retail price of electricity in Hong Kong.

6.2.3 Financial Model Design

6.2.3.1 Financial Model

2.3.1.1 Project Cash Outflow (CO)

CO considers all expenses throughout the lifetime of a CS project, including system capital costs (SCC), financing costs (FO), and operation costs (OC). (i) SCC refers to costs incurred before the facility is occupied and includes upfront installation costs (UIC) and upfront administrative costs of PV systems. The upfront installation cost of PV systems encompasses the cost of PV module, inverter, other hardware (e.g., cable connection, steel support, monitor system), and soft costs and profits (e.g., labor costs, permitting, interconnection and inspection costs). According to Yang et al. (2020), the installation cost of Mono-Si PV system in Hong Kong is 29.2 HKD/W, which will be used as a reference point in this study. The upfront administrative cost comprises marketing and communications, customer acquisition setup, outreach setup, admin setup, and subscriber management costs of first year. The total upfront administrative cost for residential, non-residential, and large subscribers are 10.89%, 9.93%, and 5.37% of the combined soft cost and profit, respectively (IREAN, 2022). (ii) FO represents the costs of financing involved in borrowing money for the construction or purchase of assets for CSS projects, including debt, debt interest payment, and debt principal payment. The total amount of debt can vary across projects, but this study assumes it to be 50% of UIC as an illustration. The average interest rate in Hong Kong, according to the 2021 annual report of the Hong Kong Monetary Authority, is 5%, which will be utilized as the debt interest rate for this study. Green loans or sustainable loans in Hong Kong typically have terms of five years, with a discounted rate of 2.75%, as provided by the Hong Kong Monetary Authority.

(iii) OC is expenses related to daily operations, materials, and other necessary components utilized by a CSS project, which includes ongoing transactional costs, operations and maintenance costs, site/land lease payments, insurance, profit tax, and system removal costs. Ongoing transactional costs consist of yearly subscription acquisition costs for new customers covering outreach, sales, and sign-up transaction, and yearly subscription management costs for existing customers covering customer service and billing admin. According to Community Solar Business Case Tool (Elevate, 2017), yearly subscription acquisition costs and yearly subscription management costs account for 0.0549% and 0.443 % of UIC, respectively. Operations and maintenance cost amounts to 1% of UIC (An et al., 2022a). In this study, site/land lease payments are not considered, as CSS projects are assumed to be located on the accessible building rooftops of developers in Hong Kong due to limited land resources and high building density.

Insurance cost is the total property insurance premium, which accounts for 0.25% of UIC for middle scale PV systems (Vignesh et al., 2022). Profit tax refers to the tax imposed on profits generated by CSS projects. According to the Land Revenue Department of Hong Kong, tax exemptions do not apply to installers as they are usually classified as business sectors. The tax rate is 8.25% on assessable profits up to 2,000,000 HKD and 16.5% on any portion of assessable profits exceeding 2,000,000 HKD. System removal cost is the expense of removing the PV system at the end of system service, which is 5% of UIC (Ouyang & Lin, 2014). Thus, CO of CSS projects is expressed by Eq. (6.3). In this analysis, the year is t and the ending year is T, where t refers to the year after a CS project is developed, and T refers to the year when the system is at the end of its service life (i.e., 25 years).

$$CO_t = (SCC_t + \sum_t^T FO + \sum_t^T OC) \quad (6.3)$$

2.3.1.2 Project cash inflow (CI)

CI refers to the revenue throughout the lifetime of a CSS project, including subscriber payments (SP), incentive payments (IP), and system production benefits (SPB). (i) SP encompasses payments received from different types of subscribers, as outlined by Eq. (6.4). (ii) IP refers to revenue sourced from external organizations that support the CS project. In the case of a CSS project in Hong Kong, the Innovation and Technology Commission' "Innovation and Technology Fund for Better Living" is identified as an appropriate incentive since this particular fund aims to finance projects related to innovation and technology that enhance the daily lives of individuals and address the needs of specific community groups. The maximum funding support offered is either 90% of the project's total eligible costs or 5 million HKD, depending on which amount is lower. In addition, as of the year 2018/19, a full deduction is permitted during the basis period for expenses incurred in procuring environmental protection installations. This presents another incentive for CDS projects in Hong Kong. (iii) SPB is total system production benefits derived from a CDS project, including the salvage value of the system and revenue generated from unsubscribed energy. The salvage value of community solar in the U.S. in considered zero by Klein et al. (2021), which will be referred to in this study. Regarding unsubscribed energy, this study assumes that it can be sold to the grid at a price equivalent to the cost of electricity from traditional sources. The cost of traditional electricity generation in Hong Kong in 2021 was calculated to be 0.627 HKD/kWh based on the data on financials and electricity (i.e., generation cost, operation cost, fuel cost, and amount of electricity generation) published by HK Electric Corporate Information in 2011. It should be noted that the unit cost of electricity has increased over time, as utility companies have progressively shifted from coal-fired to gas-fired electricity production. As of 2021, the cost of traditional electricity was determined to be 0.688 HKD/kWh. Consequently, CI of a CSS project can be expressed by Eq. (6.6).

$$SP_t = \sum_t^T S_e^r * CSR_r + \sum_t^T S_e^n * CSR_n + \sum_t^T S_e^l * CSR_l \tag{6.4}$$

Where S_e^r, S_e^n, and S_e^l refer to total cumulative subscription electricity of residential, non-residential, and large subscribers (kWh), respectively. The total annual solar PV electricity generation (E) is calculated based on daily PV system electricity generation as expressed by Eq. (6.5). CSR_r, CSR_n, and CSR_l refer to CSRs for residential, non-residential, and large subscribers (HKD/kWh), respectively.

$$E = H * A * \gamma * PR \tag{6.5}$$

Where E is total annual solar PV electricity generation (kWh), H represents the average daily global radiation (MJ/m^2/day), A is the total area of solar panels (m^2), γ is the solar panel yield (%), and PR is the performance ratio. The average daily global radiation can be obtained from Hong Kong Observatory. Figure 6.5 illustrates the monthly solar power generation per unit installed capacity in this project. γ represents the amount of energy harvested from solar panels, which is influenced by external factors such as orientation, wind speed, shade, ambient temperature, and dust deposition. For a 305 W monocrystalline PV module with a unit solar panel area of 1.64 m^2, a γ of 18.7% has been considered based on research conducted by Yang et al. (2020), with the assumption that the solar PV system is installed with 14-22° tilt angle and south-oriented for the optimized efficiency (EMSD, 2019). PR quantifies the efficiency of energy output from the PV system, considering possible internal losses during the conversion of solar energy into electricity (i.e., inverter losses and cable losses). The default value of 0.75 is commonly used for PR.

$$CI_t = \sum_t^T (SP_t + SPB_t + IP_t) \tag{6.6}$$

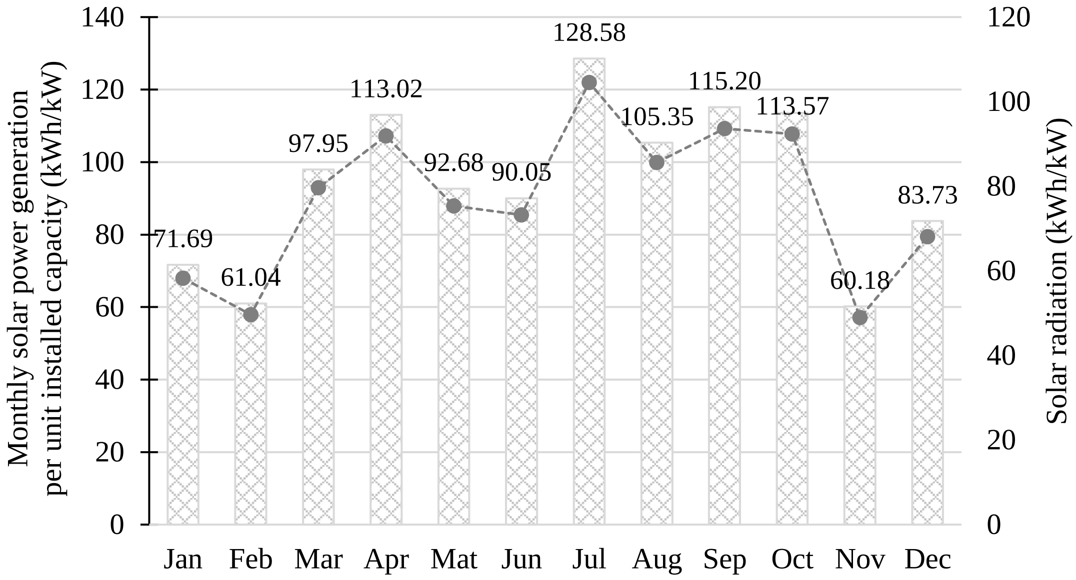


Figure 6.5 Monthly solar power generation per unit installed capacity for a CSS project in Hong Kong.

The specifications of the financial model and data used in this study are summarized in Table 6.5.

Table 6.5 The specifications of the financial model

Dimension	**Category**	**Sub-category**	**Data**
CO	SCC	UIC	29.2 HKD/W
		Upfront administrative cost	- Residential subscribers: 10.89% of soft cost and profit - Non-residential subscribers: 9.93% of soft cost and profit - Large subscribers: 5.37% of soft cost and profit
	FO	Debt	50% of UIC
		Debt interest payment	IPMT function with 5% interest rate
		Debt principal payment	PPMT function with 5% interest rate
	OC	Ongoing transactional cost	- Yearly subscription acquisition costs for new customers: 0.0549% of UIC per subscriber - Yearly subscription management costs

Dimension	Category	Sub-category	Data
			for existing customers: 0.443% of UIC per subscriber
		Operation and maintenance cost	1% of UIC
		Site lease payment	Zero
		System removal cost	5% of UIC
		Insurance cost	0.25% of UIC
		Profit tax	Refer to Eq. (5.5)
CI	SP	Total subscription of subscriber	- Residential subscribers: 500 kW - Non-residential subscribers: 250 kW - Large subscribers: 250 kW
		CSR	Objective function
	IP	Innovation and technology fund	90% of CO or 5 million HKD, whichever is less
		Expenditure on environmental protection facilities	2.8 HKD/W
	SPB	Unsubscribed energy payments	0.088 *Amount of unsubscribed energy (HKD)
		Salvage value of a CS project	Zero

6.2.3.2 Model Validation

Statistical metrics are commonly employed to test the fitness of the financial model. In the context of this study, where the calculations pertaining to CI and CO in the financial model bear significant association with the LCC and REP models, a streamlined testing approach is adopted. The validation hinges on gauging the accuracy and fitness of LCC and REP models by adopting root-mean-square error (RMSE), as depicted by Eq. (6.7). The RMSE is deemed a suitable indicator for evaluating the prediction accuracy in relative terms, thus minimizing the impact of substantial errors. A value below 25% is indicative of a good-fitting model with high prediction accuracy (An et al., 2022a; Kim et al., 2021). The statistical testing results (see Table 6.6) demonstrates the remarkable data fitness and high level of prediction accuracy exhibited by the LCC and REP models applied in this study.

$$RMSE = \frac{1}{\bar{a}_y} \sqrt{\frac{1}{n} \sum_{y=1}^{n} \left(a_y - \hat{a}_y\right)^2} \tag{6.7}$$

where $\hat{a}_y$ is the empirical value provided officially, a_y is the predicted value in this study, $\bar{a}_y$ is the mean of all predicted values, and n is the number of simulations.

Table 6.6 Model validation results

Models	**RMSE**
LCC model	4.317%
REP model of CLP residential customers	13.14%
REP model of CLP non-residential customers	12.06%
REP model of CLP large customers	9.57%
REP model of HK Electric residential customers	12.76%
REP model of HK Electric non-residential customers	12.92%

6.2.3.3 Financial Performance Evaluation

The results of the life cycle cost analysis-based financial model can be presented in various financial indices. In this study, financial performance evaluations for the developer are demonstrated as follows:

- PP reflects the length of time necessary for the cumulative after-tax cash flow to recoup the initial equity investment in the project, which can be calculated using Eq. (6.8):

$$\sum_{t=1}^{Y} \frac{CI_t - OC_t - FC_t}{(1+i)^t} = SCC_t \quad (6.8)$$

Where the minimum value of Y represents the expected value of PP and i is the discount rate (%), which is set as 2.75%, according to the average rate provided by the Hong Kong Monetary Authority (HKMA, 2021).

- Levelized profit of electricity (LPOE) serves as a metric for assessing the net profit of a CSS project (HKD/kWh) and can be determined by Eq. (6.9). It computes the ratio of discounted net benefit to discounted net power generation, where the discounted net benefit encompasses both discounted net incomes and net costs. LPOE ≥ 0 means this project is capable of achieving a net profit status for each unit electricity (Yan et al., 2019).

$$LPOE = \frac{\sum_{t=1}^{T} \frac{CI_t - CO_t}{(1+i)^t}}{\sum_{t=1}^{T} \frac{E\,(1-r)^{t-1}}{(1+i)^t}} \quad (6.9)$$

Where r is the degradation rate of the PV system (%).

Financial performance evaluation for subscribers used in this study is user-side grid parity indices (GPI), which assess the ability of distributed solar PV projects to achieve grid parity from the user or demand-side perspective (Yan et al., 2019). User-side grid parity is achieved when CSRs of CSS projects are equal to or lower than the purchasing price from the grid. GPI quantifies the ratio of CSRs of CSS projects to REP, as indicated by Eq. (6.10). If $GPI \leq 1$, the CSR is either equal to or lower than the local electricity purchasing cost, implying that the project has attained user-side grid parity.

$$GPI = CSR/REP \quad (6.10)$$

6.3 Results and Discussion

6.3.1 Results of Community Solar Rate under Scenarios A and B

Table 6.7 presents the CSRs determined for each type of subscriber under Scenario A. It is revealed that the CSRs for residential, non-residential, and large subscribers are 3.64 HKD/kWh, 3.63 HKD/kWh, and 3.55 HKD/kWh, respectively, when only a single subscriber type (i.e., 100% subscription rate for each type of subscribers) is involved in a CSS project under the current market which is assumed to commence in 2021. This disparity in CSRs arises from variations in upfront administrative costs and ongoing transaction costs. The higher upfront administrative costs for each residential subscriber contribute to a higher CSR, as these costs encompass marketing and communications, customer acquisition setup, outreach setup, admin setup, and subscriber management. Furthermore, the large number of residential subscribers increases ongoing transaction costs during the operation stage, as yearly subscription acquisition costs for new customers and yearly subscription management costs for existing customers are incurred, resulting in a higher CSR. Similarly, when multiple subscriber types are engaged in a CSS project under the current market, distinct CSRs for residential, non-residential, and large subscribers are determined to be 3.65 HKD/kWh, 3.63 HKD/kWh, and 3.54 HKD/kWh, respectively (see Table 6.7). Among different types of subscribers, large subscribers show the lowest CSR while residential subscribers show the highest CSR due to the difference in the distribution of costs across different subscriber types. A lower upfront administrative cost leads to a lower CSR, while a smaller number of subscribers results in a lower ongoing transaction cost and CSR since ongoing transaction cost is imposed on a per-subscriber basis and thus its total cost is affected by the total number of each subscriber type. Nevertheless, similar to the case involving only a single subscriber type, all determined CSRs are two to three times greater than REPs in Hong Kong, thereby signaling the infeasibility of CSS projects in terms of subscriber benefits within the current market context. Additionally, all CSRs are found higher than the current FiT rates in Hong Kong (i.e., 3 HKD/kWh for generating capacity more than 200 kW), enhancing the economic appeal of CSS projects for developers due to higher economic profits. However, the FiT rates have decreased over the past decade and will be expired in 2033. In such a case, the economic conflict between subscribers and developers necessitates the interest balance and a lower CSR to promote the implementation of CSS projects.

Therefore, this study calculated CSRs for each type of subscriber under Scenario B where a CSS project is assumed to commence in the future (after 2021). This allows to investigate the specific point at which the CSR equals to the REP, providing references for developers in appropriate investment time of a CSS project in a nascent market. As depicted in Figure 6.6, when only residential subscribers are involved in a CSS project, GPI referring to user-side grid parity can reach 1 by 2031 for HK Electric customers, while for all residential subscribers, it can be lower than 1 starting from 2032. This indicates that CSRs can be equal to REP for CLP customers by 2031, and for all residential subscribers by 2032. When only non-residential subscribers participate in a CSS project, CSRs can be lower than REP for all non-residential subscribers starting from 2031. Similarly, when only large subscribers are involved in a CSS project, CSRs can be lower than REP starting from 2032. Furthermore, Figure 6.6 (d) reveals that when multiple subscriber types are engaged in a CSS project, GPIs for different types of subscribers are various. GPIs $\leqslant 1$ for non-residential and large subscribers can be achieved by 2031. Starting from 2032, GPIs for all types of subscribers can be lower than 1, indicating CSRs are lower than the local electricity purchasing cost and the CSS project is considered to have reached user-side grid parity. Additionally, LPOE is consistently greater than 0, implying a CSS project reach net profit status of electricity for developer. Therefore, it can be concluded that a CSS project can be economically attractive to both subscribers and developers from 2032 onwards, further indicating the feasibility and practicality of CSS projects in the future market.

Except that a CSS project can be economically attractive to both subscribers and developers from 2032 onwards based on the results above, 2033 is also the year when the FiT scheme will be expired in Hong Kong. Year 2033 therefore can be regarded be a good start point for CSS projects. So, this study calculated the specific CSRs for each subscriber type assuming a CSS project commenced in 2033. In such a case, it is found that when only a single subscriber type is involved in a CSS project, the CSRs for residential, non-residential, and large subscribers are almost identical, with values of 1.59 HKD/kWh, 1.59 HKD/kWh, and 1.55 HKD/kWh, respectively. That all CSRs are lower than the REPs in Hong Kong indicates that all customers can be benefited from participating in a CSS project, highlighting the feasibility and attractiveness of CSS projects in Hong Kong in 2033. On the other hand, when multiple subscriber types are engaged in the CSS project, distinct CSRs are determined for residential, non-residential, and large subscribers, amounting to 1.65 HKD/kWh, 1.62 HKD/kWh, and 1.42 HKD/kWh, respectively. Similar to current market, large subscribers show the lowest CSR while residential subscribers show the highest CSR due to the difference in the distribution of costs across different subscriber types. The smallest number of large subscribers leads to the lowest burden of ongoing transaction costs for each subscriber compared to other two types, thereby brings a lower CSR.

The different results of CSRs in the current and future markets can be mainly explained by the following reasons. Firstly, the upfront installation cost of PV systems is declining worldwide because of technological advancements, economies of scale, and improved project management practices (IREAN, 2020). According to *Renewable Power Generation Costs* published by the International Renewable Energy Agency in 2022, the average installed cost for solar PV worldwide has plummeted by 82% from 4,808 US$/kW to 857 US$/kW between 2010 to 2021 (IREAN, 2022). Furthermore, it is widely recognized that Hong Kong's present solar PV market is still in its nascent stage of development, while the global solar PV industry has been evolving for several decades and has already attained a level of maturity (Mah et al., 2018). As the solar market in Hong Kong progresses and matures over time, the upfront installation cost of PV systems is expected to follow the same decreasing pattern observed globally, consequently resulting in reduced CSRs. Secondly, the REP in Hong Kong is projected to steadily increase, as evidenced by the annual growth rate of retail price for CLP and HK Electric over the past twenty years (CLP, 2022). Consequently, the disparity between CSRs and REPs gradually diminishes over time, eventually reaching a point where the CSR equals to the REP. Ultimately, the CSS project become economically attractive to both developers and subscribers.

Table 6.7 CSRs for subscribers in a CSS project under Scenario A.

Subscriber type	**CSRs (HKD/kWh)**		**REP (HKD/kWh)**	
	Single subscriber type	**Multiple subscriber types**	**CLP**	**HK Electric**
Residential	3.64	3.65	1.32	1.16
Non-residential	3.63	3.63	1.07	1.50
Large	3.55	3.54	1.35	N/A

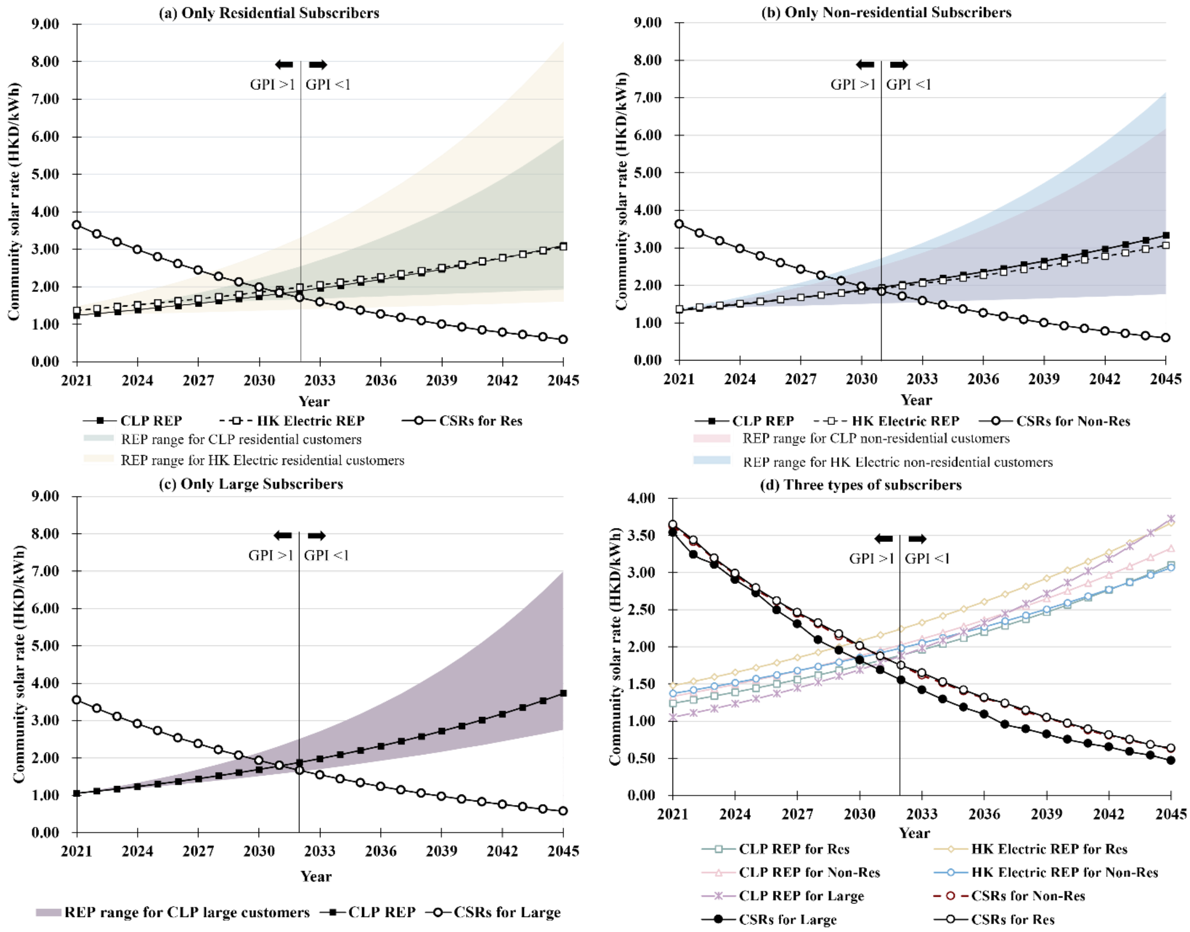


Figure 6.6 Changes of CSRs and REPs in the future under Scenario B.

6.3.2 Results of Subscription Rate under Scenario C

Figure 6.7 displays the changes of CSRs as subscription rate declines from 100% and the specific subscription rate at which the CSR equals the REP under Scenario C. Based on the analysis above, since 2033 is a good start point for CSS projects in Hong Kong, analysis under Scenario C assumed the CSS project commences from 2033. It can be seen that as subscription rate decreases, CSRs for all subscriber types steadily increase in a CSS project with only a single subscriber type. The reduced number of subscribers amplifies the financial burden on each subscriber in terms of total system capital costs and unsubscribed energy costs, leading to a higher CSR. To enhance the economic attractiveness of CSS projects, the implementation of a low-price strategy can stimulate subscription rates and achieve mutually beneficial outcomes for both subscribers and developers. Nonetheless, the specific subscription rates at which the CSR equals the REP vary among different subscriber types due to disparities in REPs. The lowest subscription rate for residential, non-residential, and large subscribers are 78.2%, 71.6%, and 75.2%, respectively. This finding implies that a CSS project with exclusively non-residential subscribers necessitates the lowest subscription rate due to its highest retail price level, making the implementation of such CSS projects more practicable. Conversely, a CSS project with only residential or large subscribers can achieve the target financial goals of developers with a relatively high subscription rate (i.e., more than 75%), thereby enhancing the challenges of CSS projects.

Similarly, as shown in Figure 6.7, the changes in CSRs exhibit inconsistency across subscriber types when multiple subscriber types are engaged in a CSS project, despite all CSRs increasing as subscription rate decreases. A lower subscription rate reduces the total number of subscribers, intensifies the cost burden on each subscriber, and ultimately raises the CSRs. The inclusion of more subscribers in a CSS project can lead to lower CSRs, thereby promoting the implementation of the project by considering the economic benefits of both developer and subscriber. However, it is important to note that the lowest subscription rate in this case is 80%, which is even higher than the rates observed in projects with a single subscriber type. This can likely be attributed to the maintenance and administrative costs associated with operating a CSS project. The inclusion of multiple subscriber types can increase operation costs because of frequent changes in customers through increasing yearly subscription acquisition costs for new customers and yearly subscription management costs for existing customers. Notably, achieving a subscription rate of 80% might still be a challenging goal in a new market. To promote the implementation of CSS projects in such markets, developers may need to compromise on benefits and are encouraged to seek support in the early stages to lower CSRs and attract more subscribers. Additionally, governments are also encouraged to provide relevant solar policies or financial support schemes to facilitate the adoption of CSS in the early stages.

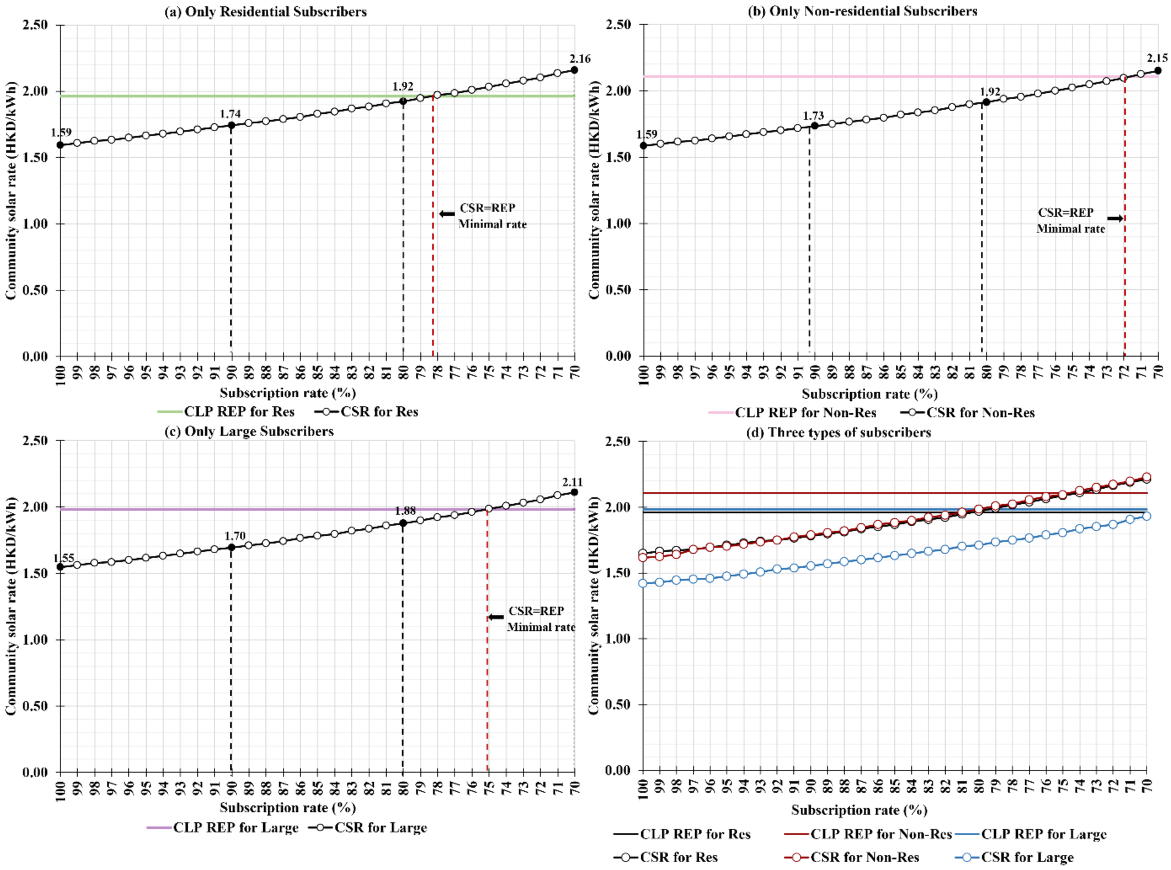


Figure 6.7 Changes in CSRs when subscription rates change in a CSS project under Scenario C.

6.3.3 Results of Sensitivity Analysis

Sensitivity analysis has been conducted to evaluate the influences of various factors on project cost and revenues in both current and future markets, allowing for a comparison of key variables under different market conditions. The sensitivity analysis considered factors with a 5% and 10% increase and decrease (i.e., -/+ 5% and -/+ 10%). The results for the current market are depicted in Figure 6.8, where the length of the bars symbolizes the degree of sensitivity, with longer bars indicating greater sensitivity. It can be observed from Figure

6.8 (a) and (b) that the upfront installation cost exhibits the highest degree of influence or sensitivity on project costs, followed by dept payment, operation and maintenance cost, and profit tax. A 5% increase in upfront installation cost and a 10% increase will lead to approximately a 2.50 HKD/W and 4.95 HKD/W increase in 25-year costs of the project, respectively. This implies that the significant impact that variations in upfront installation cost can have on the overall cost of a CSS project. Deceasing the upfront installation cost can have an important role in releasing the financial burden of developers and promoting the implementation of CSS projects. Conversely, in terms of revenue (see Figure 6.8 (c) and (d)), residential subscribers' payments emerge as the most sensitive variable, followed by non-residential and large subscribers' payments. A 5% decrease in residential subscribers' payments and a 10% decrease will result in approximately a 2.44 HKD/W and 4.87 HKD/W decrease in 25-year revenue of the project, respectively. This emphasizes the significant impact that changes in residential subscribers' payments can have on the revenue potential of a CSS project. These findings underscore the importance of carefully considering and managing the upfront installation cost and residential subscribers' payments structure in order to optimize the economic performance of CSS projects in Hong Kong. By doing so, stakeholders can effectively control project costs and maximize revenue streams, thereby enhancing the financial viability and sustainability of CSS projects.

Besides, Figure 6.9 represents the results of sensitivity analysis in the future market which assumes a CSS project to be commenced in 2033 based on the results in section 6.3.1. It can be found that sensitive variables are the same as in the current market, albeit with different levels of influence. A 5% increase in upfront installation cost and a 10% increase will lead to around a 1.17 HKD/W and 2.33 HKD/W increase in 25-year costs of the project in the future market, respectively. Similarly, a 5% decrease in residential subscribers' payments and a 10% decrease will lead to around a 1.10 HKD/W and 2.20 HKD/W decrease in 25-year revenue of the project, respectively. The lower upfront installation costs and CSRs determined in the future market contribute to the reduced impact of these factors on cost and revenue. However, despite the diminished impact, upfront installation cost and residential subscribers' payments remain the most sensitive variables in the future market and should receive increased attention to optimize the economic performance of CSS projects.

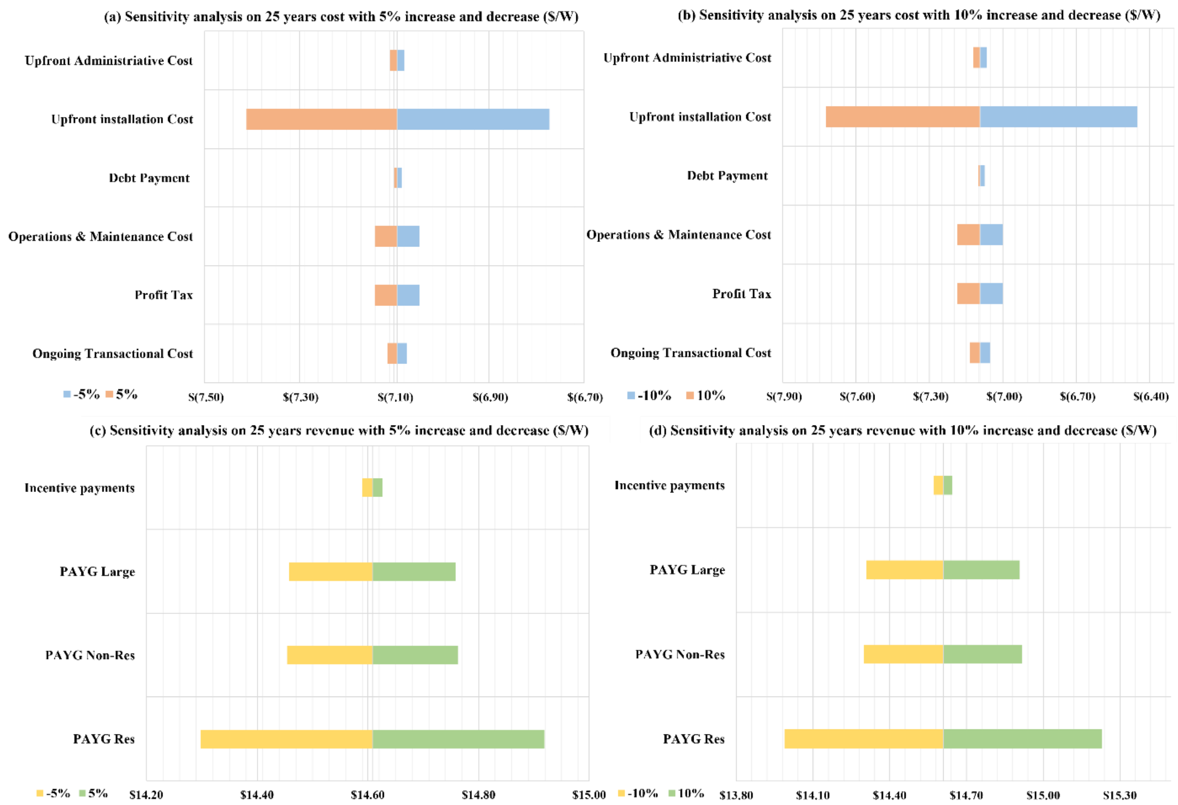


Figure 6.8 Sensitivity analysis on 25 years cost and revenue for current market.

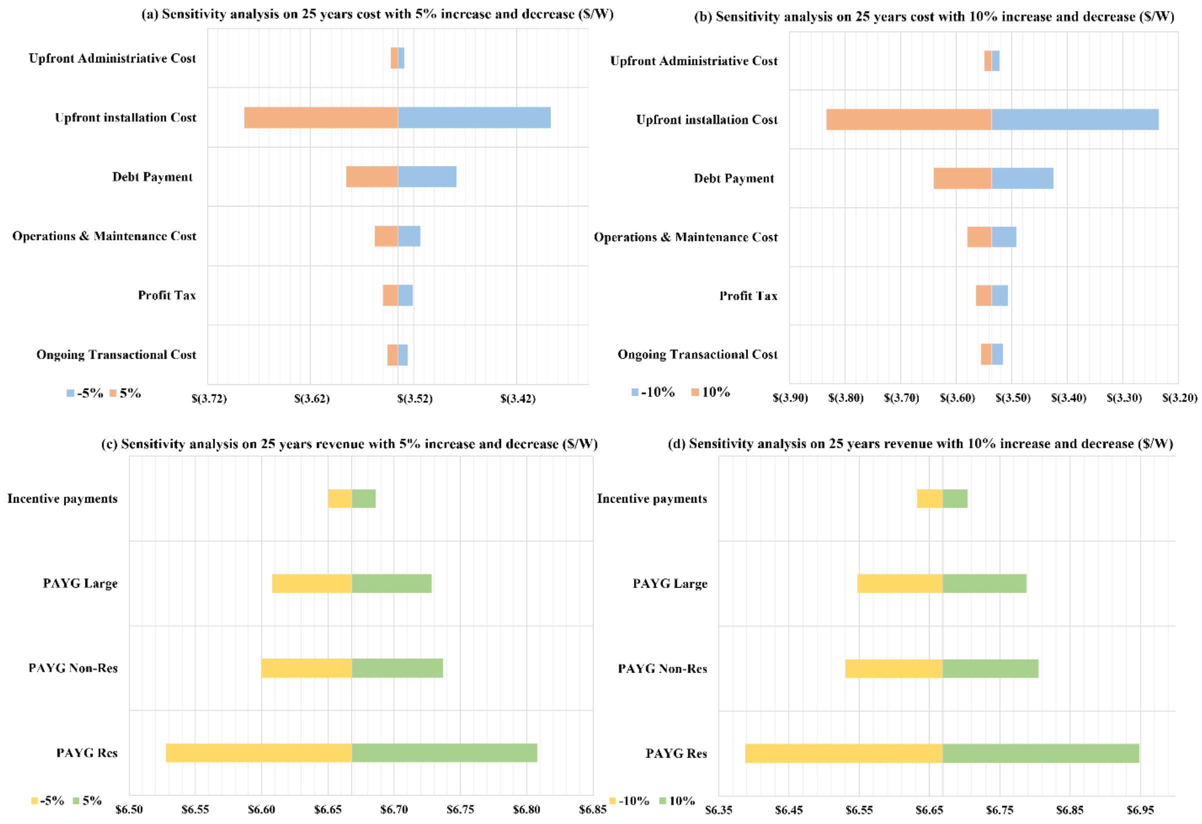


Figure 6.9 Sensitivity analysis on 25 years cost and revenue for future market.

6.4 Summary of the Chapter

This Chapter addresses the burgeoning interest in CSS projects as a response to climate change and energy transitions, focusing on the nascent market. Despite their popularity, the financial viability of CSS projects for both developers and customers remains uncertain. To address this gap, this study proposes a new business model tailored for CSS projects in nascent markets and develops a financial model utilizing a life cycle analysis approach, enabling a comprehensive analysis of the CSR and subscription rates of a CSS project under different conditions. The findings revealed that under current market conditions in Hong Kong, CSS projects are financially unviable, with CSRs for each type of subscriber being nearly two to three times higher than the REPs. Conversely, future market conditions suggest that CSRs could be lower than the REPs, thereby indicating the potential financial feasibility of CSS projects. Moreover, a minimum subscription rate of approximately 75% was identified as necessary to ensure mutual benefits for both developers and subscribers in the future market, thereby enhancing the practicability of CSS projects. In addition, sensitivity analysis reveals that upfront installation costs exhibits the highest degree of influence on project costs, while residential subscribers' payments emerge as the most sensitive variable affecting project revenue in both the current and future markets. These findings highlight the need to optimize the economic performance of CSS projects by paying closer attention to these critical factors.

The contribution of this study is fourfold. Firstly, this study proposes a new business model of CSS project in nascent markets (e.g., Hong Kong), serving as a reference and potential foundation for future research on community solar adoption in different countries. Secondly, this study developed a financial model tailored for CSS projects, which can be adopted and adjusted to serve as an effective analysis tool to analyze the techno-economic performance of CSS projects under various scenarios. Thirdly, this study provides a preliminary exploration of CSRs and subscription rates of CSS projects, which can provide insights into designing appropriate pricing and recruitment strategies to promote community solar adoption in the early stages. Lastly, by integrating current and future market analyses, the study provides guidance for the long-term economic development of CSS projects.

Chapter 7 Optimal Sites for Community Shared Solar Projects (Geographic suitability)

7.1 Introduction

Globally, numerous renewable energy projects have been initiated to combat climate change, reduce reliance on imported fossil fuels, and enhance energy security. The process of siting, which involves identifying land suitable for renewable energy projects, has become a critical decision in the project development due to its significantly impact on feasibility, efficiency, and environmental sustainability. Consequently, siting for various types of renewable energy has been extensively explored worldwide. By meticulously selecting suitable locations based on various considerations, developers can maximize the benefits of clean energy generation while addressing potential challenges and risks associated with project development. Within the renewable energy landscape, solar energy plays a pivotal role by offering a sustainable, versatile, and increasingly cost-effective solution for meeting energy needs. Effective site selection of solar energy projects is of importance to optimize energy production, maximize benefits, and enhance project performance by choosing sites with high solar irradiance levels and minimal shading from trees, buildings, or other obstructions, and considering local climate conditions and regulatory compliance. Previous studies have attempted to identify suitable sites for solar energy projects worldwide.

It is noteworthy that existing studies on solar siting have predominantly focused on rooftop solar, solar power plants or utility-scale solar projects (Sward et al., 2021; Yousefi et al., 2018), which can serve as references for the land siting of community shared solar projects (CSS projects). However, the need to optimize sites for CSS projects cannot be overlooked, as community solar offers distinct advantages that make them an important component of the solar energy landscape by providing accessibility to solar energy benefits for individuals without the constraints of PV system installations, and fostering local engagement and participation in renewable energy initiatives with community preferences. Moreover, the locations of CSS projects differ significantly from rooftop solar and utility-scale solar projects. Optimal geographic location of CSS projects can maximize project performance and minimize project risks in the project development (e.g., transition loss of several PV systems within a community). However, siting for CSS projects has been rarely explored in previous studies. In the few existing studies related to CSS projects, criteria that directly or indirectly affect economic payback are commonly used (Al Garni & Awasthi, 2017; Wanderer & Herle, 2013).

Although attempts to identify optimal sites for solar projects have been made in existing studies, research gaps still exist. Firstly, few studies on siting for solar projects pay attention to CSS projects. CSS projects offer distinct advantages in harnessing solar energy for individuals and require unique location conditions, indicating the need to optimize sites for CSS projects to maximize their overall performance. Secondly, the criteria for CSS projects siting lack exploration, especially in emerging solar markets. Existing studies on solar project siting in niche markets have focused purely on techno-economic factors. However, solar power may not be ‘zero-emissions’ or completely clean from a life-cycle perspective (Li et al., 2021), necessitating the incorporation of environmental criteria in solar siting. Additionally, since the desire for renewable energy does not always equate to support for specific project in specific locations (O’Neil, 2021), especially for CSS projects typically located within or nearby communities, social considerations need more attention in solar siting analysis. Therefore, comprehensive criteria for CSS projects siting requires to be explored. Thirdly, despite its popularity, the traditional MCDA approach is often criticized for factors such as imprecise and uncertain information resulting from ambiguity and uncertainty in expert judgment, and lack of consideration of the correlations among criteria associated with site evaluation. Fuzzy set theory can be integrated into AHP to allow for uncertainty (Bandaru et al., 2021). Additionally, many studies rely on a single method and may not provide comprehensive results, requiring the integration of multiple methods to provide more accurate and reliable results.

To address these research gaps, this study aims to introduces a novel approach to optimize site identification for CSS projects by incorporating technical, economic, social, physical, and environmental criteria and integrating GIS with different MCDA approaches (Boolean, Fuzzy-ANP, Fuzzy-VIKOR). The utilization of GIS for data processing and analysis enables the generation of thematic maps accurately identifying and prioritizing potential sits for CSS projects in this study. Boolean method is adopted to assign a weight for each exclusive criterion and determine the feasible sites for CSS projects by differentiating feasible areas from the infeasible ones. The fuzzy-ANP method can handle imprecise criteria and is used to evaluate and determine the suitable sites for CSS projects. By combing the results of Boolean and fuzzy-ANP analyses, highly suitable sites can be identified as alternatives for CSS project siting. Following this, Fuzzy-VIKOR can be adopted to rank the alternatives and determine the most suitable sites for a CSS project. The findings are expected to provide a comprehensive understanding and adequate support for site selection of CSS projects to promote distributed solar generation through community solar adoption. Moreover, the proposed innovative method can serve as a robust analytical tool for evaluating the optimal sites for CSS projects.

7.2 Methods and Materials

The optimal geographic location of CSS projects can significantly enhance the output of PV systems and minimize transition losses of several PV systems within a community. Therefore, this study aims to propose a GIS-MCDA-based site selection support framework considering multiple criteria for the placement of CSS projects, demonstrated through a case study in Hong Kong. To this end, a research design integrating objective definition and GIS-MCDA model is proposed, as illustrated in Figure 7.1.

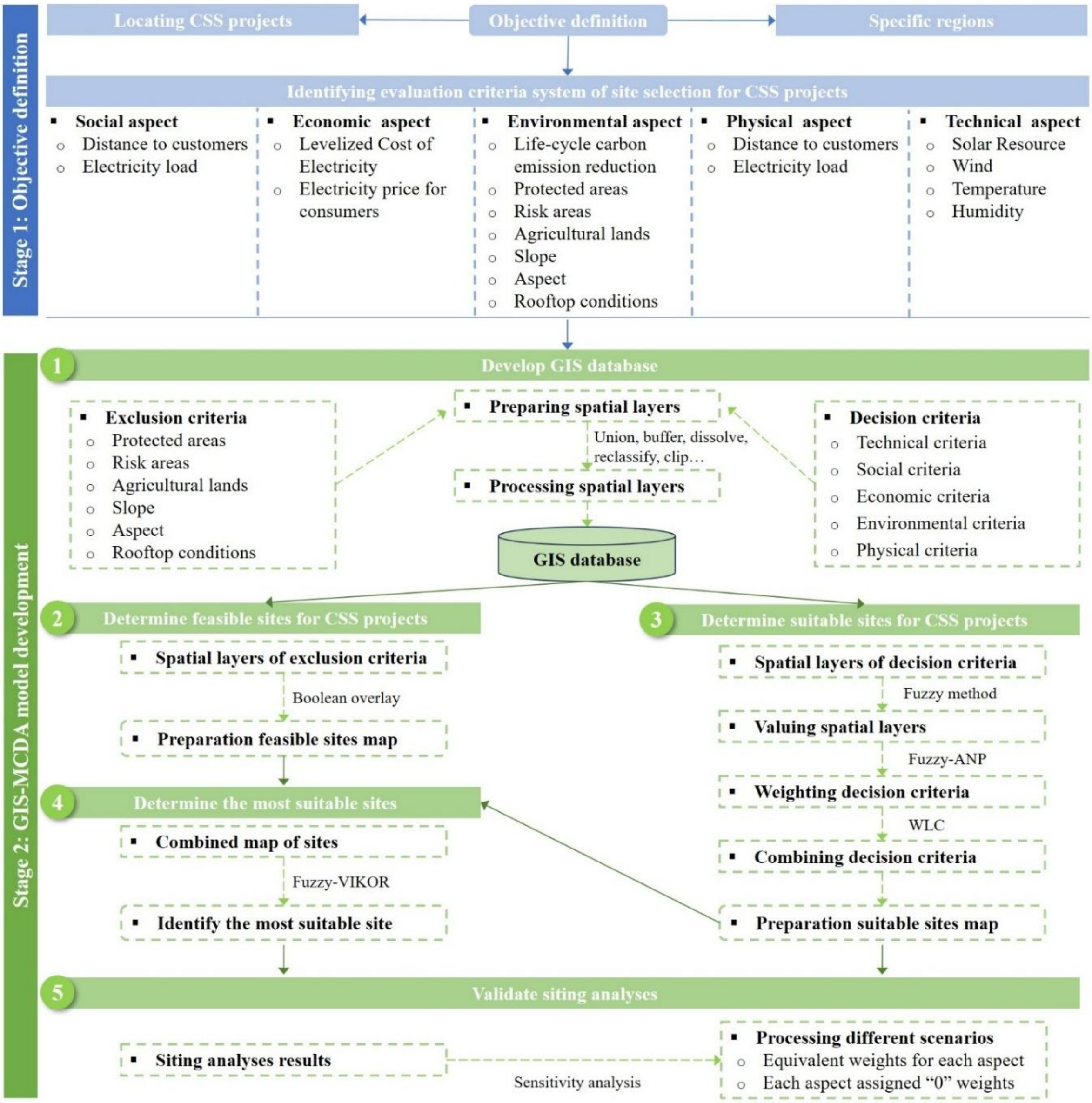


Figure 7.1 The research design of this chapter.

7.2.1 Stage one: Objective Definition

The primary objective of this study is to determine the optimal location for a CSS project. To achieve this, an evaluation criteria system for CSS project site selection is established based on various location-related parameters derived from existing research and previous experiences. These parameters encompass social, economic, environmental, physical and technical aspects. Hong Kong is selected as a case study area due to its high suitability for exploring the adoption of CSS projects.

Hong Kong, located in southern China, is a densely populated and energy-intensive city with high PV potential (EMSD, 2019), as depicted in Figure 7.2. To combat climate change and achieve carbon emission peak before 2030 and carbon neutrality before 2060, the Hong Kong government has announced both the Hong Kong Climate Action Plan 2030+ in 2017 (EEB, 2017) and the Hong Kong Climate Action Plan 2050 in 2021 (EEB, 2021). According to them, the Hong Kong government has put forward many green initiatives, including making some initial efforts in solar PV development with over 50 government-funded projects, primarily rooftop solar PV projects (EMSD, 2023). However, Hong Kong faces multiple challenges in installing and disseminating rooftop PV systems due to high upfront installation costs and limited rooftop access (Yang et al., 2020). In this context, CSS projects offer a promising solution to overcome some of these challenges and provide opportunities for low-income households and those with limited rooftop access to participate in and benefit from renewable energy generation (Brummer, 2018; Lo et al., 2018).

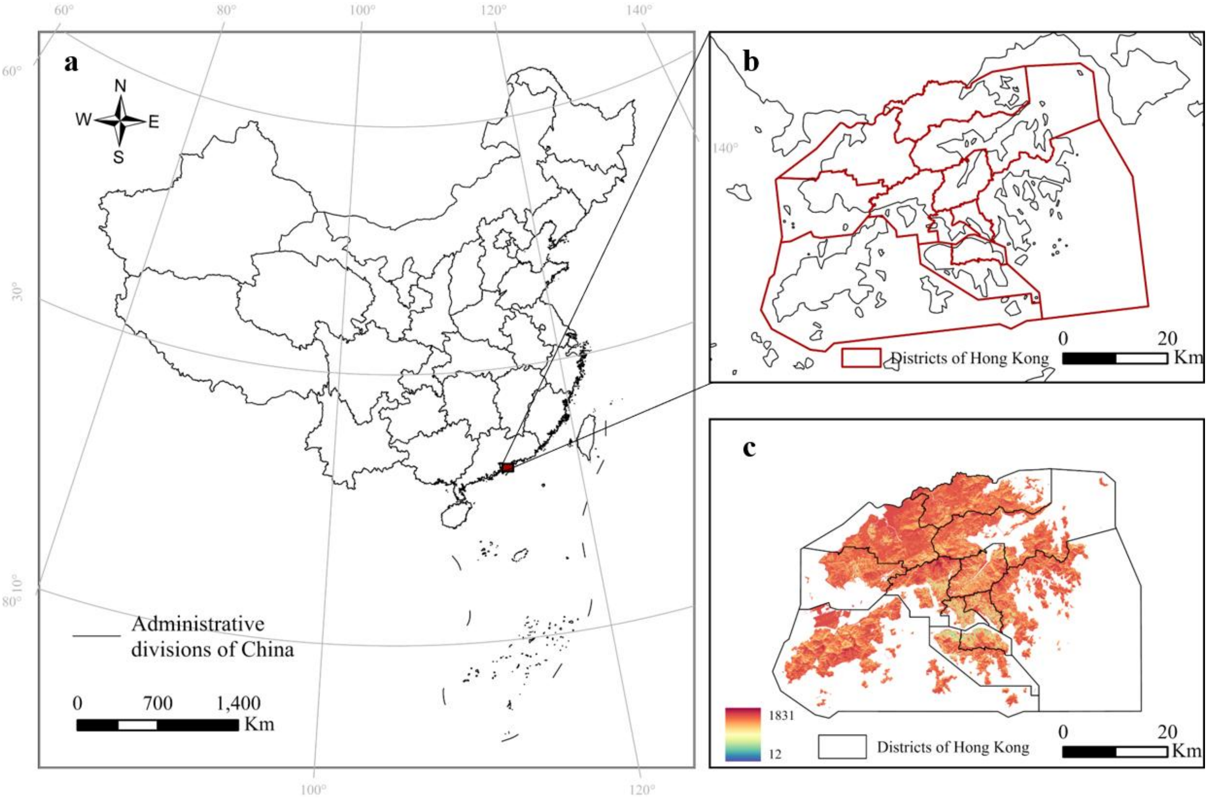


Figure 7.2 (a) The location and administrative divisions of China; (b) the location and administrative boundary of Hong Kong; (c) irradiation of Hong Kong (kWh/m^2/year).

7.2.2 Stage Two: GIS-MCDA Model Development

The GIS-MCDA model development involves five steps for siting selection of CSS projects, as shown in Figure 7.1.

7.2.2.1 Step One: Develop GIS Database

The first step involves developing a spatial database in GIS. Criteria identified through literature review and expert consultation are categorized into exclusion and decision criteria. All effective criteria are prepared as spatial map layers and converted to raster format as a GIS database in the ArcGIS software. The ArcGIS software is utilized to store, organize, and manage spatial data by using its information analysis and processing techniques, including statistical analysis, classification, overlay, union, buffer, dissolve, reclassify, clip, etc. The

ArcGIS software is also utilized to pre-process the spatial data for further analysis by employing Spatial Analyst tool (e.g., distance accumulation and raster calculator), Data Management tool (e.g., calculate field and mosaic to new raster), Geostatistical Analyst tool (e.g., ordinary kriging), etc.

- Exclusion criteria are used to identify and eliminate restricted areas within the region, which are unsuitable for CSS project construction due to local, national, and international regulations. These criteria relate to location type, location classification, communication lines, and infrastructure, such as topography, hydrology, heritage and protected areas. On the other hand, restricted areas also include those with unsuitable conditions for CSS project construction, the exclusion criteria of which can be related to rooftop type, slope, aspect, etc. In total, six exclusion criteria are considered in this study, including protected areas (e.g., seas, wetlands, open space) (Moradi et al., 2020), risk areas (e.g., rocky store, wildfire zones) (Kocabaldır & Yücel, 2023), agricultural lands (Kocabaldır & Yücel, 2023), facilities (e.g., roads, transport facilities) (Heo et al., 2021; Sánchez-Lozano et al., 2013), areas with slopes greater than 30% (Moradi et al., 2020), and field orientation (Sánchez-Lozano et al., 2013). Table 7.1 summarizes the exclusion criteria and their data sources.
- Decision criteria evaluate the capacity degree and rank the suitability level of lands. The location of a CSS project can not only directly impact its feasibility and efficiency, but also influence the social and environmental sustainability (Sánchez-Lozano et al., 2013). Therefore, decision criteria considered in this study include technical (C1), economic (C2), physical (C3), social (C4), and environmental (C5) aspects.

  Technical aspect includes solar resource (C11), slope (C12), and temperature (C13). C11 measures annual total solar irradiation, evaluating the intensity of sunshine for a candidate site and affecting PV system performance (Coruhlu et al., 2022; Pojadas & Abundo, 2022). Higher solar irradiation results in more electricity production by a CSS project. Methods for calculating solar irradiance in existing research include numerical estimation (Wang et al., 2016), solar map generation via interpolation (Alami Merrouni et al., 2016), Area Solar Radiation tool in the ArcGIS software (Alami Merrouni et al., 2016), and satellite image analysis (Pillot et al., 2015). This study employs the Digital Surface Model (DSM) data and Digital Terrain Model (DTM) data with a high spatial resolution of 0.5 m to generate the solar irradiation map of Hong Kong in raster format by adopting the Area Solar Radiation tool in the ArcGIS software, which considers both building and terrain shadows. DSM and DTM data are generated by the airborne Light Detection and Ranging (LiDAR) point cloud data covering entire Hong Kong territory and are acquired by the Civil Engineering and Developing Department (CEDD) of Hong Kong. C12 measures the percentage of land slope, the presence of which highly affects the project feasibility and investment costs (Coruhlu et al., 2022). There is no unified threshold for slope in existing literature, with many slope thresholds are present, such as 3% (Domínguez Bravo et al., 2007) and 5% (Charabi & Gastli, 2011). The slope map in this study was calculated from DTM. C13 measures ambient temperatures of sites, with high temperature (> 30 ℃) diminishing PV cell and system performance on electricity production (Günen, 2021), affecting module lifetime and durability (Alami Merrouni et al., 2018). Lower average annual temperatures increase suitability. Annual average temperature data obtained from common spatial data infrastructure (CSDI) of Hong Kong are used to create a spatial distribution map by utilizing a spatial interpolation technology (i.e. the ordinary Kriging method) in the ArcGIS software.

Economic aspects include Levelized Cost of Electricity (LCOE) (C21) and differences between retail electricity price and LCOE (C22). C21measures the net present value of average cost per energy unit (HKD/kWh) over a CSS project's lifecycle. It is commonly used for cost comparisons among different power generation technologies and is important to investigate the attractiveness of a CSS project from the perspectives of developer (Awad and Gül (2018) Deutsch and Berényi (2020)). The LCOE highly affects the price of PV-generated electricity, which can be regarded as a benchmark value to effectively respond to a CSS project. Lower LCOE increases the attractiveness of a CSS project. Favorable LCOE of a CSS project in a certain region should not exceed local retail tariffs of traditional electricity (e.g., fossil fuels), indicating PV system investment profitability (Zhang, Lee, & Huang, 2023). LCOE is calculated by Eq. (7.1). C22 measures the differences between retail electricity price and LCOE, unraveling the attractiveness of a CSS project from the perspectives of both the developer and customers. Electricity prices for various types of customers in different regions in Hong Kong are different. Hongkong Electric Company, Limited (HK Electric) supplies electricity to Hong Kong and Lamma islands, while all electricity in the rest of Hong Kong are supplied by CLP Power Hong Kong Limited (CLP) (EMSD, 2018). Therefore, the greater the difference between retail electricity price and LCOE is, the higher the attractiveness of a CSS project for both developers and customers will be.

$$LCOE = \frac{\sum_{t=1}^{T} \frac{CC_t + FC_t + OC_t}{(1+i)^t}}{\sum_{t=1}^{T} \frac{G_e\,(1-r)^{t-1}}{(1+i)^t}} \tag{7.1}$$

Where CC_t refers to unit capital costs of CSS projects (HKD/kW), which is 29.2HKD/W; FC_t refers to unit financing costs of CSS projects (HKD/kW); OC_t

refers to the unit operation costs of CSS projects (HKD/kW); i is the discount rate (%) and is set as 2.75%, according to the average rate provided by the Hong Kong Monetary Authority (HKMA, 2021); G_e refers to unit electricity generation of CSS projects (kWh/kW), which can be calculated by Eq. (7.2). r is the degradation rate of the PV system (%) and is set as 0.5% based on a median degradation rate published by NREL (NERL, 2018).

$$G_e = H * A * \gamma * PR \tag{7.2}$$

Where H is the annual solar irradiation (kWh/m^2), data on which is obtained from C11. A is solar panel area (m^2), which is taken from a 305 W Mono-Si PV module with a unit area of 1.64 m^2 (Yang et al., 2020); γ is the solar panel yield (%), which is taken as 21.6% based on the current average efficiency of crystalline silicon PV systems (Simon et al., 2024). PR is the performance ratio, measuring the efficiency of energy output, which is taken as 0.83 based on the current typical one (Simon et al., 2024).

Physical aspects include distance to main roads (C31) and land types (C32). C31 measures the distance to main roads, which is highly related to equipment transportation cost reduction and ease of access to CSS projects for installation and maintenances (Alami Merrouni et al., 2018; Colak et al., 2020). Shorter distance to main roads increases the suitability of CSS projects. This study obtained the Road Centerline data from CSDI provided by Lands Department (LD) of Hong Kong (CSDI, 2025) and generated the spatial distance map via the Euclidean Distance technology in the ArcGIS Software. C32 measures coverage area of vacant land and building rooftops, with more available area increasing the suitability of CSS projects. Vacant land is extracted from the Land Utilization Map (LUM) of Hong Kong presenting broad land use patterns for the entire territory of Hong Kong, which is prepared annually by the Hong Kong Planning Department (PD). Building rooftops are extracted from a polygon map provided by LD (CSDI, 2025) showing the permanent buildings or structures, including the building footprint and attributes (e.g., building type, building name, building height).

Social aspects include distance to customers (C41) and electricity load (C42). C41 highly influences ease of electricity supply to customers and the reduction of transmission losses (Akinci & Özalp, 2022). Shorter distance increases suitability of CSS projects. This study uses the polygon map and generates its spatial distance map through the Euclidean Distance technology in the ArcGIS Software. C42 impacts customer acquisition potential and CSS project feasibility (Beck et al., 2020; Mah et al., 2018; Thakur & Wilson, 2022). High electricity load increases the suitability of CSS projects. The energy end-use data showing the unit electricity consumption (kWh/m^2) of various types of building are provided by the Electrical and Mechanical Services Department (EMSD) of Hong Kong (EMSD, 2023), which is used to calculate electricity load of each building based on building type, footprint, and stores or heights.

Environmental aspects include life-cycle carbon emission (C51) and emission reduction compared to traditional electricity (C52), assessing the environmental impact of CSS projects. According to (Deveci et al., 2021), fossil fuel-based power plants can generate 504 g/kWh carbon emissions, while solar PV projects generate 99 g/kWh. Therefore, more electricity from solar PV projects enhances environmental sustainability. Life-cycle carbon emission and emission reduction in this study are calculated by Eq. (7.3) and Eq. (7.4), respectively.

$$\mathrm{CE} = \mathrm{CI}_{pv} * G_e * Y \tag{7.3}$$

Where CE is the carbon emission of CSS projects (g); CI_{pv} is the average carbon intensity of solar PV projects (g/kWh); Y is the lifetime of CSS projects (i.e., 25 years).

$$\mathrm{ER} = (CI_f - \mathrm{CI}_{pv}) * L_e * Y \tag{7.4}$$

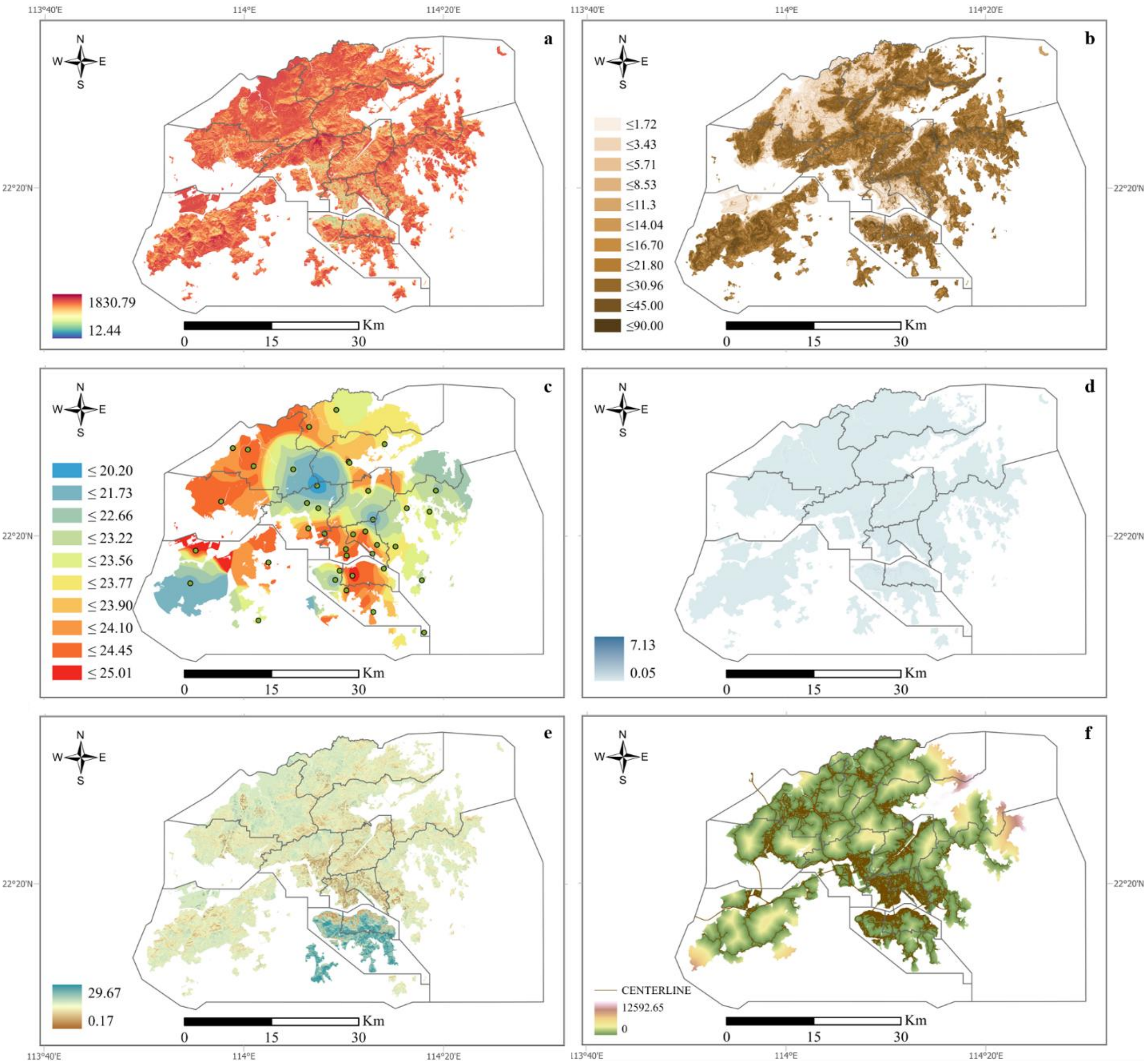
Where ER is the carbon emission reduction of CSS projects (g/kWh); CI_f is the average carbon intensity of fossil fuel-based power plants (g/kWh); L_e represents the expected energy load (kWh). Table 7.2 summarizes the decision criteria with their measures and data sources. Figure 7.3 displays the spatial layers of each decision criterion.

Table 7.1 Exclusion criteria for CSS projects

Criteria	**Data source**
Protected areas: sea, open space and recreation, critical environmental areas, wetlands, ...	Raster Grids on Land Utilization
Risk areas: earthquake prone areas, dust-storm prone areas, flood zones, wildfire zones, rocky store, …	Raster Grids on Land Utilization
Agricultural lands	Raster Grids on Land Utilization
Facilities: roads and transport facilities, utilities, Others	Raster Grids on Land Utilization
Slope > 30%	Digital surface model
Aspect: north, northeast, and northwest	Digital surface model

Table 7.2 Decision criteria for CSS projects

Criteria	Sub-criteria	Measurement	Influence of the criteria	Data source
Technical	Solar Resource	Solar irradiation (kWh/m2/year)	Increasing the intake rate of solar energy	DSM
	Slope	Percentage of land slope (%)	Influencing the construction of PV systems	DSM
	Temperature	Average temperature (℃)	Influencing the performance of a PV collector	Common spatial data infrastructure
Economic	Electricity cost for developers	LCOE (HKD/kWh)	Interest on PV adoption of developers	DSM, (HKMA, 2021; Simon et al., 2024)
	Electricity price for consumers	REP/LCOE	Interest on PV adoption of customers	DSM, (CLP, 2023; EMSD, 2018; HK Electric Company, 2023)
Physical	Distance to main roads	Total distance to each road (km)	Ease of access to location and reduction of equipment transportation costs	Common spatial data infrastructure
	Land type	The coverage area of vacant land and different types of buildings	Ease of access to potential installation location	PD
Social	Distance to customers	Total distance to each building (km)	Ease of access to CSS project	Common spatial data infrastructure
	Electricity load	Total electricity load within boundary (kWh)	Influence of subscription acquisition	EMSD, Census and statistic department of Hong Kong, Common spatial data infrastructure
Environmental	Life-cycle carbon emission	Average carbon intensity (g/kWh) × Expected energy yield (kWh/year) × Lifetime of the system	Influence of developers' PV adoption	(Bandaru et al., 2021; Deveci et al., 2021; Simon et al., 2024), DSM
	life-cycle carbon emission reduction	Average grid carbon reduction (g/kWh) × Expected energy load (kWh/year) × Lifetime of the system	Influence of customers' PV adoption	(Bandaru et al., 2021; Deveci et al., 2021), EMSD, Census and statistic department of Hong Kong, Common spatial data infrastructure


113°40'E
114°E
114°20'E
22°20'N
a
1830.79
12.44
b
≤1.72
≤3.43
≤5.71
≤8.53
≤11.3
≤14.04
≤16.70
≤21.80
≤30.96
≤45.00
≤90.00
c
≤ 20.20
≤ 21.73
≤ 22.66
≤ 23.22
≤ 23.56
≤ 23.77
≤ 23.90
≤ 24.10
≤ 24.45
≤ 25.01
d
7.13
0.05
e
29.67
0.17
f
CENTERLINE
12592.65
0
Km
0
15
30

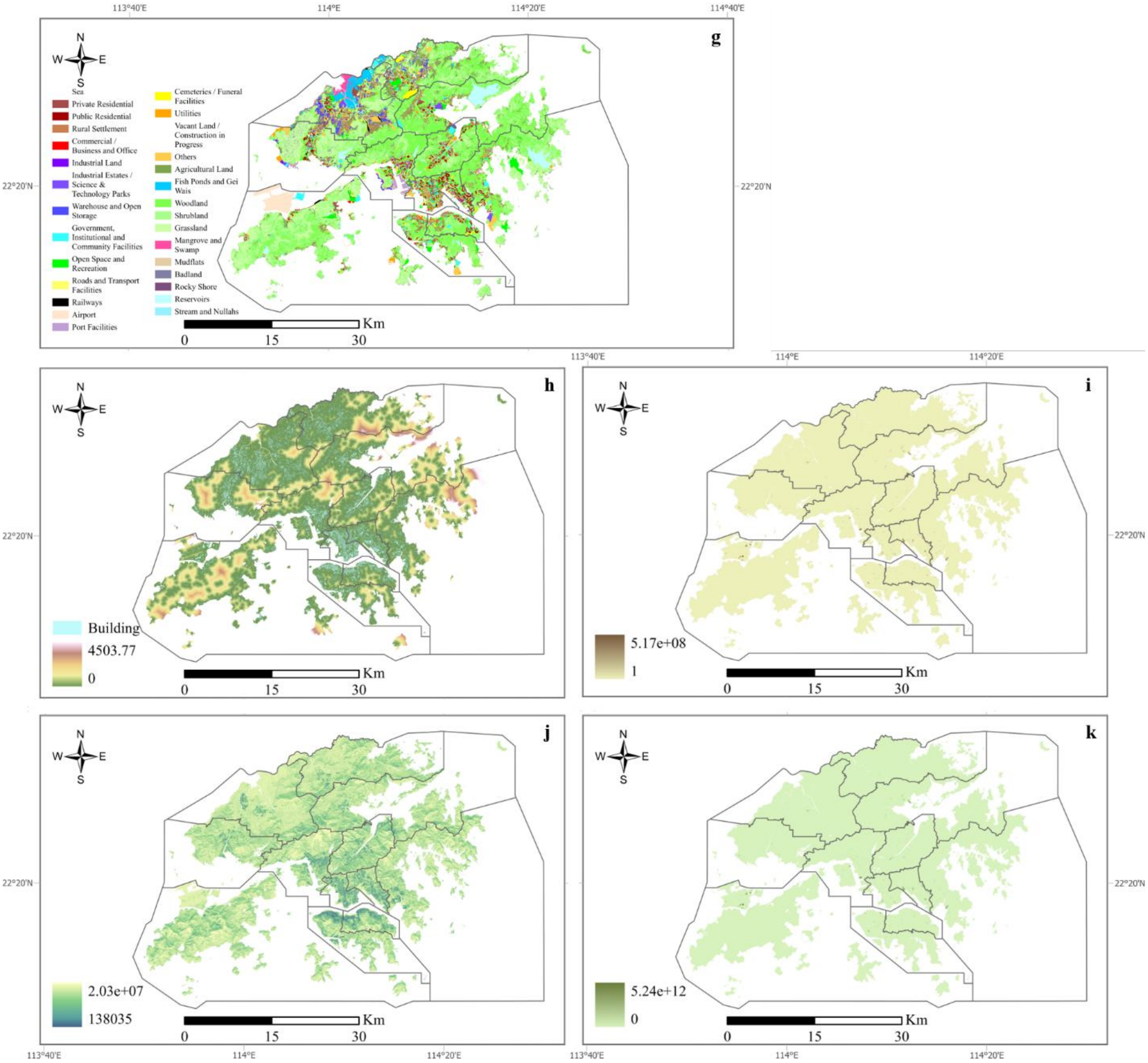


Figure 7.3 The spatial layer of (a) solar irradiation (kWh/m^2/year) , (b) slope (%), (c) temperature (℃), (d) LCOE (HKD/kWh), (e) electricity price (/), (f) distance to roads (km), (g) land type (types), (h) distance to customers (km), (i) energy load (kWh), (j) carbon emission (g), (k) carbon emission reduction (g).

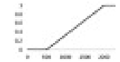
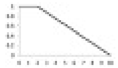
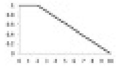
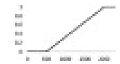
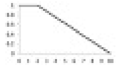
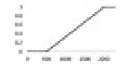
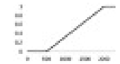
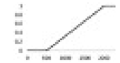
7.2.2.2 Step Two: Determine Feasible Area for CSS Projects

The second step involves determining feasible areas for CSS projects using exclusion criteria and the Boolean overlay method, with the aim of identifying potential sites for solar projects within a region and supporting CSS project localization decisions. In this step, the Boolean method is adopted to assign a weight of zero (proper) or one (improper) to each exclusion criterion listed in Table 7.1. After this, the obtained spatial maps for each weighted criterion will be overlaid in the ArcGIS software using the OR operator of the Boolean logic to differentiate feasible areas from infeasible ones. The final improper potential areas and feasible areas considering constraints are illustrated by layers created by the ArcGIS software.

7.2.2.3 Step Three: Evaluate Suitable Areas for CSS Projects

The third step evaluates suitable areas for CSS projects by classifying areas according to their suitability to accommodate CSS projects using fuzzy-ANP method. To achieve it, (1) this step firstly valuate decision criteria layers in the ArcGIS software, considering criteria's influence on plot carrying capacity. Since suitability of a location for CSS projects cannot be simply represented by binary values (0 or 1), the fuzzy method is adopted to value the spatial layer of each decision criterion by utilizing fuzzy membership functions and scaling the value of each decision criteria to the interval [0, 1] for the acquisition of fuzzy criteria. Given that the degree of membership for all pixels on a map, as determined by a function, varies for each decision criterion, it is necessary to adopt different functions in this study. For certain factors, such as the distance to main roads, a shorter distance corresponds to a higher score. Conversely, in cases such as the distance to customers, the score decreases if the buffer extends beyond the maximum allowable distance. It is worth noting that four commonly used types of fuzzy membership functions are adopted in this study, namely, linear increasing function, linear decreasing function, triangular function, and trapezoidal function (Davtalab & Alesheikh, 2018; Hosseini et al., 2021; Taha & Rostam, 2011), as shown in Table 7.3. Based on it, raster layers of all decision criteria are fed into the ArcGIS software and the proper fuzzy membership function are chosen for each of them for evaluation.

Table 7.3 Fuzzy functions and weights for decision criteria.

Criteria	Sub-criteria	Weight	Membership function	Function parameters				Chart type
				a	b	c	d	
Technical	Solar radiation	0.139	Linear Increasing	12.44 kWh/m^2	1830.79 kWh/m^2			
	Slope	0.059	Linear Deceasing	3%	10%			
	Temperature	0.042	Triangular	-5 ℃	0 ℃	25 ℃		
Economic	Electricity cost for developers	0.159	Linear Deceasing	0	1.22 HKD/kWh			
	Electricity price for consumers	0.116	Linear Increasing	100 %	3000 %			
Physical	Distance to main roads	0.060	Trapezoidal	1,000 m	3,000 m	5,000 m	10,000 m	
	Land types	0.045	Trapezoidal	Rural settlements	Residential and commercial	Vacant Land	others	
Social	Distance to customers	0.048	Linear Deceasing	0	1,500m			
	Electricity load	0.254	Linear Increasing	80 kWh/ year	300,000 kWh/ year			
Environmental	Life-cycle carbon emission	0.040	Linear Increasing	5,000g	800,000g			
	Life-cycle carbon emission reduction	0.038	Linear Increasing	800,000g	$3*10^{\wedge 9}$ g			

After this, (2) this study assigns weights to each criterion to determine its importance in the final decision-making process. Higher weights indicate greater importance (Davtalab & Alesheikh, 2018). Changes in weight values affect final decisions, making weight assignment method choice crucial. AHP has been broadly adopted by researchers to obtain factor weights and determine their relative importance in the assessing process (Alami Merrouni et al., 2018; Arán Carrión et al., 2008; Sánchez-Lozano et al., 2013). However, AHP cannot explain the correlation between different criteria. ANP, a general form of AHP, first introduced by Saaty (1986) in 1996, considers various factors affecting final decisions and their correlations. Given potential interrelationships between criteria levels, the ANP method is employed in this study. ANP ranks and analyzes decision criteria relative to one another based on their importance at various levels when assessing suitable areas. This process incorporates the opinions of 30 experts in solar energy, investment, and spatial information engineering. Given the challenges associated with providing accurate numerical estimates and human judgment regarding the priority of different criteria, the combination of fuzzy set theory and ANP is utilized to manage ambiguity in human assessments and evaluate suitable locations for CSS project locations (Nadizadeh Shorabeh et al., 2021). Results are expected to indicate interactions and derived priority weights of decision criteria, with weights range from 0 to 1 for each variable and sum to 1 (Nadizadeh Shorabeh et al., 2021). Specific steps and calculations of fuzzy-ANP are described below. Final decision criteria weights are illustrated in Table 7.3.

Step 1: Network Structure Construction

To develop a hierarchical network model that captures both intra-level and inter-level dependencies among criteria and alternatives. The model should explicitly represent feedback relationships between clusters, interdependencies among elements within clusters, and directional influence paths. Therefore, this study develops a hierarchical network model in the Super Decisions Software based on the decision criteria, as shown in Figure 7.4.

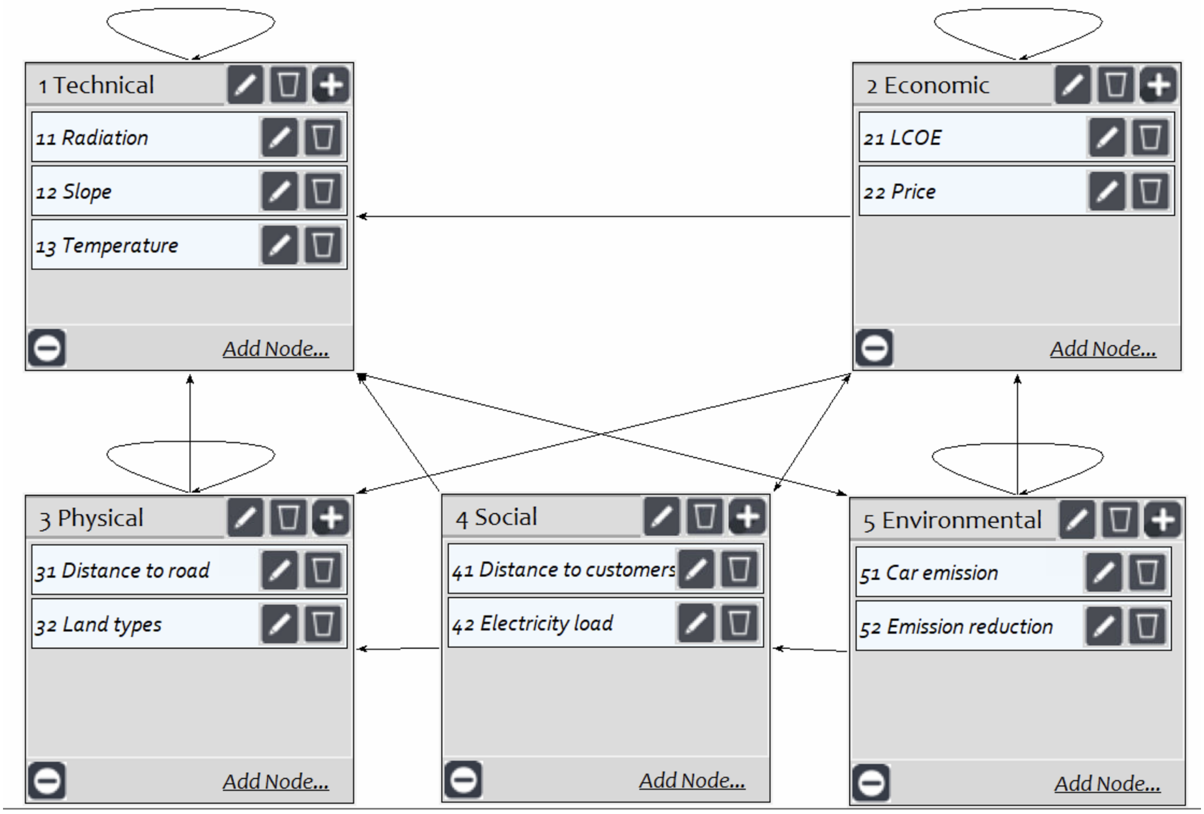


Figure 7.4 The hierarchical network model.

Step 2: Pairwise Comparison and Judgment Matrices

To collect experts' opinions on pairwise comparisons using triangular fuzzy numbers (TFNs) $\tilde{a}_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$ for each comparison i vs. j. The TFN scale adapted in this study is shown in Table 7.4. This study incorporates expert judgments from 30 domain specialists in energy, renewable energy, and solar energy through questionnaires, with 20 staff and project manager of solar PV projects in Hong Kong, 2 founders of solar PV projects, and 8 researchers from universities in Hong Kong. Judgments from these experts are combined using the geometric mean through Eq. (7.5).

$$\tilde{a}_{ij}^{agg} = \left(\prod_{k=1}^{K} l_{ij}^{k}\right)^{1/K}, \left(\prod_{k=1}^{K} m_{ij}^{k}\right)^{1/K}, \left(\prod_{k=1}^{K} m_{ij}^{k}\right)^{1/K} \quad (7.5)$$

Where $\tilde{a}_{ij}^{agg}$ is the aggregation value of all judgments from experts; K is the total number of experts.

Table 7.4 The TFN scale of fuzzy-ANP.

Linguistic term	**TFN (l, m, u)**
Equally important	(1, 1, 1)
Weakly More Important	(1, 1.5, 2)
Moderately More Important	(1.5, 2, 2.5)
Strongly More Important	(2, 2.5, 3)
Absolutely Important	(2.5, 3, 3.5)

Step 3: Defuzzification to Crisp Values

The TFN values need to be transferred from fuzzification to Crisp values (a_{ij}^{crisp}) by using weighted center of area (COA) method, which adopts Eq. (7.6).

$$a_{ij}^{crisp} = \frac{l_{ij} + 2m_{ij} + u_{ij}}{4} \quad (7.6)$$

After this, the consistency needs to be checked using Consistency ratios (CR), the value of which should be maintained below 0.1 for all matrices. CR can be calculated by Eq. (7.7).

$$\mathrm{CR} = \frac{(\alpha_{max} - n)/(n-1)}{RI} \quad (7.7)$$

Where α_{max} is largest eigenvalue of the pairwise comparison matrix; n is the order of matrix; RI is the Random Index, which is shown in Table 7.5.

Table 7.5 The Random Index of fuzzy-ANP.

Matrix order (n)	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 4: Super Decisions Workflow

To conduct ANP analysis in the Super Decisions Software based on two steps. Firstly, enter defuzzied crisp values into Super Decisions Software. Secondly, generate unweighted super matrix, weighted super matrix, and the limit super matrix. Based on the limit super matrix, the final weights of each criterion can be extracted.

According to the conceptual model, the criteria were compared using Super Decision software to do the calculations of ANP. The Super Decision software was used to create the corresponding super matrix using pairwise comparisons. The results of ANP method are shown in Tables 7.6 to 7.8.

Table 7.6 The unweighted super matrix

Main Network: 1 decision criteria for solar siting.sdmod: ratings: Unweighted Super Matrix

Clusters	Nodes	11 Radiation	12 Slope	13 Temperature	21 LCOE	22 Price	31 Distance to road	32 Land types	41 Distance to customers	42 Electricity load	51 Car emission	52 Emission reduction
1 Technical	11 Radiation	0.000000	0.000000	0.000000	0.670795	0.670795	0.000000	0.000000	0.000000	0.000000	0.166667	0.000000
	12 Slope	0.857143	0.000000	0.000000	0.255956	0.255956	1.000000	0.000000	1.000000	0.000000	0.833333	0.000000
	13 Temperature	0.142857	0.000000	0.000000	0.073249	0.073249	0.000000	0.000000	0.000000	1.000000	0.000000	1.000000
2 Economic	21 LCOE	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000
	22 Price	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	1.000000
3 Physical	31 Distance to road	0.000000	0.000000	0.000000	0.833333	0.833333	0.000000	0.000000	0.166667	0.000000	0.000000	0.000000
	32 Land types	0.000000	0.000000	0.000000	0.166667	0.166667	1.000000	0.000000	0.833333	0.000000	0.000000	0.000000
4 Social	41 Distance to customers	0.000000	0.000000	0.000000	1.000000	0.111111	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	42 Electricity load	0.000000	0.000000	0.000000	0.000000	0.888889	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
5 Environmental	51 Car emission	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
	52 Emission reduction	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Done

Table 7.7 The weighted super matrix

Main Network: 1 decision criteria for solar siting.sdmod: ratings: Weighted Super Matrix

Clusters	Nodes	11 Radiation	12 Slope	13 Temperature	21 LCOE	22 Price	31 Distance to road	32 Land types	41 Distance to customers	42 Electricity load	51 Car emission	52 Emission reduction
1 Technical	11 Radiation	0.000000	0.000000	0.000000	0.138007	0.101742	0.000000	0.000000	0.000000	0.000000	0.062390	0.000000
	12 Slope	0.857143	0.000000	0.000000	0.052660	0.038822	0.666667	0.000000	0.645028	0.000000	0.311949	0.000000
	13 Temperature	0.142857	0.000000	0.000000	0.015070	0.011110	0.000000	0.000000	0.000000	0.354972	0.000000	0.178288
2 Economic	21 LCOE	0.000000	0.000000	0.000000	0.000000	0.262776	0.000000	0.000000	0.000000	0.000000	0.625662	0.000000
	22 Price	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.645028	0.000000	0.297987
3 Physical	31 Distance to road	0.000000	0.000000	0.000000	0.088490	0.065237	0.000000	0.000000	0.059162	0.000000	0.000000	0.000000
	32 Land types	0.000000	0.000000	0.000000	0.017698	0.013047	0.333333	0.000000	0.295810	0.000000	0.000000	0.000000
4 Social	41 Distance to customers	0.000000	0.000000	0.000000	0.688076	0.056363	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	42 Electricity load	0.000000	0.000000	0.000000	0.000000	0.450903	0.000000	0.000000	0.000000	0.000000	0.000000	0.484340
5 Environmental	51 Car emission	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.039385
	52 Emission reduction	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Done

Table 7.8 The limit super matrix

Main Network: 1 decision criteria for solar siting.sdmod: ratings: Limit Matrix

Clusters	Nodes	11 Radiation	12 Slope	13 Temperature	21 LCOE	22 Price	31 Distance to road	32 Land types	41 Distance to customers	42 Electricity load	51 Car emission	52 Emission reduction
1 Technical	11 Radiation	0.043978	0.043978	0.043978	0.043978	0.043978	0.043978	0.000000	0.043978	0.043978	0.043978	0.043978
	12 Slope	0.236086	0.236086	0.236086	0.236086	0.236086	0.236086	0.000000	0.236086	0.236086	0.236086	0.236086
	13 Temperature	0.023130	0.023130	0.023130	0.023130	0.023130	0.023130	0.000000	0.023130	0.023130	0.023130	0.023130
2 Economic	21 LCOE	0.171562	0.171562	0.171562	0.171562	0.171562	0.171562	0.000000	0.171562	0.171562	0.171562	0.171562
	22 Price	0.023859	0.023859	0.023859	0.023859	0.023859	0.023859	0.000000	0.023859	0.023859	0.023859	0.023859
3 Physical	31 Distance to road	0.025508	0.025508	0.025508	0.025508	0.025508	0.025508	0.000000	0.025508	0.025508	0.025508	0.025508
	32 Land types	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.000000	0.051777	0.051777	0.051777	0.051777
4 Social	41 Distance to customers	0.125912	0.125912	0.125912	0.125912	0.125912	0.125912	0.000000	0.125912	0.125912	0.125912	0.125912
	42 Electricity load	0.023805	0.023805	0.023805	0.023805	0.023805	0.023805	0.000000	0.023805	0.023805	0.023805	0.023805
5 Environmental	51 Car emission	0.249990	0.249991	0.249991	0.249991	0.249991	0.249990	0.000000	0.249990	0.249991	0.249990	0.249991
	52 Emission reduction	0.024393	0.024393	0.024393	0.024393	0.024393	0.024393	0.000000	0.024393	0.024393	0.024393	0.024393

Done

Following criteria weight assignments, (3) the combination of criteria is conducted using Weighted Linear Combination (WLC) method where each layer is multiplied by its own weight. Summarizing results of each decision criterion produces a map showing suitable CSS project areas. WLC is frequently used to generate suitability maps in different MCDA models (Aydi et al., 2016; Babalola, 2018; Shahabi et al., 2014; Shorabeh et al., 2020; Zoghi et al., 2017). WLC is based on the weighted average product of target criteria by corresponding pixel values. Areas with higher pixel values are selected as suitable sites for CSS projects. WLC is formulated by Eq. (7.8):

$$\mathrm{SA} = \sum_{i=1}^{n} w_i * c_i \tag{7.8}$$

Where SA means suitable areas for CSS project establishments, n indicates the total number of criteria, w_i denotes the relative weight of factor i, and c_i is the criterion value of factor i for each pixel.

7.2.2.4 Step Four: Determine the Most Suitable Sites for CSS Projects

The fourth step determines final potential suitable sites for CSS projects by combing results from steps two and three and adopting fuzzy-VIKOR method. Combination results serve as alternatives with varying suitability levels of CSS project siting and might remain several options for siting. This provides references for city-level decision making on CSS projects siting and remain the most suitable sites to be explored among all potential suitable sites at the project level. To achieve this, this study introduces fuzzy-VIKOR to rank the alternatives and determine the most suitable sites for CSS projects at the project level. Considering existing CSS projects' installed capacity typically ranges from 20 kW to 2,000 kW [34], this study considers an average value of 1,000 kW as the size of CSS project for alternatives selection. The minimum area required for a 1,000 kw CSS project is 5,377 m^2 when using 305 W Mono-Si PV module with a unit solar panel area of 1.64 m^2 (Yang et al., 2020). Thus, sites with area around 5,400 m^2 in the very high suitability level are considered as alternatives in this study.

Fuzzy-VIKOR, with low computational complexity (Hosseini et al., 2021), is then employed to rank alternatives and determine the most suitable sites for CSS projects. VIKOR is also frequently used in MCDA models, offering advantages such as reflecting decision makers' subjective preferences, representing "closeness to the ideal" based on an aggregating function, and presenting compromise solutions to rank alternatives based on non-commensurable and conflicting criteria (San Cristóbal, 2011). VIKOR is then employed to prioritize alternatives and select the best CSS project establishment option, the hierarchical diagram of which is shown in Figure 7.5. Fuzzy set theory is also combined with VIKOR to address human judgment ambiguity. Specific steps of fuzzy-ANP are illustrated as follows.

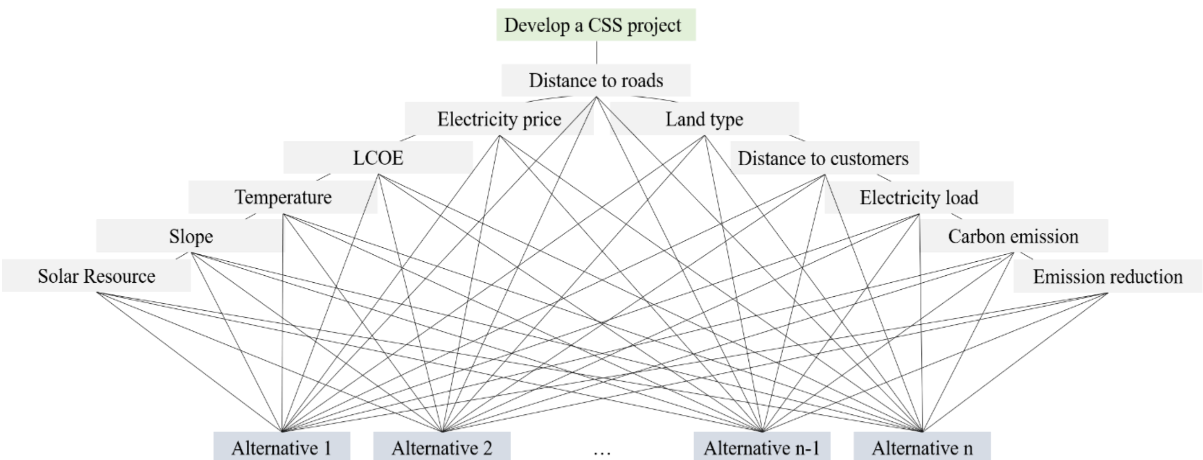


Figure 7.5 The hierarchical diagram of prioritizing the suitable site for CSS projects.

1) Construct the Decision Matrix

Based on selected alternatives and decision criteria listed in Table 7.2, the decision matrix X is constructed by Eq. (7.9):

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{7.9}$$

Where x_{ij} is the performance of alternative *i* under criterion *j*.

2) Normalize the Decision Matrix

To eliminate unit differences, matrix normalization is needed. Formulas for benefit and cost criteria as well as the normalized matrix R are shown in Eqs. (7.10) to (7.12):

- For benefit-type criteria where higher is better:

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{7.10}$$

Where x_j^{max} and x_j^{min} are the best and worst values for criterion j.

- For cost-type criteria where lower is better:

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{7.11}$$

- The normalized matrix *R* is:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{7.12}$$

3) Assign criteria weight

w_j is assigned to each criterion, with weights ranging from 0 to 1 for each variable and summing to 1. Fuzzy set theory is also utilized to improve judgment accuracy. As criteria for alternatives match those for suitable siting selection in step three, weights indicating interactions and derived priority weights from step three are also utilized in this step.

4) Determine the ideal and anti-ideal solutions

The ideal (f_{ij}^{+}) and anti-ideal solutions (f_{ij}^{-}) are the best and worst values for each criterion, respectively, which can be calculated through Eq. (7.13) and (7.14), respectively.

$$f_{ij}^{+} = \begin{cases} max_i(r_{ij}), & j \text{ is the benifit criteria} \\ min_i(r_{ij}), & j \text{ is the cost criteria} \end{cases} \tag{7.13}$$

$$f_{ij}^{-} = \begin{cases} min_i(r_{ij}), & j \text{ is the benifit criteria} \\ max_i(r_{ij}), & j \text{ is the cost criteria} \end{cases} \tag{7.14}$$

5) Compute distance metrics

The group utility (S_i) means weighted Manhattan distance from ideal, while individual regret (R_i) means weighted Chebyshev distance from ideal. They are calculated by Eq. (7.15) and (7.16), respectively.

$$S_i = \sum_{j=1}^{n} (w_j * \frac{f_{ij}^{+} - r_{ij}}{f_{ij}^{+} - f_{ij}^{-}}) \tag{7.15}$$

$$R_i = max_j(w_j * \frac{f_{ij}^{+} - r_{ij}}{f_{ij}^{+} - f_{ij}^{-}}) \tag{7.16}$$

6) Formulate VIKOR Index

The VIKOR Index (Q_i) is a compromise measure balancing S_i and R_i. $Q_i \in$ [0,1], is derived as Eq. (7.17):

$$Q_i = \mathrm{v}\frac{S_i - S^{+}}{S^{-} - S^{+}} + (1 - v)\frac{R_i - R^{+}}{R^{-} - R^{+}} \tag{7.17}$$

Where v ∈ [0,1] represents the decision-making coefficient (typically v=0.5); S^+ is the minimum value of S_i; S^- is the maximum value of S_i; R^+ is the minimum value of R_i; R^- is the maximum value of R_i.

7) Ranking and solution validation

Alternatives are ranked by ascending Q_i values, with lower values preferred. The optimal solution must satisfy acceptable advantage condition measured by Eq. (7.18) and decision stability condition where the best alternative ranks first when considering S_i or R_i individually.

$$Q(A_2) - Q(A_1) \geq \frac{1}{m-1} \tag{7.18}$$

Where A_1 or A_2 are the top two alternatives. If acceptable advantage condition is violated, the set of compromise solutions includes {A_1, A_2, … A_p}, where Q (A_p) – Q (A_1) < 1/(m-1).

7.2.2.5 Step Five: Validate Siting Analyses

The final step involves validating the siting analysis. As previous studies have not explored the suitable sites for CSS projects and no typical CSS project exists in this region, this study could not conduct a comparison to validate the results. Considering weight changes in different criteria might influence MCDA model output, sensitivity analysis is conducted to assess result robustness, determine criteria significance, and identify errors in weight assignments and their effects on final results. Six scenarios are considered in this study for sensitivity analysis of suitability maps, as shown in Table 7.9. As for the results of most suitable sites for CSS projects, three scenarios with changes in the decision-making coefficient v (i.e., v=0.4, 0.5 and 0.6) are compared in this study.

Table 7.9 Scenarios of sensitivity analysis.

Scenarios	**Characteristics**
Scenario A	Equal weights
Scenario B	No technical criteria
Scenario C	No economic criteria
Scenario D	No physical criteria
Scenario E	No social criteria
Scenario F	No environmental criteria

7.3 Results and Discussion

7.3.1 Feasible Sites for CSS projects

The restricted areas determined by exclusive criteria, are identified using spatial analysis, as depicted in Figure 7.6 where areas with a value of 1 represent restricted sites. It is evident that various exclusive criteria lead to different restricted areas. Among these, the most restricted areas are formed by protected areas, slope and aspect restrictions, primarily due to Hong Kong's unique urban characteristics. Hong Kong encompasses a total jurisdiction area of 2,755 km^2, with a land area of 1,115 km^2. However, due to environmental protection and other related measures, Hong Kong's built-up area accounts for about 25% of the total land area, while the remaining 75% is suburban, characterized by abundant natural ecology. Additionally, Hong Kong located at the southeastern tip of China, comprises Hong Kong Island, Lantau Island, Kowloon Peninsula, and the New Territories. As a mountainous city, Hong Kong features more mountains and fewer plains, with naturally formed plains primarily concentrated in the northwest of the New Territories, near the Pearl River Estuary. By superimposing various restricted areas, the total restricted area is obtained, as shown in Figure 7.6 (g), covering a land area of 962.7 km^2.

Based on these restricted areas, the final potential feasible areas are identified, as shown in Figure 7.7, covering a total area of 152.3 km^2. Initial research on the acceptance capacity of CSS projects indicates that 13.7 % of the studied area is feasible for use. This percentage is lower than those explored in other regions (e.g., 25.5 % in Murcia, Spain (Sánchez-Lozano et al., 2013)), highlighting the importance of suitable site selection to maximize the benefits of CSS projects in such cities. Overall, the northwest of the New Territories and built-up areas had the highest share of feasible lands for CSS project construction, while mountainous and environmentally sensitive areas had the highest share of unsuitable lands for the construction.

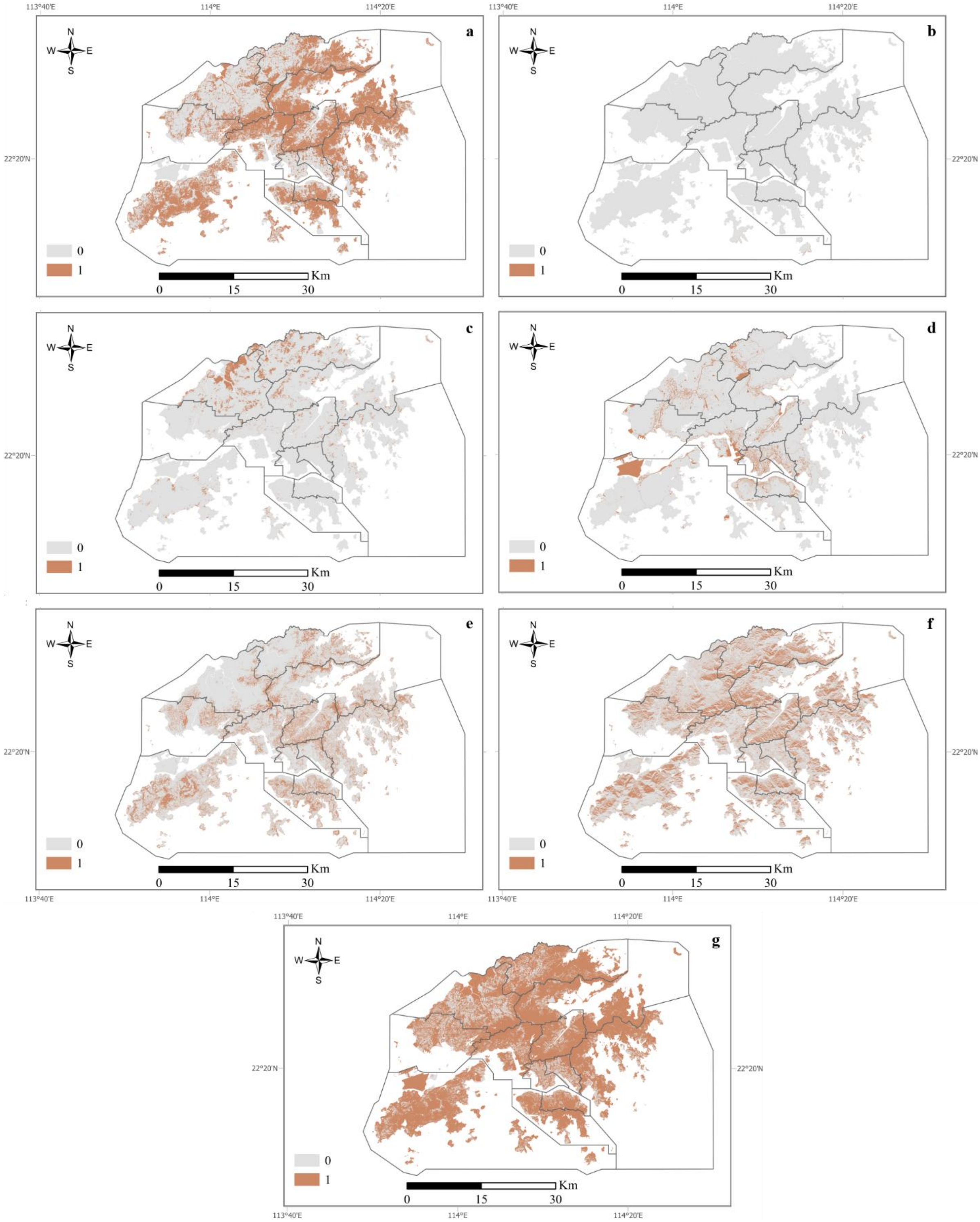


Figure 7.6 The spatial map of (a) protected areas; (b) risk areas; (c) agricultural lands; (d) feasibilities; (e) slope; (f) aspects; and (g) total restricted areas.

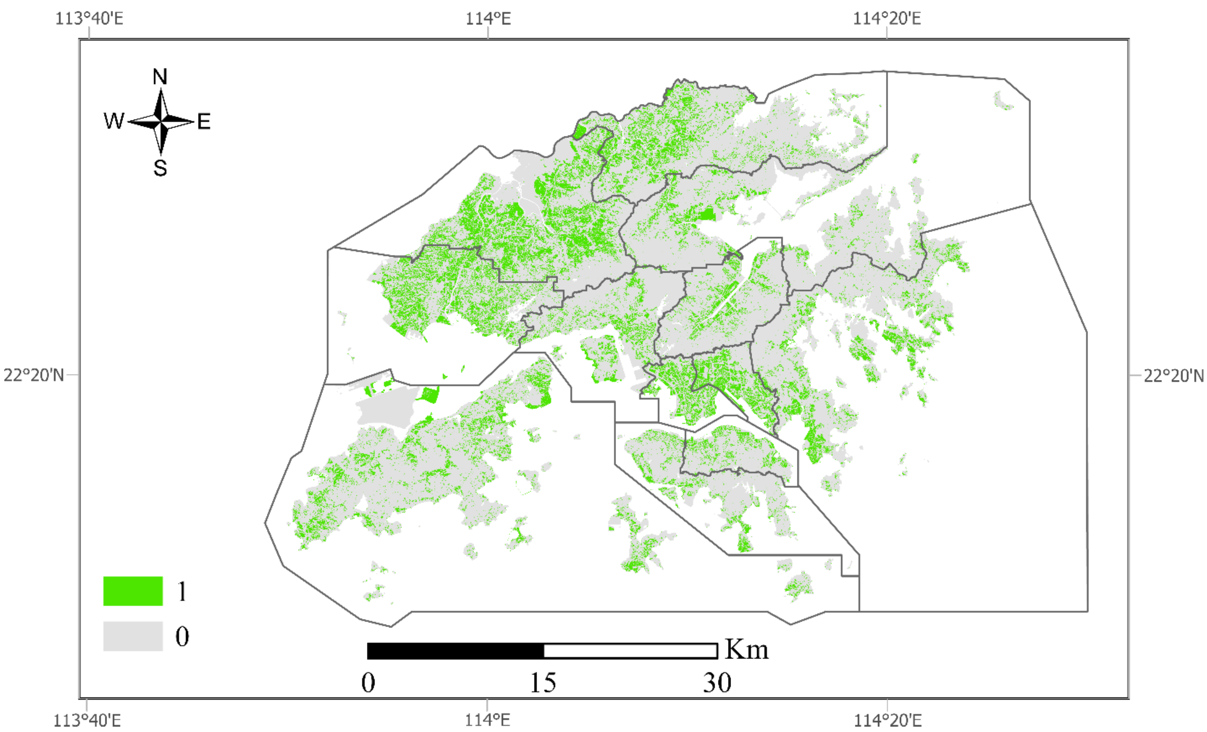
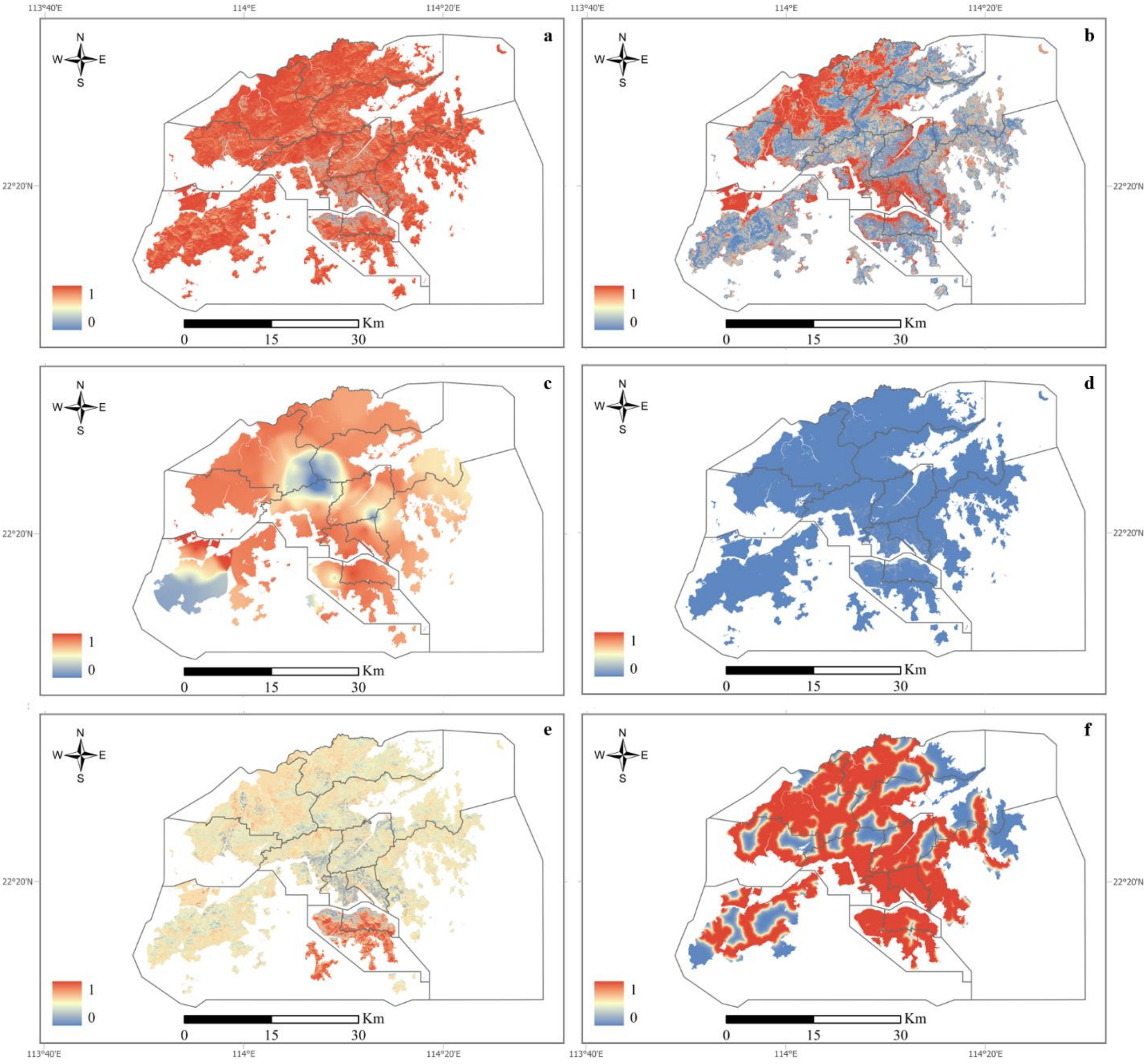


Figure 7.7 Feasible areas for CSS projects in Hong Kong.

7.3.2 Suitable Sites for CSS projects

7.3.2.1 Evaluation of Suitable Sites for CSS projects

Based on decision criteria, this study evaluates suitable areas for CSS projects by classifying areas according to their suitability to accommodate CSS projects. The spatial layers representing decision criteria are illustrated in Figure 7.8 where criteria values range from 0 and 1, with values close to 1 indicating higher suitability for CSS project construction. It can be seen that most areas are suitable for CSS projects in terms of solar irradiation, temperature, distance to roads, and distance to customers. However, the distribution of slope, energy load, and carbon emission reduction results in high suitability areas being more concentrated in specific regions. Additionally, the spatial map of LCOE indicates that economic feasibility remains a challenge for solar PV projects across Hong Kong due to unaffordable upfront installation costs of PV systems compared to other regions or countries (WAI, 2014).



113°40'E
114°E
114°20'E
22°20'N
a
b
c
d
e
f
N
W
E
S
1
0
Km
0
15
30

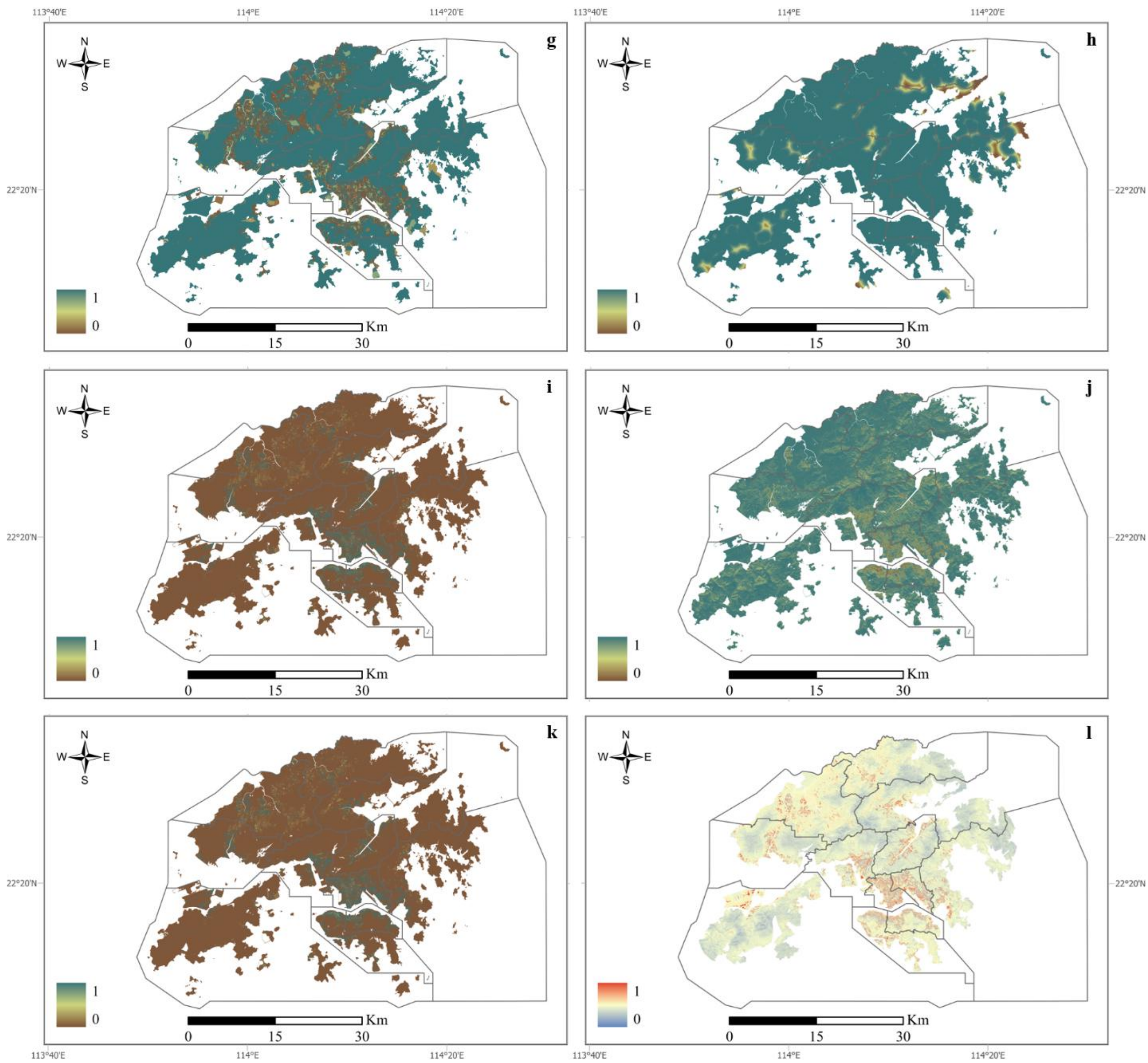


Figure 7.8 The spatial map of (a) solar irradiation; (b) slope; (c) temperature; (d) LCOE; (e) electricity price; (f) distance to main roads; (g) land types; (h) distance to customers; (i) energy load; (j) carbon emissions; (k) carbon emission reduction; and (l) suitable areas.

Therefore, by eliminating restricted areas subject to exclusive criteria and considering all decision criteria using the fuzzy-ANP method, the final suitable areas for CSS projects in Hong Kong are identified, as shown in Figure 7.9. The suitable areas are categorized into five suitability levels: "very low," "low," "medium", "high", and "very high" using an equal-interval classification method (Davtalab & Alesheikh, 2018). Green territories represent regions with very high suitability for CSS project establishment. The results show that 1.75 %

of the study area is very high, 0.92 % is high, 7.02 % is medium, 3.43 % is low, 0.02 % is very low, and 86.67 % is unsuitable for CSS projects. High and very high suitability areas are mainly distributed in industrial areas and new town roofs in the northwest of the New Territories (such as Yuen Long and Tin Shui Wai), dense urban areas (such as Central and Tsim Sha Tsui), and vacant lands in Island District (such as some sites in Tung Chung). These areas feature flat terrain, sufficient sunshine, high energy demand, and convenient transportation. Medium and low suitability areas are primarily located in mixed-use areas (such as Tsuen Wan and Shatin), limited by local shading, old building structures, or medium development intensity.

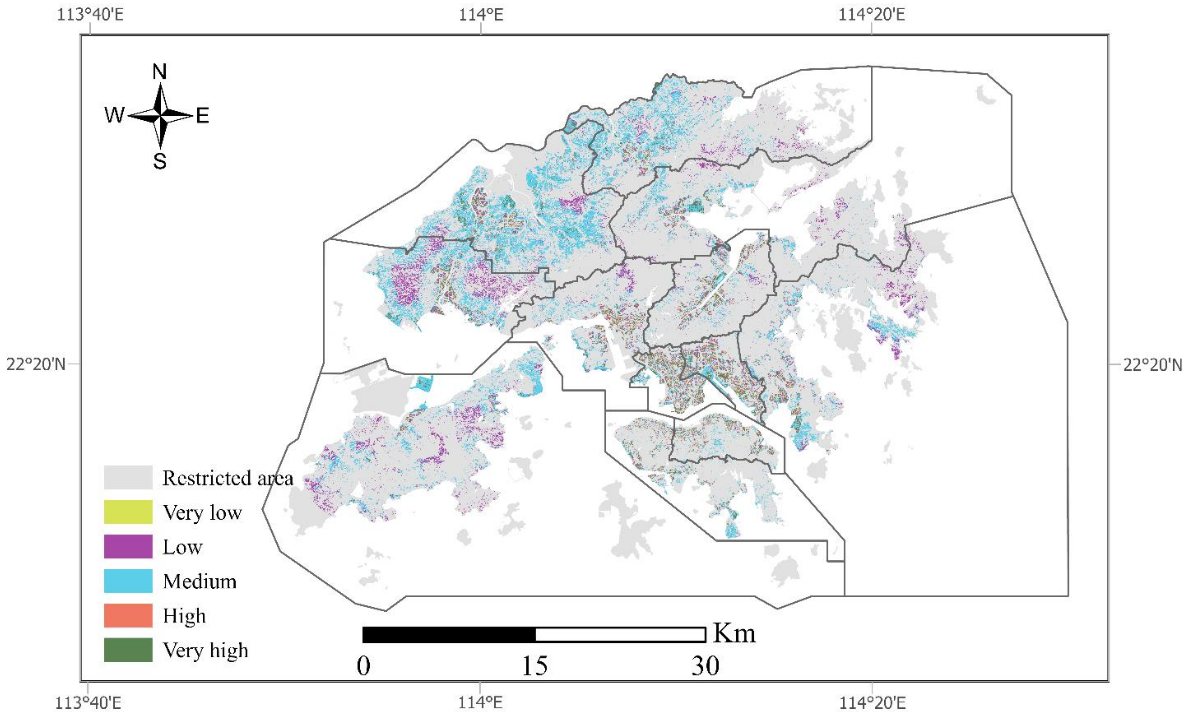


Figure 7.9 The final suitable areas for CSS projects in Hong Kong.

Furthermore, this study explored the potential of electricity generation in areas with different suitability levels and compared it with energy consumption in Hong Kong to assess the potential for developing CSS projects. As shown in Figure 7.10, suitability areas of very low,

low, medium, high, and very high for CSS projects are 2.40 km^2, 38.28 km^2, 78.24 km^2, 10.29 km^2, and 19.48 km^2, respectively. When CSS projects are fully installed in each suitability category, they can generate electricity annually with capacity of 30.97 GWh, 1352.36 GWh, 4194.13 GWh, 407.28 GWh, and 853.42 GWh, respectively, accounting for 0.06 %, 3.01 %, 9.32 %, 0.91 %, and 1.89 % of Hong Kong's total electricity consumption in 2023. Even though the annual amount of electricity generated in medium is the highest, its unit electricity generation capacity still ranks in the middle. In addition, the results indicate that the annual total amount of electricity generated from CSS projects in high and very high suitability areas accounts for 2.80 % of Hong Kong's total electricity consumption in 2023, while the amount of PV-generated electricity accounts for 15.20 % when CSS projects are installed in medium, high, and very high suitability areas.

Comparing this with existing research on power potential of PV systems in Hong Kong, the potential calculated in this study is higher than that generated from available rooftop area (Lu, 2013), which reached 10.7% of Hong Kong's energy consumption in 2024. This is because this study covers not only building rooftops but also available grounds. In addition, Liang et al. (2024) explored the solar potential of Hong Kong's roofs and facades, accounting for up to 16.3% of Hong Kong's total electricity consumption in 2022 due to high building floor area ratio. This is slightly higher than the power potential calculated in this study, indicating prospects for implementing PV technology on building surfaces and through CSS projects. Moreover, the results of this study show that carbon emissions can be reduced by 4.6 million tons through installing CSS projects in medium, high, and very high suitability areas, which is slightly higher than the reduced greenhouse gas emissions explored by (Lu, 2013). Since 97% of the city's carbon dioxide emissions result from electricity generation (Lu, 2013), there is an urgent need to develop alternative energy sources.

Overall, the results on suitable sites for CSS projects in this study underscore the importance of harnessing Hong Kong's green potential through energy transition. However, current renewable energy contributes less than 1% of Hong Kong's output (Lo, 2017), lagging behind other economies with populations similar to that of Hong Kong. For example, Singapore used waste, biomass and solar to generate 4.4 % of its electricity in 2023 (Ivy, 2023). Hong Kong requires more extensive adoption of renewable energies to achieve its carbon neutrality goal proposed in the Hong Kong Climate Action Plan 2050 (EEB, 2021). The results on suitable sites for CSS projects offer valuable insights for policymaking and implementation strategies of solar PV towards a low-carbon future. However, there are still many sites that can be considered as alternatives for a CSS project even in very high suitability areas, which is insufficient for project launch and calls for the research on alternative selection for a specific CSS project.

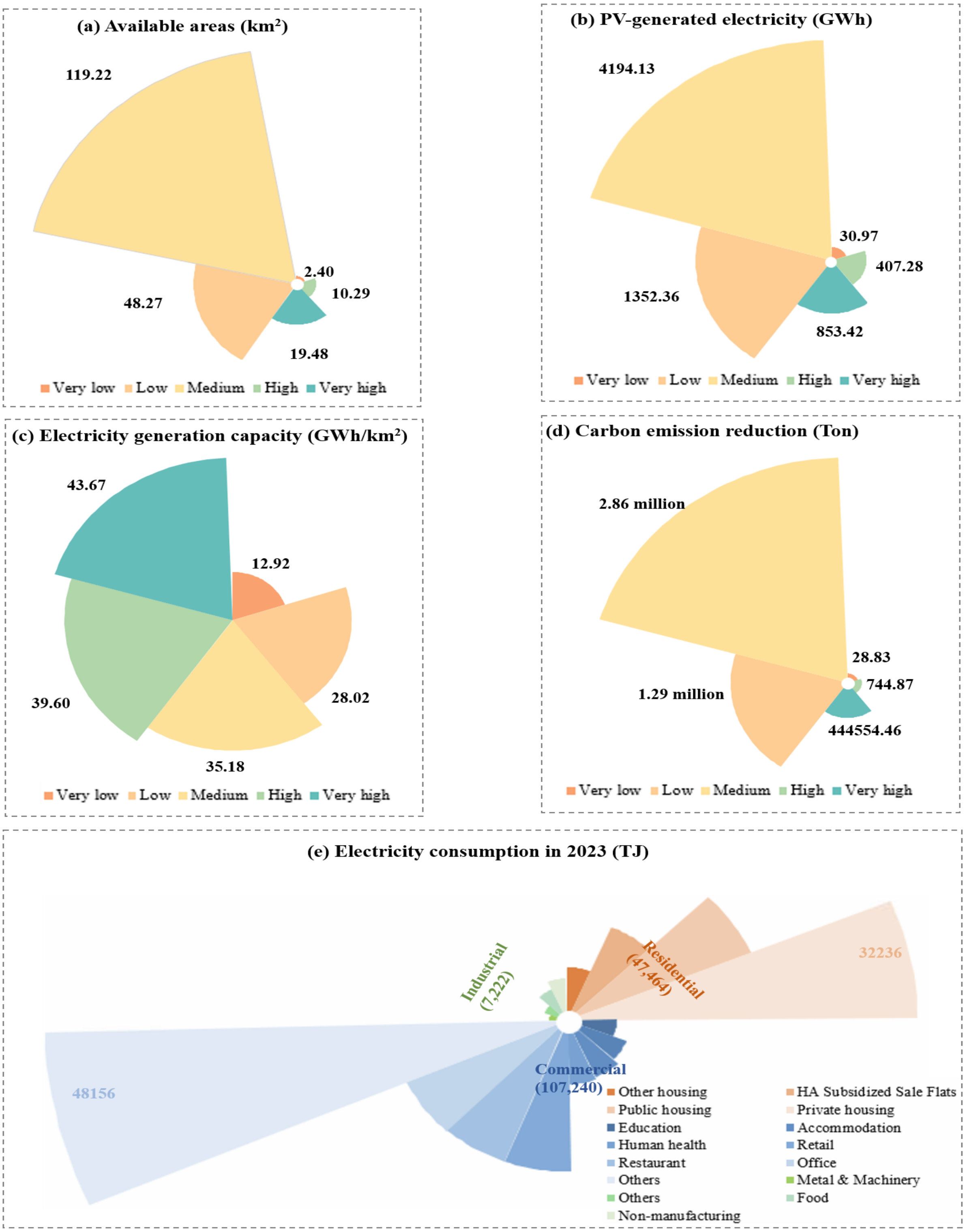


Figure 7.10 (a) The area of land with different suitability; (b) The PV-generated electricity from land with different suitability; (c) Energy consumption for different types of customers in Hong Kong.

7.3.2.2 The Most Suitable Sites for CSS projects

To identify the most suitable sites for CSS projects among several potential suitable sites at the project level, this study employs fuzzy-VIKOR to rank the alternatives and determine the most suitable sites, which is expected to provides references for decision making in a specific CSS project in practice. Based on the rules described in Section 2.2.4, seven alternatives are selected for exploration for a 1,000 kW CSS project, with locations illustrated in Figure 7.11. By adopting fuzzy-VIKOR described in Section 2.2.4, the priority order of the seven alternatives is determined and shown in Table 7.10.

The priority orders by Q_i in increasing order is A2 > A4 > A3 > A7 > A1> A6> A5. Based on the comprehensive evaluation results, A2 is the best alternative site and A4 is the suboptimal option for a 1,000 kW CSS project. A2 is the rooftop of an industrial building surrounded by several industrial centers with high energy demand. A project installed in A2 can annually generate electricity of 1.38 MWh, accounting for 10.65 % of its total annual energy consumption. In addition, A4 is the rooftop of a residential building surrounded by residential areas with high population density and energy load, which poses no significant challenge in customer acquisition.

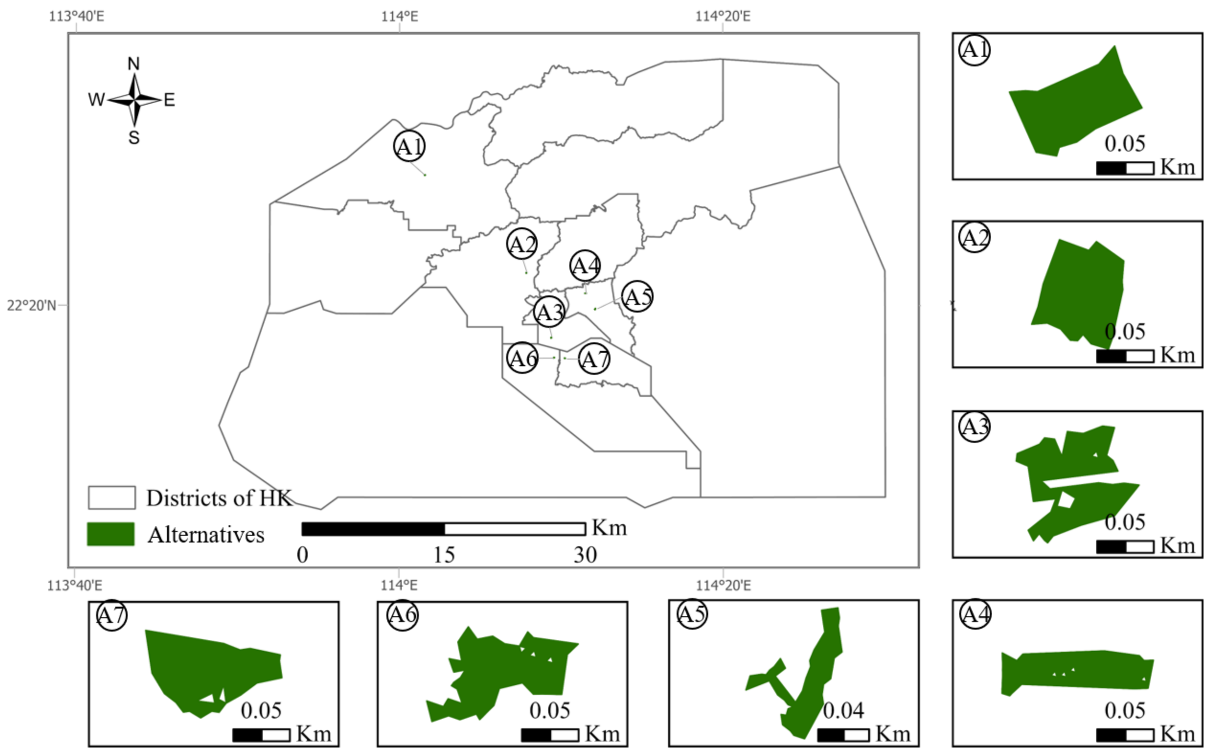


Figure 7.11 The georgical location of alternatives.

Table 7.10 The value and priority of the different alternatives using fuzzy-VIKOR.

Alternative	S_i	R_i	Q_i	Priority		
				S_i	R_i	Q_i
A1	0.455	0.254	0.631	3	7	5
A2	0.381	0.142	0.025	2	1	1
A3	0.489	0.154	0.232	4	3	3
A4	0.363	0.151	0.040	1	2	2
A5	0.714	0.230	0.892	7	5	7
A6	0.635	0.240	0.825	6	6	6
A7	0.516	0.159	0.293	5	4	4

7.3.3 Sensitivity Analysis

This study conducts sensitivity analysis by altering the weights of criteria to validate the results on suitable sites for CSS projects. Obviously, changes in the weights assigned to different criteria result in changes in the area of different categories relative to the original area. This can be interpreted as the importance of weight assignment in determining suitable areas for CSS project establishment. Figure 7.12 shows the results on the impact of area changes across different categories. Figure 7.13 shows area across different categories in different scenarios. It is observed that land variance differs in each scenario. Applying equal weights to criteria in Scenario A shows a decrease in very high suitable sites and an increase in medium and high sites. However, in Scenario B without technical criteria, the situation for medium suitability and above differs significantly from the ideal original scenario, with areas decreasing, indicating that eliminating technical criteria significantly reduces suitable areas for CSS projects, emphasizing the importance of technical criteria in project site selection. In scenarios without economic or physical or environmental criteria (i.e., Scenario C, D, and F), the area of high and very high suitable sites remains largely unchanged, while medium suitable sites change slightly. In Scenario E without social criteria, the area of high and very high suitable sites increases significantly. Since social criteria have the greatest impact on high and very high suitable sites, eliminating the impact of social criteria is the best way to increase the potential suitable area for CSS projects. This suggests that the site selection should fully consider energy demand and distance to consumers to enhance project success probability.

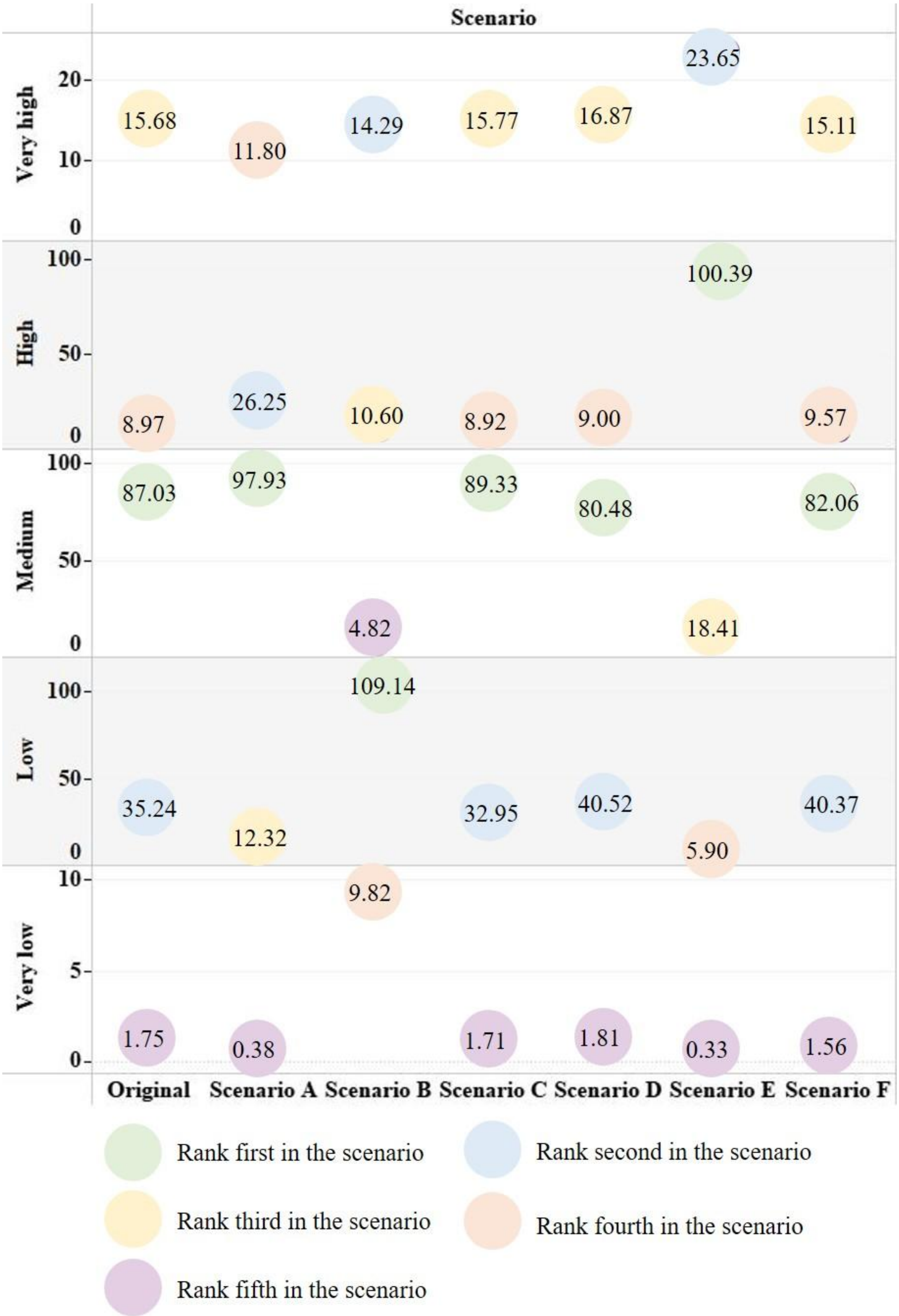


Figure 7.12 The sensitivity analysis results of suitable sites for CSS projects.

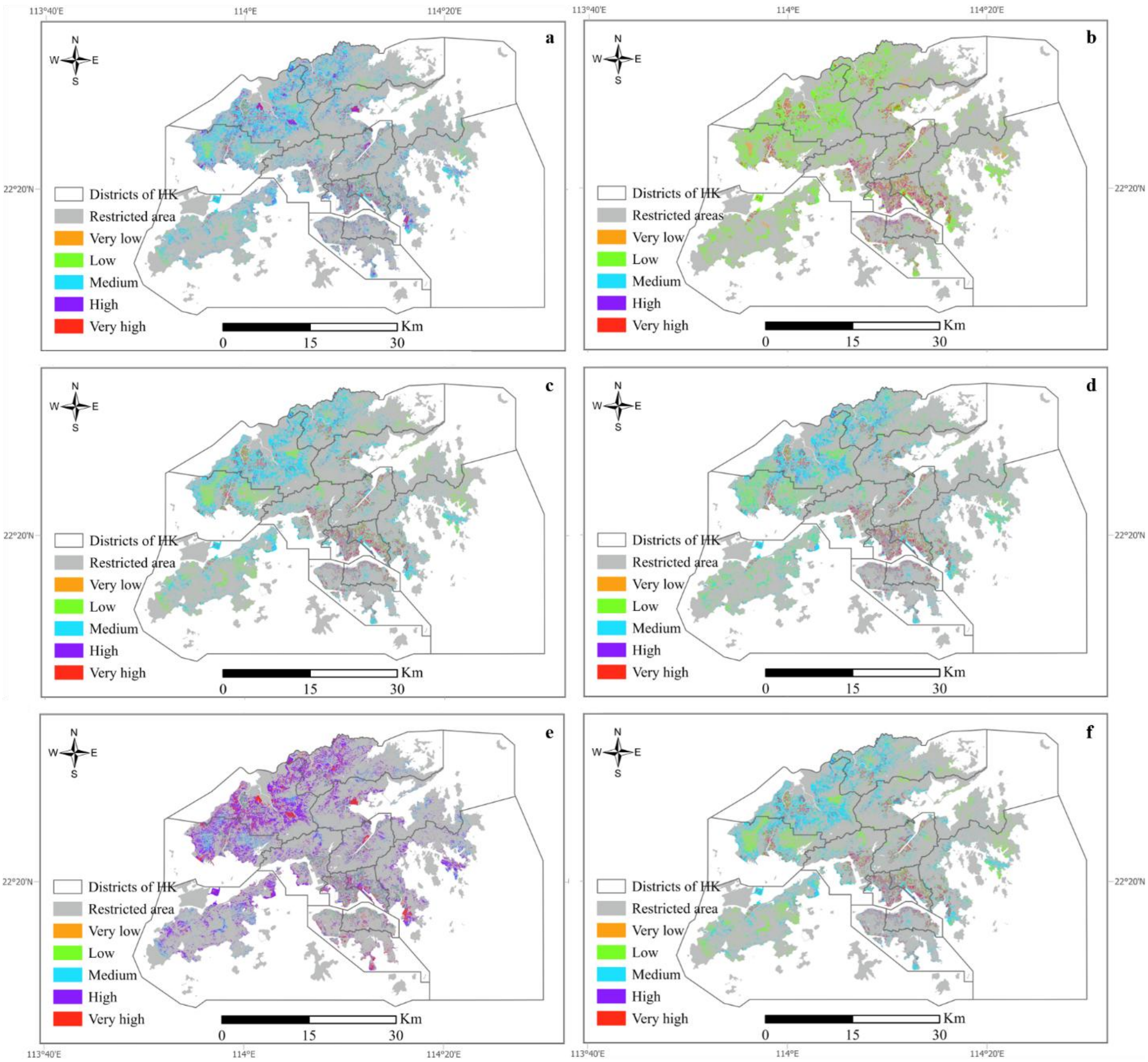


Figure 7.13 The area changes across different categories in different scenarios: (a) equal weights; (b) no technical criteria; (c) no economic criteria; (d) no physical criteria; (e) no social criteria; and (f) no environmental criteria.

In addition, to investigate the robustness of results on the most suitable sites for CSS projects, sensitivity analysis is conducted by adjusting the decision-making coefficient v. Changes in the criteria priorities may impact the best site of a CSS project as a result. Table 7.11 displays the results of sensitivity analysis when v changes. The ranking trends in the three scenarios remain unchanged, indicating they are unaffected by the v value. Notably, the ranking of A2 consistently shows it as the optimal solution, unaffected by the v value. This result confirms that the evaluation of the most suitable sites for CSS projects through the fuzzy-VIKOR method proposed in this study is robust and reliable. Moreover, further analysis of the sensitivity analysis shows that when the v value ranges from 0.3 to 0.9, the ranking of all alternatives remains unchanged. However, when the v value ranges from 0.1 to 0.2, although the optimal solution remains unchanged, the ranking of A1 gradually moves forward while A5 and A6 move backward. This indicates that changes in decision-maker preferences impact decision results. When decision-maker preference is unrelated to group utility, A5 and A6 rank higher than A1. However, when considering group utility, A1 gradually outperforms A5 and A6. Therefore, the proposed method can accommodate various decision-maker attitudes in real decision-making practice, providing effective and useful references for site selection of specific CSS projects.

Table 7.11 The results of sensitivity analysis for the most suitable sites for CSS projects.

Alternative	**Qi (Ranking)**		
	v = 0.4	**v = 0.5**	**v = 0.6**
1	0.705 (5)	0.631 (5)	0.557 (5)
2	0.020 (1)	0.025 (1)	0.030 (1)
3	0.207 (3)	0.232 (3)	0.257 (3)
4	0.048 (2)	0.040 (2)	0.032 (2)
5	0.871 (7)	0.892 (7)	0.914 (7)
6	0.835 (6)	0.825 (6)	0.815 (6)
7	0.264 (4)	0.293 (4)	0.322 (4)

7.4 Summary of the Chapter

This chapter aims to investigate the selection of suitable sites for CSS projects to facilitate energy transformation through solar PV adoption. To this end, this chapter proposed a comprehensive research resign involving objective definition and GIS-MCDA model development. Based on it, this chapter firstly identified feasible sites based on exclusive criteria and GIS spatial analysis. Subsequently, this chapter created a suitability map by assigning values between 0 and 1 to corresponding areas based on multiple criteria encompassing technical, economic, physical, social, and environmental aspects, integrating GIS spatial analysis and fuzzy-ANP method. Following this, seven alternatives for a CSS project were prioritized using the fuzzy-VIKOR method. Finally, results on suitable sites and the most suitable site for CSS projects were validated using sensitivity analysis. The major findings are elaborated below:

(1) The final feasible sites cover 152.3 km^2, showing that 13.7 % of the study area is potentially useable.

(2) In terms of suitability, 1.7 % of study area is classified as very high, 0.9 % as high, 7.0 % as medium, 3.4 % as low, 0.02 % as very low, and 87.6 % as unsuitable for CSS projects. High and very high suitability areas are primarily located in industrial areas and new town rooftops in the northwest of the New Territories, dense urban areas, and vacant lands. Additionally, when CSS projects are installed in medium, high, and very high suitability areas, the amount of PV-generated electricity accounts for 15.20 % of total energy consumption in 2023, while carbon emissions can be reduced by 4.6 million tons.

(3) By prioritizing the proposed seven alternatives, this study identified the rooftop of an industrial center and the rooftop of a residential building as the best sites for a specific CSS project.

Moreover, the contribution of this study is threefold. First, in terms of solar PV practice, this study serves as a preliminary exploration of suitable site determination for CSS projects at both city and project level, providing significant insights and decision support for CSS project site selection within a city. The results can be regarded as a valuable reference for future work related to community solar site selection in various regions. Second, in terms of decision criteria, this study proposes a comprehensive decision criteria system that reflects the characteristics of community solar from multiple dimensions. This criteria system can be adopted and adapted to suit different market contexts, making it applicable beyond the specific case of Hong Kong. Third, in terms of analysis method, this study integrates GIS spatial analysis, fuzzy-ANP method, and fuzzy-VIKOR method, quantitatively evaluating site selection for CSS projects and comprehensively supporting the qualitative goal of community solar adoption. This attempt is proved to be effective and can be referred by future research on site selection. Overall, this study makes significant contributions to the CSS project domain by introducing an integrated analysis method, incorporating comprehensive and customized decision criteria, and providing insights into suitable site selection of CSS project. These contributions pave the way for further advancements in the field and offer practical guidance for promoting community solar adoption.

Nonetheless, while this study effectively demonstrates how different criteria can be incorporated into the site selection decision for community solar, there are other important factors that cannot be incorporated into raster-based GIS-MCDA studies, such as community acceptance of community solar and developer recognition of community solar. Future research is suggested to explore methods that can combine different forms of data, both qualitative and quantitative, to conduct a more in-depth analysis of site selection. In addition, this study enables decision makers to select suitable sites from an energy perspective. Future research is recommended to combine the model results proposed in this study with those of economic models, risk models, and others to further enhance the applicability of the research findings for decision makers.

Chapter 8 Conclusions

8.1 Introduction

This chapter summarizes the key research findings and proposes future research directions based on limitations presented in this study.

The global challenge of climate change has driven numerous countries to set ambitious targets aimed at promoting energy conservation, reducing emissions, and increasing the utilization of renewable energy sources. Renewable energy technologies are advancing rapidly and are being widely implemented worldwide as they are considered crucial alternatives for reducing carbon emissions and dependence on fossil fuels. Among these technologies, community solar offers accessibility and affordability of solar power to individuals facing financial or location constraints. However, various barriers impede the adoption and scaling of community solar, indicating the necessity of understanding the feasibility of CSS projects from social, techno-economic, and environmental perspectives. Addressing these barriers is crucial for promoting community solar adoption and facilitating energy transmission. Social acceptance explores public receptivity to new renewable technologies in niche markets and provides insights into strategies for overcoming barriers to enhance market and community acceptance. Techno-economic acceptance examines the financial attractiveness of CSS projects for both developers and customers, as well as their potential responses to community solar over extended periods. Geographic acceptance assesses the site suitability of CSS projects affected by the environment and determines optimal locations for sustainable development. In summary, to address research questions in this study, the primary aim of this study is to develop a multi-level decision support framework for the adoption of CSS projects considering social, techno-economic, and geographic feasibilities, to promote distributed solar generation through community solar adoption and achieve energy democracy in a city.

To achieve this, Chapter 1, Chapter 2, and Chapter 3 identified the motivations and challenges associated with community solar adoption, particularly in niche markets, serving as a theoretical foundation and solid reference for further in-depth analysis. To achieve Objective 1, Chapter 4 comprehensively investigated key barriers to community solar adoption through ISM-DEMATEL and comparison analysis. The causal and hierarchical relationships among these barriers were explored and presented. To achieve Objective 2, Chapter 5 and Chapter 6 proposed a business model and a financial model for CSS projects in emerging markets and evaluated the financial performance of CSS projects under current and future market conditions. Scenario analysis was conducted to further explored the financial attractiveness under varying conditions, considering changes in subscriber combination, subscription rate, expected payback period, and subsidy. To achieve Objective 3, Chapter 7 integrated Boolean, fuzzy-ANP, and fuzzy-VIKOR into a GIS-MCDA model for suitable site identification for CSS projects, identifying feasible, suitable, and optimal sites for CSS projects. To achieve object 4, Chapters 4 to 7 constructed and validated the multi-level decision support framework for the adoption of CSS projects through experimental studies in Hong Kong.

8.2 Summary of Research Findings

8.2.1 Findings on social acceptance

In terms of social acceptance, key barriers to community solar adoption from the perspectives of different stakeholders and the causal and hierarchical relationships among these barriers have been comprehensively identified using ISM-DEMATEL and comparison analysis. The findings are as follows:

(1) The ISM results show complex relationships between barriers to community solar adoption. From the perspective of customers, immaturity (A1), insufficient policy support (A13), and ineffective policy support (A14) were positioned at the lowest level of the ISM model due to their high driving power but low dependence power, while lack of information (A9), legal and regulation constraints (A12), reliability (A2), high prices (A5), and accessibility (A10) exhibit low driving power and high dependence power. From the perspective of developers, immaturity (B1), weather (B6), lack of knowledge (B15), conversion efficiency (B5), and existing technical capacity (B16) exhibit strong driving power. Conversely, long payback period (B7), insufficient incentives (B13), high maintenance cost (B9), high upfront cost (B8), and high transaction costs (B10) demonstrate strong dependence power.

(2) According to the DEMATEL results, from the perspective of customers, A1, A2, A3, A4, and A13 are identified as causal factors affecting community solar adoption. Among them, A1 exhibits the greatest causation and exerts the most significant influence on other factors. Result factors, including A5, A6, A7, A8, A9, A10, A11, A12, and A14, are influenced by the causal factor and consequently impact community solar adoption. From the perspective of developers, causal factors include B1, B3, B4, B5, B6, and B12, with B1 exhibiting the greatest causation and exerting the most significant influence on other factors. Result factors influenced by the cause factor and consequently impacting community solar adoption include B2, B7, B8, B9, B10, B11, B13, B14, B15, B16, and B17.

(3) The ISM-DEMATEL results were compared with those of a questionnaire survey, revealing consistency in terms of technical and economic barriers. The findings underscore

the importance of technology advancement and policy support in driving community solar adoption. Furthermore, customers pay more attention to policy support, conversion efficiency, and reliability, while developers focus more on weather, lack of information, and reliability as they affect the successful implementation of CSS projects.

8.2.2 Findings on techno-economic feasibility

In terms of techno-economic acceptance, attractiveness of CSS projects to both developers and customers in nascent markets (e.g., Hong Kong) has been explored by proposing a new business model for CSS projects in emerging markets, developing a customized financial model using LCCA, and analyzing techno-economic performance of CSS projects under current and future market conditions. The financial attractiveness of CSS projects has been further explored under different conditions through scenario analysis, considering changes in subscriber combination, subscription rate, expected payback period, and subsidy. The findings are as follows:

(1) The CSRs for each type of subscriber are nearly two to three times higher than its retail electricity price, revealing that CSS projects are financially infeasible under current market conditions in Hong Kong. Nonetheless, the CSRs proposed in this study can serve as a benchmark value for both the developer and subscribers to effectively respond to a CSS project as Hong Kong's solar PV market matures.

(2) The estimated PPs for CSS projects require at least over 20 years to achieve acceptable financial performance under current market conditions, with CSRs no greater than retail electricity prices, which greatly exceed the desired payback period of eight years.

(3) The minimum amount of extra subsidy required for the developer to ensure the financial sustainability and attractiveness of a CSS project under current market conditions accounts for around 11% of the total upfront installation cost of PV systems.

(4) Under current market conditions in Hong Kong, CSS projects are financially unviable, with CSRs for each type of subscriber being nearly two to three times higher than the REPs. Conversely, future market conditions suggest that CSRs could be lower than the REPs, thereby indicating the potential financial feasibility of CSS projects.

(5) A minimum subscription rate of approximately 75% was identified as necessary to ensure mutual benefits for both developers and subscribers in the future market, thereby enhancing the practicability of CSS projects.

(6) Sensitivity analysis reveals that upfront installation costs exhibits the highest degree of influence on project costs, while residential subscribers' payments emerge as the most sensitive variable affecting project revenue in both the current and future markets. These findings highlight the need to optimize the economic performance of CSS projects by paying closer attention to these critical factors.

8.2.3 Findings on geographic suitability

In terms of geographic acceptance, feasible sites, suitable sites, and the most suitable sites for CSS projects in Hong Kong have been identified through a GIS-MCDA model integrating GIS spatial analysis, Boolean overlay, fuzzy-ANP, and fuzzy-VIKOR methods to facilitate energy transformation through solar PV adoption. The results on suitable sites and the most suitable site for CSS projects were validated using sensitivity analysis. The findings are as follows:

(1) The final feasible sites cover 152.3 km^2, showing that 13.7 % of the study area is potentially useable. The northwest of the New Territories and built-up areas had the highest share of feasible lands for CSS project construction, while mountainous and environmentally sensitive areas had the highest share of unsuitable lands for the construction.

(2) In terms of suitability, 1.7 % of study area is classified as very high, 0.9 % as high, 7.0 % as medium, 3.4 % as low, 0.02 % as very low, and 87.6 % as unsuitable for CSS projects. High and very high suitability areas are primarily located in industrial areas and new town rooftops in the northwest of the New Territories, dense urban areas, and vacant lands. Additionally, when CSS projects are installed in medium, high, and very high suitability areas, the amount of PV-generated electricity accounts for 15.20 % of total energy consumption in 2023, while carbon emissions can be reduced by 4.6 million tons.

(3) By prioritizing the proposed seven alternatives, this study identified the rooftop of an industrial center (A2) as the best site for a specific CSS project and the rooftop of a residential building as the suboptimal site. A CSS project installed in A2 can annually generate electricity of 1.38 MWh, accounting for 10.65 % of its total annual energy consumption.

(4) The sensitivity analysis indicates land variance differs in each scenario, emphasizes the importance of technical criteria in project site selection, and suggests that the site selection should fully consider energy demand and distance to consumers to enhance project success probability. Additionally, the ranking trends of seven alternatives for a 1,000 kW CSS project in three scenarios remain unchanged, confirming the evaluation of the most suitable sites for CSS projects through the fuzzy-VIKOR method proposed in this study is robust and reliable. Further analysis of the sensitivity analysis with the v value ranges from 0.1 to 0.9 shows that the proposed method can accommodate various decision-maker attitudes in real decision-

making practice, providing effective and useful references for site selection of specific CSS projects.

8.3 Contributions of the Research

8.3.1 Contributions to Current Knowledge

This study makes several contributions to current knowledge. Firstly, this study proposes a hybrid ISM-DEMATEL tool to identify hierarchical and causal relationships among barriers to community solar adoption from the perspectives of different stakeholders, serving as a reference for addressing barriers in a nascent market and laying the groundwork for future research on community solar adoption in various countries. Secondly, this study proposes a new business model for CSS projects in niche markets, offering an innovative approach that enables direct selling of PV-generated electricity to end-users, which can be further expanded and adapted to fit different market contexts in future studies. Thirdly, this study develops a heuristic financial model specifically customized for CSS projects, which can be used not only to analyze the techno-economic performance of CSS projects under different scenarios, but also to determine and optimize favorable CSRs to achieve desired financial performance. This fills the gap that no tool in existing studies can be adopted to effectively determine prices of PV-generated electricity in emerging markets. Additionally, the flexibility of the financial model allows it to be expanded and adapted to suit different market contexts, accommodating various tax types, subsidy types, and other financial incentives. Fourthly, this study proposes a comprehensive decision criteria system that reflects the characteristics of community solar from multiple dimensions. This criteria system can be adopted and adapted to suit different market contexts, making it applicable beyond the specific case of Hong Kong. Fifthly, this study integrates GIS spatial analysis, fuzzy-ANP method, and fuzzy-VIKOR method, quantitatively evaluating site selection for CSS projects and comprehensively supporting the qualitative goal of community solar adoption. The proposed innovative method can serve as a robust analytical tool for evaluating the optimal sites for CSS projects. This attempt is proven to be effective and can be referred by future research on site selection. Lastly, this study establishes a multi-level decision support framework for the adoption of CSS projects considering the benefits of different stakeholders, which could provide valuable information of sustainable community solar adoption from social, techno-economic, and environmental aspects for various decision-makers in the early stages.

In summary, this research contributes to the knowledge of sustainable community solar adoption and fills the knowledge gap in systematically understanding the acceptance of community solar from social, techno-economic, and geographic aspects. These contributions pave the way for further advancements in the field and offer practical guidance for promoting community solar adoption.

8.3.2 Practical Contributions to the Industry

Practically, (1) the proposed framework serves as an effective and comprehensive tool for analyzing community solar issues before making decisions and implementing relevant strategies. This research provides a scientific foundation for decision-makers to understand the implementation of CSS projects sustainably, promoting CSS adoption. (2) The key barriers to community solar adoption of different types of stakeholders identified by the proposed ISM-DEMATEL tool can further our understanding of how to successfully implement community solar projects by filtrating these barriers, and provide constructive guidance for the development of CSS projects to different types of decision-makers. (3) The analysis of CSRs and other financial performance metrics (e.g., PP and subsidy) through the proposed financial model provides insights into designing appropriate pricing and subsidy strategies to promote community solar adoption in niche markets in the early stages. CSS projects in niche markets typically face uncertainties and challenges regarding their operation, financial performance, and pricing strategies. The proposed financial model is designed to avoid complex business structures, time-consuming processes, and the need for extensive data, thereby making it practical for quick and effective decision-making in nascent community solar markets. (4) The exploration of suitable site determination for CSS projects at both city and project level provides significant insights and adequate decision support for CSS project site selection within a city to promote distributed solar generation through community solar adoption.

In summary, the multi-level decision support framework for community solar adoption is an effective tool for analyzing the feasibility of CSS projects in niche markets from perspectives of social acceptance, techno-economic acceptance, and geographic acceptance, which could offer practical guidance for promoting community solar adoption and energy transmission in emerging markets.

8.4 Limitations of the Research and Recommendations for Future Research

Despite the theoretical and practical contributions to existing studies, it is important to acknowledge several limitations inherent in the present research.

Firstly, this study utilized questionnaire to gather opinions on dominant barriers to community solar adoption from customers (e.g., residential, non-residential, and large customers) and developers (e.g., technical staff, project managers, and researchers and professionals) with knowledge and experience in solar energy projects. The questionnaires were developed on the Qualtrics platform and distributed online via the Dynata platform. A total of 275 questionnaires were issued, and 214 valid questionnaires were returned with a response rate of 77.8%. Although this meets the requirements for data analysis, the number of questionnaires may still introduce bias and subjectivity. Future research is suggested to include more respondents or integrate subjective and objective data to analyze key barriers.

Secondly, as the establishment of contextual relationship among identified barriers is of great importance for ISM and DEMATEL methods, expert interviews were conducted to develop SSIM and DRM. Prior to conducting expert interviews, a group of 50 professionals (e.g., technical staff, project managers, and researchers and professionals) with extensive experience and knowledge in applying solar energy in Hong Kong was identified from related publications and websites. In addition to face-to-face interviews, questionnaire with invitation letters were emailed to the group, resulting in 50 acceptances. 19 useable questionnaires were returned, representing a good response rate of 76%, which is acceptable for data analysis referring to previous studies. However, accurate numerical estimates and human judgment regarding the priority of different factors are challenging tasks. Future research is recommended to incorporate fuzzy set theory to address ambiguity in human judgment.

Thirdly, this study develops a comprehensive financial model specifically customized for CSS projects. This model can be used to analyze the techno-economic performance of CSS projects under different scenarios, particularly in determining acceptable and reasonable CSRs within either an established or new market to support relevant decision-making. However, this model only considered PAYG subscription model as it is proven to boost the participation rate by enhancing financial availability and flexibility. Future research is advised to involve different types of subscription models to ensure the proposed model can be adopted and customized for effective analysis in other locations and settings.

Fourthly, while this study effectively demonstrates how different criteria can be incorporated into the site selection decision for community solar, there are other important factors that cannot be incorporated into raster-based GIS-MCDA studies, such as community acceptance of community solar and developer recognition of community solar. Future research is suggested to explore methods that can combine different forms of data, both qualitative and quantitative, to conduct a more in-depth analysis of site selection.

Fifthly, this study enables decision makers to select suitable sites from an energy perspective. Future research is recommended to combine the model results proposed in this study with those of economic models, risk models, and others to further enhance the applicability of the research findings for decision makers.

Appendix I: Questionnaire for barriers to community solar adoption in cities

Barriers to community solar adoption in cities: Perspectives of potential subscribers or developers in Hong Kong

WELCOME TO THE STUDY

This questionnaire survey collects data and information about your views on barriers to the adoption of community shared solar (CSS) projects in Hong Kong.

The survey consists of **7 sections** and will take around **10** minutes. Your invaluable input by sharing your experience and opinions on this topic is very much appreciated. The information collected will be kept **strictly confidential** and will also be **destroyed** after use.

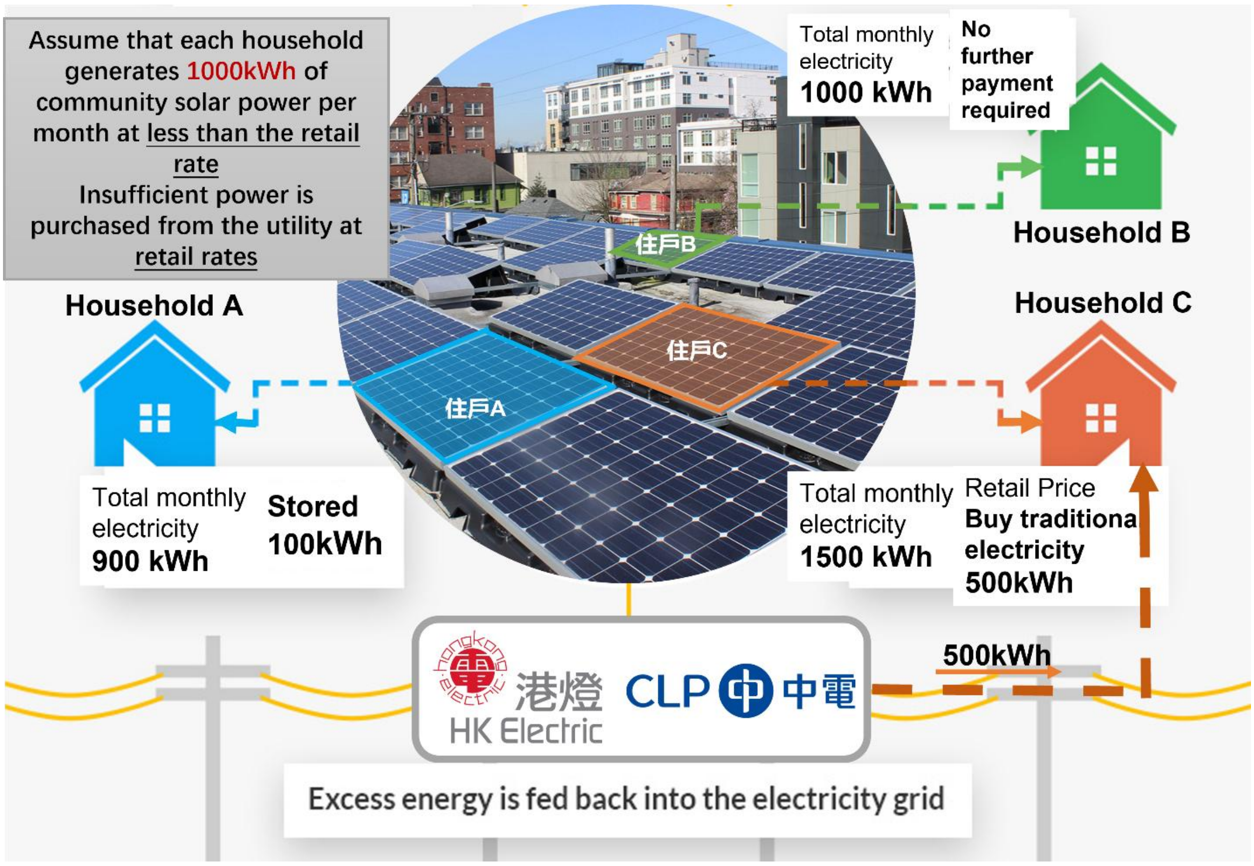
Please read the instructions carefully and answer every question as sincerely as possible. There are no right or wrong answers, so feel free to provide an answer that you think is true for you.

Introduction of Community shared solar project

*Please read the following description about **Community shared solar (CSS) project** carefully, and make sure that you fully understood the concept. Questions related to it will be presented afterward.*

Community Shared Solar (CSS) project allows households or organizations to adopt solar **without installing a solar photovoltaic (PV) system** on their own property but rather **subscribe to a portion of a CSS project installed elsewhere in their community**.

This program is designed and operated for those who are unable to install a PV system on their own property due to various reasons but still want to contribute to generating clean energy. Subscribers participating typically subscribe to a portion of a CSS project installed elsewhere in their community and pay a subscription rate (usually lower than the retail electricity price) for the electricity generated from their share.
This program is currently not available in Hong Kong, but successfully operated in the United States (U.S.), and thus, its applicability has already been validated.



1. If you have a clear understanding of the solar program explained above, please type the **Community shared solar (CSS) project** below.

____

2. Do you have any experience in developing a PV project?
   A. Yes Go to question 3 and 4
   B. No Go to question 5

3. What kind of PV project did you develop before?
   A. Residential PV projects
   B. Commercial PV projects
   C. Utility-scale PV projects
   D. CSS projects

4. In general, are you willing to develop a CSS project if it is available in Hong Kong?
   A. Strongly disagree
   B. Disagree
   C. Neutral
   D. Agree
   E. Strongly agree

5. In general, are you willing to join a CSS project if it is available in Hong Kong?
   F. Strongly disagree
   G. Disagree
   H. Neutral
   I. Agree
   J. Strongly agree

Section 1: Technical barriers

This section will ask you perspectives on technical barriers to CSS adoption, which relate to the quality and installation of PV systems in a CSS project.

Are PV technologies considered mature enough in Hong Kong?

A. Mature
B. Immature
C. Not sure

Will the immaturity of PV technologies, encompassing aspects such as PV system generation, installation, management, and related factors, influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Do you think the general product lifespan of PV systems (25 years) is long enough if you want to join a CSS project?

A. Enough
B. Not enough
C. Not sure

Will the short product lifespan of PV systems influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the reliability of PV systems (e.g., performance problems, vulnerability to water ingress and the condensation created by humidity, the risk of technological obsolescence, etc.) influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the conversion efficiency of PV systems (i.e., the percentage of incident solar energy that is converted to electricity) influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will safety issues for installing/developing a CSS project influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree

C. Neutral
D. Agree
E. Strongly agree

Will the lack of standards related to PV systems and insufficient guidelines on PV installation influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will immaturity of PV technologies, encompassing aspects such as PV system generation, installation, management, maintenance, and related factors, influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the restricted grid access to a CSS project influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will the limited space for a CSS project influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the quality of PV systems (e.g., performance problems, the risk of technological obsolescence, etc.) influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will the conversion efficiency of PV systems (i.e., the percentage of incident solar energy that is converted to electricity) influence your willingness to develop a CSS project?

F. Strongly disagree

G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will local weather conditions (e.g., humidity, solar irradiance) influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Section 2: Economic barriers

This section will ask you perspectives on economic barriers to CSS adoption, which relate to the cost and financing for a CSS project.

Will the high community solar rates (i.e., prices for PV-generated electricity) of a CSS project influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the payment inflexibility for a CSS project influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Would your willingness to join a CSS project be affected if it involves upfront costs?

A. Affected
B. Unaffected
C. Not sure

Will the payment with high upfront cost for a CSS project influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the lack of suitable financing mechanism influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the lack of subsidies for subscribers in joining a CSS project influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will a long payback period of a CSS project influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the high upfront cost of PV systems influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the high maintenance cost of PV systems influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the uncertainty over cost of a CSS project influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the high transaction costs of a CSS project influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the grid connection costs of a CSS project influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will the lack of suitable financing mechanism influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will insufficient incentives for developer in developing a CSS project influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Section 3: Market barriers

This section will ask you perspectives on market barriers to CSS adoption, which relate to the characteristics of electricity and PV markets.

Will the lack of information about CSS projects such as the subscription methods, management measures, market information, etc., influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will accessibility of CSS projects (i.e., whether it is easy or difficult to access to or join a CSS project) influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the existence of market monopoly (i.e., only CLP and HK Electric are available utility companies in the market) influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the lack of availability of energy services company that can handle the development, design, construction, financing, and maintenance aspects of energy projects influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the low electricity demand of your household influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will low electricity price from traditional energy sources in the local market influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will monopoly of utilities (i.e., only CLP and HK Electric are available utility companies in the market) influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree

J. Strongly agree

Will the lack of adequate knowledge about developing or managing CSS projects influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will the difficulty to successfully recruit subscribers in CSS projects influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the lack of subscribers with high electricity demand influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will ineffective marketing approaches and education campaigns in the local market influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Section 4: Social barriers

This section will ask you perspectives on social barriers to CSS adoption, which relate to the local conditions of the user's environment in a CSS project.

Will skepticism towards solar PV from you which arise from misconceptions about the reliability or complexity of solar power influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree

E. Strongly agree

Will negative peer perception on solar PV influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Are you interested in environmental action (i.e. An activity that intentionally addresses an environmental problem, need, or hazard, either directly or indirectly)?

A. Interested
B. Uninterested
C. Not sure

Will your personal interests in environmental action influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will esthetic considerations of PV systems influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will a negative impression or perception of PV panels influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will the existing national solar PV capacity and relevant infrastructure which can reduce technology risk and complexity influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will low social acceptance of CSS projects influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Section 5: Policy barriers

This section will ask you perspectives on policy barriers to CSS adoption, which relate to the policy measures to support renewable energies in local contexts.

Will insufficient policy support for CSS projects influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will ineffective policy support for CSS projects influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will legal and regulation constraints for CSS projects such as uncertain application and approval procedures influence your willingness to join a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will insufficient policy support for CSS projects influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will ineffective policy support for CSS projects influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Will legal and regulation constraints for CSS projects influence your willingness to develop a CSS project?

F. Strongly disagree
G. Disagree
H. Neutral
I. Agree
J. Strongly agree

Will skepticism regarding the feasibility of CSS projects or opposition from the central or local government influence your willingness to develop a CSS project?

A. Strongly disagree
B. Disagree
C. Neutral
D. Agree
E. Strongly agree

Section 6: Attitudes and preferences

1. In general, are you willing to develop a CSS project if it is available in Hong Kong?
   A. Strongly disagree
   B. Disagree
   C. Neutral
   D. Agree
   E. Strongly agree

2. In general, are you willing to join a CSS project if it is available in Hong Kong?
   A. Strongly disagree
   B. Disagree
   C. Neutral
   D. Agree
   E. Strongly agree

3. Please list the top two barriers affecting your adoption in CSS projects and give the reasons:

   ____

4. Except for the barriers above, please list other important barriers affecting your adoption in CSS projects and give the reasons, if any:

   ____

Section 7: Physical and socio-demographic characteristic information

1. My gender is:
   A. Male
   B. Female
   C. Others

2. My age is (in a numerical value):

   ____

3. My highest education level is:
   A. Primary and below
   B. Secondary
   C. Post-secondary: Diploma/Certificate
   D. Post-secondary: bachelor's degree
   E. Post-secondary: master's degree
   F. Post-secondary: doctorate degree

4. The type of entity I am working in is:
   A. Not-for-profit private institute
   B. University/ School
   C. (Quasi-) Government department
   D. Industry
   E. Business/Developer

5. Your job position is:

   ____

6. My current employment status is:
   A. Full-time employment
   B. Part-time employment

C. Unemployment
D. Retired

7. I live in:
A. Villas, bungalows, or village houses
B. Residential flats

8. What is the ownership status of your house?
A. Owner
B. Sole tenant
C. Co-tenant

9. The number of people in my household is:
A. 1
B. 2
C. 3
D. 4
E. 5 and above

10. My **monthly** household income (in HKD) is around:
A. ≤$9,999
B. $10,000 to $19,999
C. $20,000 to $29,999
D. $30,000 to $39,999
E. $40,000 to $49,999
F. $50,000 to $59,999
G. $60,000 to $79,999
H. ≥ $80,000

11. The **monthly** electricity bill of my household by season is around:

	250 HKD or below	250 to 500 HKD	500 to 750 HKD	750 to 1000 HKD	1000 to 1250 HKD	1250 to 1500 HKD	1500 HKD or above
Spring/Fall							
Summer							
Winter							

12. I live in:

New Territories	Islands
	Kwai Tsing
	North
	Sai Kung
	Sha Tin
	Tai Po
	Tsuen Wan
	Tuen Mun
	Yuen Long
Kowloon	Kowloon City
	Kwun Tong
	Sham Shui Po
	Wong Tai Sin
	Yau Tsim Wong
Hong Kong Island	Central and Western
	Eastern
	Southern
	Wan Chai

Appendix II: Questionnaire for relationships between barriers to community shared solar adoption in cities

Relationships between barriers to community shared solar adoption in cities

WELCOME TO THE STUDY

This questionnaire survey collects data and information about your views on relationships between barriers to the adoption of community shared solar (CSS) projects in Hong Kong.

The survey consists of **3 sections** and will take around **10** minutes. Your invaluable input by sharing your experience and opinions on this topic is very much appreciated. The information collected will be kept **strictly confidential** and will also be **destroyed** after use.

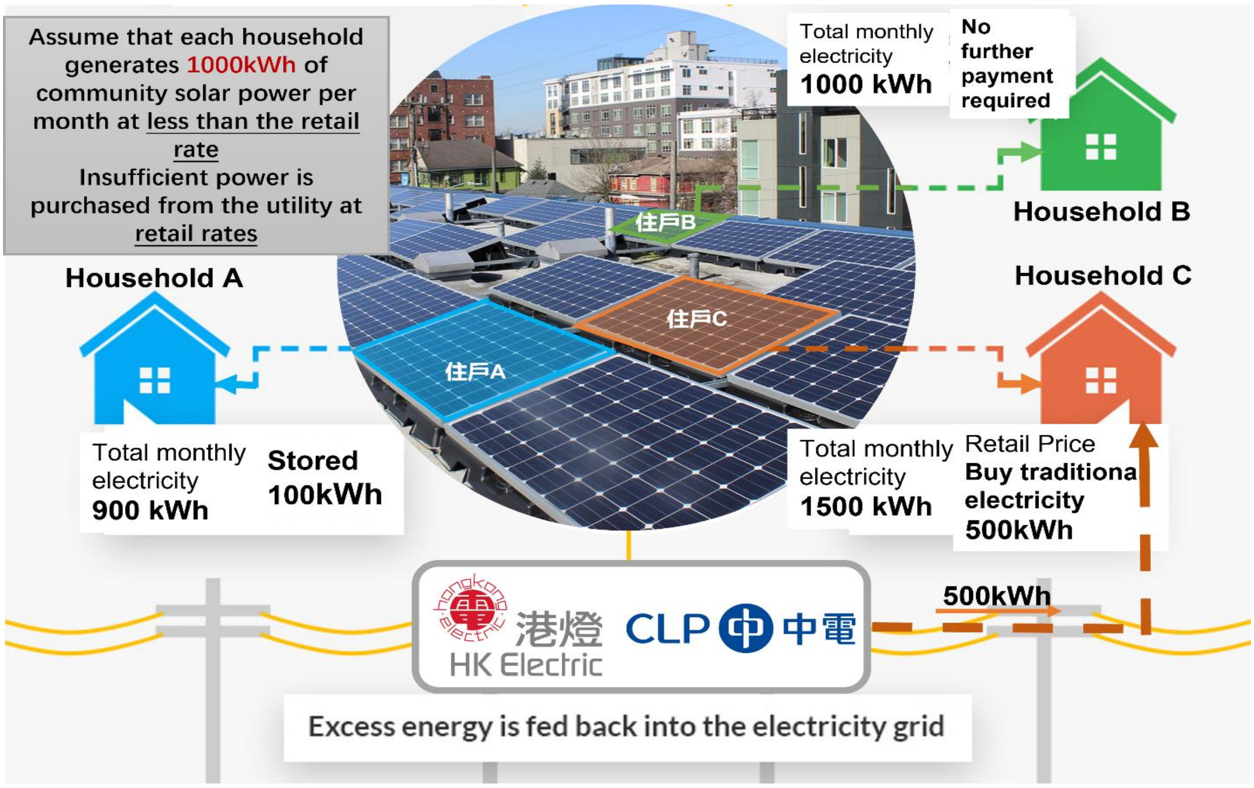
Please read the instructions carefully and answer every question as sincerely as possible. There are no right or wrong answers, so feel free to provide an answer that you think is true for you.

Introduction of Community shared solar project

Please read the following description about ***Community shared solar (CSS) project*** *carefully, and make sure that you fully understood the concept. Questions related to it will be presented afterward.*

Community shared Solar (CSS) project allows households or organizations to adopt solar **without installing a solar photovoltaic (PV) system** on their own property but rather **subscribe to a portion of a CSS project installed elsewhere in their Community**.

This program is designed and operated for those who are unable to install a PV system on their own property due to various reasons but still want to contribute to generating clean energy. Subscribers participating typically subscribe to a portion of a CSS project installed elsewhere in their Community and pay a subscription rate (usually lower than the retail electricity price) for the electricity generated from their share.
This program is currently not available in Hong Kong, but successfully operated in the United States (U.S.), and thus, its applicability has already been validated.



1. If you have a clear understanding of the solar program explained above, please type the **Community shared solar (CSS) project** below.

____

Section 1: Barriers of customers

This section will ask you perspectives on the relationship direction between each two variables, which relate to barriers of CSS adoption from the perspective of customers. There will be **two ways** to identify the relationships for each pair of barriers.

The below variables are barriers to community solar adoption **from the customer's perspective.**

A1	**Immaturity**	Immature solar technologies related to solar PV project installation, operation, management
A2	**Reliability**	Reliability of PV systems (e.g., performance problems)
A3	**Conversion efficiency**	The conversion efficiency of PV systems
A4	**Safety issues**	Safety issues for installing/developing a community solar project
A5	**High prices**	High PV-generated electricity prices
A6	**High upfront cost**	High upfront cost for joining community solar
A7	**Lack of financing mechanism**	The lack of suitable financing mechanisms to join community solar
A8	**Lack of subsidies**	The lack of subsidies for customers to join community solar
A9	**Lack of information**	The lack of information about community solar (e.g., subscription methods, market information)
A10	**Accessibility**	Accessibility of community solar (i.e., whether it is easy to join community solar)
A11	**Lack of energy services company**	The lack of availability of companies that can handle different aspects of energy projects
A12	**Legal and regulation constraints**	Legal and regulation constraints for community solar (e.g., uncertain application procedures)
A13	**Insufficient policy support**	Insufficient policy support to join community solar
A14	**Ineffective policy support**	Ineffective policy support to join community solar

Method one: Please define the **relationship direction** between two variables (i and j) by using **four symbols/codes** (see example 1).

A (V) = barrier i will influence barrier j;

S (A) = barrier i will be influenced by barrier j;

D (X) = barrier i and j influences each other; and

F (O) = barriers i and j doesn't influence each other, or there are no relations between i and j.

Example 1.

9	A1	A2	A3	A4
A1	-	V	X	A
A2	-	-	O	V
A3	-	-	-	X
A4	-	-	-	-

V, X, and A in row 2: A1 will influence A2; A1 and A3 influences each other; A1 will be influenced by A4.

O and V in row 3: A2 and A3 doesn't influence each other, A2 will influence A4.

X in row 4: A3 and A4 influences each other.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	-													
A2	-	-												
A3	-	-	-											
A4	-	-	-	-										
A5	-	-	-	-	-									
A6	-	-	-	-	-	-								
A7	-	-	-	-	-	-	-							
A8	-	-	-	-	-	-	-	-						
A9	-	-	-	-	-	-	-	-	-					
A10	-	-	-	-	-	-	-	-	-	-				
A11	-	-	-	-	-	-	-	-	-	-	-			
A12	-	-	-	-	-	-	-	-	-	-	-	-		
A13	-	-	-	-	-	-	-	-	-	-	-	-	-	
A14	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Method two: please identify the **direct effect** between each pair of barriers using a Likert scale, with a scale of **1 to 10** representing increasing influence depending on the influence of one barrier on other barriers. (see example 2)

Example 2.

	A1	A2	A3
A1	0	5	9
A2	2	0	7
A3	6	3	0

5 and 9 in row 2: A1 has moderate impact on A2; A1 has high impact on A3.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	-													
A2		-												
A3			-											
A4				-										
A5					-									
A6						-								
A7							-							
A8								-						
A9									-					
A10										-				
A11											-			
A12												-		
A13													-	
A14														-

Section 2: Barriers of developers

This section will ask you perspectives on the relationship direction between each two variables, which relate to barriers of CSS adoption from the perspective of developers. There will be **two ways** to identify the relationships for each pair of barriers.

The below variables are barriers to community solar adoption **from the developer's perspective.**

B1	**Immaturity**	Immature solar technologies related to solar PV project installation, operation, management
B2	**Grid access**	Restricted grid access to a community solar project
B3	**Limited space**	Limited space for the installation of solar PV systems
B4	**Reliability**	Reliability of PV systems (e.g., performance problems)
B5	**Conversion efficiency**	The conversion efficiency of PV systems
B6	**Weather**	Local weather conditions (e.g., humidity, solar irradiance)
B7	**Long payback period**	Long payback period of a community solar project
B8	**High upfront cost**	High upfront cost for developing community solar
B9	**High maintenance cost**	High maintenance cost of PV systems
B10	**High transaction costs**	High transaction costs of community solar
B11	**Grid connection costs**	Grid connection costs of community solar
B12	**Lack of financing mechanism**	The lack of suitable financing mechanisms to develop community solar
B13	**Insufficient incentives**	Insufficient incentives for developers in developing community solar
B14	**Uncertainty over cost**	Uncertainty over cost of community solar
B15	**Lack of knowledge**	Knowledge about developing or managing community solar
B16	**Existing technical capacity**	Existing national technical capacity and infrastructure which can reduce technology risk
B17	**Ineffective policy support**	Ineffective policy support to develop community solar

Method one: Please define the **relationship direction** between two variables (i and j) by using **four symbols/codes** (see example 1).

V = barrier i will influence barrier j;

A = barrier i will be influenced by barrier j;

X = barrier i and j influences each other; and

O = barriers i and j doesn't influence each other, or there are no relations between i and j.

Example 1.

	B1	B2	B3	B4
B1	-	O	V	A
B2	-	-	A	X
B3	-	-	-	V
B4	-	-	-	-

O, V and A in row 2: B1 and B2 doesn't influence each other; B1 will influence B3; B1 will be influenced by B4.

A and X in row 3: B2 be influenced by B3; B2 and B4 influence each other.

V in row 4: B3 will influence B4.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	-																
B2	-	-															
B3	-	-	-														
B4	-	-	-	-													
B5	-	-	-	-	-												
B6	-	-	-	-	-	-											
B7	-	-	-	-	-	-	-										
B8	-	-	-	-	-	-	-	-									
B9	-	-	-	-	-	-	-	-	-								
B10	-	-	-	-	-	-	-	-	-	-							
B11	-	-	-	-	-	-	-	-	-	-	-						
B12	-	-	-	-	-	-	-	-	-	-	-	-					
B13	-	-	-	-	-	-	-	-	-	-	-	-	-				
B14	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
B15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
B16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
B17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Method two: please identify the direct effect between each pair of barriers using a Likert scale, with a scale of **1 to 10** representing increasing influence depending on the influence of one barrier on other barriers. (see example four)

Example four.

	B1	B2	B3
B1	0	5	9
B2	2	0	7
B3	6	3	0

5 and 9 in row 2: B1 has moderate impact on B2; B1 has high impact on B3.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	-																
B2	-	-															
B3	-	-	-														
B4	-	-	-	-													
B5	-	-	-	-	-												
B6	-	-	-	-	-	-											
B7	-	-	-	-	-	-	-										
B8	-	-	-	-	-	-	-	-									
B9	-	-	-	-	-	-	-	-	-								
B10	-	-	-	-	-	-	-	-	-	-							
B11	-	-	-	-	-	-	-	-	-	-	-						
B12	-	-	-	-	-	-	-	-	-	-	-	-					
B13	-	-	-	-	-	-	-	-	-	-	-	-	-				
B14	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
B15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
B16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
B17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Section 3: Physical and socio-demographic characteristic information

1. My gender is:
   D. Male
   E. Female
   F. Others

2. The type of entity you are working in is:
   F. Not-for-profit private institute
   G. University/ School
   H. (Quasi-) Government department
   I. Industry
   J. Business/Developer

3. Your job position is:
   ____

Appendix III: Procedures and results of ISM and DEMATEL

Appendix III.1. The structural self-interactional model from the perspective of customers.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	-	A	A	A	A	A	D	A	F	A	D	A	D	D
A2	-	-	F	D	F	F	F	F	F	A	S	F	S	S
A3	-	-	-	F	A	F	F	F	F	F	A	F	F	F
A4	-	-	-	-	A	S	F	F	F	A	F	A	S	S
A5	-	-	-	-	-	S	S	S	F	A	S	F	S	S
A6	-	-	-	-	-	-	F	F	S	F	S	F	S	S
A7	-	-	-	-	-	-	-	F	F	A	F	F	S	S
A8	-	-	-	-	-	-	-	-	F	A	A	F	S	S
A9	-	-	-	-	-	-	-	-	-	D	S	F	S	S
A10	-	-	-	-	-	-	-	-	-	-	S	S	S	S
A11	-	-	-	-	-	-	-	-	-	-	-	F	S	S
A12	-	-	-	-	-	-	-	-	-	-	-	-	D	D
A13	-	-	-	-	-	-	-	-	-	-	-	-	-	D
A14	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix III.2. The structural self-interactional model from the perspective of developers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	-	A	F	A	A	F	A	A	A	A	A	A	D	F	D	S	D
B2	-	-	F	F	F	F	F	F	F	F	A	F	A	A	F	F	D
B3	-	-	-	F	F	F	F	F	A	F	F	F	A	F	F	F	S
B4	-	-	-	-	D	S	A	A	A	A	F	F	A	A	F	D	F
B5	-	-	-	-	-	S	A	F	F	F	F	A	A	A	S	A	F
B6	-	-	-	-	-	-	A	F	A	A	F	F	F	A	F	F	A
B7	-	-	-	-	-	-	-	S	S	S	S	D	S	S	F	S	S
B8	-	-	-	-	-	-	-	-	F	F	S	F	F	S	S	S	S
B9	-	-	-	-	-	-	-	-	-	F	F	F	F	S	S	S	F
B10	-	-	-	-	-	-	-	-	-	-	F	F	F	S	F	F	F
B11	-	-	-	-	-	-	-	-	-	-	-	F	F	S	F	D	S
B12	-	-	-	-	-	-	-	-	-	-	-	-	A	F	S	F	S
B13	-	-	-	-	-	-	-	-	-	-	-	-	-	F	S	F	S
B14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	S	S
B15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	D
B16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D
B17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix III.3. The reachability matrix from the perspective of customers.

Barriers	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	Driving power
A1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	13
A2	0	1	0	1	0	0	0	0	0	1	0	0	0	0	3
A3	0	0	1	0	1	0	0	0	0	0	1	0	0	0	3
A4	0	1	0	1	1	0	0	0	0	1	0	1	0	0	5
A5	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
A6	0	0	0	1	1	1	0	0	0	0	0	0	0	0	3
A7	1	0	0	0	1	0	1	0	0	1	0	0	0	0	4
A8	0	0	0	0	1	0	0	1	0	1	1	0	0	0	4
A9	0	0	0	0	0	1	0	0	1	1	0	0	0	0	3
A10	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
A11	1	1	0	0	1	1	0	0	1	1	1	0	0	0	7
A12	0	0	0	0	0	0	0	0	0	1	0	1	1	1	4
A13	1	1	0	1	1	1	1	1	1	1	1	1	1	1	13
A14	1	1	0	1	1	1	1	1	1	1	1	1	1	1	13
Dependence power	5	5	2	6	10	6	4	4	5	12	6	5	4	4	

Appendix III.4. The reachability matrix from the perspective of developers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	Driving power
B1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0	1	13
B2	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	5
B3	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	3
B4	0	0	0	1	1	0	1	1	1	1	0	0	1	1	0	1	0	9
B5	0	0	0	1	1	0	1	0	0	0	0	1	1	1	0	1	0	7
B6	0	0	0	1	1	1	1	0	1	1	0	0	0	1	0	0	1	8
B7	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2
B8	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
B9	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
B10	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
B11	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1	0	4
B12	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	3
B13	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	3
B14	0	0	0	0	0	0	1	1	1	1	1	0	0	1	0	0	0	6
B15	1	0	0	0	1	0	0	1	1	0	1	1	1	0	1	1	0	9
B16	1	0	0	1	0	0	1	1	1	0	1	0	0	1	0	1	1	9
B17	1	1	1	0	0	0	1	1	0	0	1	1	1	1	0	1	1	11
Dependence power	5	3	2	5	5	1	14	8	8	5	7	6	9	7	2	6	5	

Appendix III.5. The direct relation matrix from the perspective of customers.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	0.00	4.50	5.00	4.25	4.25	4.25	4.50	3.00	3.50	4.00	4.50	4.25	4.25	4.00
A2	2.50	0.00	2.75	4.25	3.25	3.00	2.75	2.50	2.50	3.25	4.50	2.75	2.50	2.50
A3	4.25	4.00	0.00	0.75	4.75	3.50	2.50	2.75	1.75	2.50	3.50	3.00	3.25	2.75
A4	4.00	4.00	0.75	0.00	3.25	4.00	2.50	2.00	1.50	3.00	4.75	3.00	3.00	2.75
A5	2.75	2.50	1.50	2.50	0.00	4.25	3.50	3.75	3.00	3.25	3.75	3.75	2.75	3.25
A6	2.00	2.50	1.00	3.00	4.67	0.00	4.25	3.50	2.75	3.25	3.50	2.50	2.50	3.25
A7	2.50	2.00	0.75	1.75	4.00	3.50	0.00	3.00	1.75	3.25	3.75	2.50	3.25	3.50
A8	2.00	1.75	0.75	1.25	3.00	2.50	4.00	0.00	1.00	3.75	3.50	2.75	2.50	2.25
A9	2.00	1.75	0.75	2.00	1.25	1.25	2.00	1.75	0.00	3.00	3.25	2.75	2.50	2.25
A10	2.00	2.50	1.50	3.00	3.25	3.50	3.00	2.75	4.25	0.00	4.25	2.50	2.50	2.50
A11	1.50	1.25	0.75	2.25	3.50	3.50	4.00	3.25	4.00	3.50	0.00	2.00	2.50	1.50
A12	2.25	3.25	1.50	2.50	2.75	3.50	3.00	3.25	3.25	2.25	3.25	0.00	3.00	2.75
A13	2.75	2.75	1.25	3.75	3.50	3.50	3.00	3.75	3.50	3.75	3.25	2.75	0.00	4.25
A14	2.75	3.00	1.25	4.00	2.50	2.75	2.50	3.50	3.00	3.00	2.25	1.75	2.50	0.00

Appendix III.6. The direct relation matrix from the perspective of developers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	0.00	3.25	1.50	5.00	5.00	1.00	5.00	5.00	5.00	3.50	3.75	4.25	3.75	3.25	4.75	3.75	4.00
B2	1.50	0.00	1.75	1.50	1.00	1.00	2.50	2.00	1.75	1.75	3.75	2.00	2.25	2.50	2.25	2.75	2.75
B3	0.50	3.00	0.00	1.25	1.50	0.75	3.75	2.50	2.50	1.75	1.25	2.00	2.75	1.75	1.00	1.75	1.25
B4	3.50	5.00	0.50	0.00	3.50	1.50	4.50	3.00	3.25	2.00	1.75	1.50	2.75	3.75	1.75	3.00	2.25
B5	3.00	2.00	1.00	1.00	0.00	3.00	3.50	2.75	1.75	1.75	1.50	1.75	2.50	2.25	2.50	2.75	2.50
B6	1.00	4.50	1.00	4.00	3.00	0.00	4.25	2.75	3.00	2.75	2.75	2.25	1.75	3.50	1.25	2.50	2.25
B7	2.00	1.00	2.50	1.00	1.00	1.00	0.00	2.00	2.50	2.75	1.25	2.00	2.75	2.50	2.25	2.50	2.25
B8	1.00	1.00	1.50	1.00	1.00	1.00	5.00	0.00	2.00	3.50	2.00	2.00	2.25	2.75	2.00	2.75	2.00
B9	1.00	1.00	1.50	1.00	1.00	1.00	4.50	1.00	0.00	2.25	1.00	1.75	2.25	3.00	1.75	2.50	1.50
B10	1.00	1.00	1.50	1.00	1.00	1.00	4.50	1.00	1.00	0.00	2.50	2.25	1.50	2.00	1.50	2.00	1.75
B11	1.00	2.50	1.50	1.00	1.00	1.00	4.50	2.00	1.00	3.00	0.00	1.50	1.75	1.50	2.00	2.25	1.75
B12	2.00	2.00	1.00	2.00	1.00	1.00	4.00	3.00	2.50	3.00	3.00	0.00	3.75	2.75	2.75	3.00	2.75
B13	1.00	1.00	1.00	1.00	1.00	1.00	4.50	2.00	1.50	2.00	1.50	2.50	0.00	2.25	3.00	2.50	3.50
B14	1.50	1.00	1.00	1.00	1.00	1.00	3.50	2.00	2.00	1.00	2.00	1.00	1.50	0.00	2.25	2.75	2.25
B15	3.50	1.50	1.00	3.00	3.00	1.00	1.50	1.50	1.50	2.00	1.50	3.00	2.00	2.50	0.00	3.50	3.50
B16	2.50	2.50	1.00	3.00	1.00	1.00	1.50	2.00	1.00	1.50	1.50	1.50	2.00	2.00	4.00	0.00	2.25
B17	1.00	3.50	2.00	1.50	1.00	1.00	2.00	2.00	1.50	2.00	2.00	3.00	3.00	2.50	1.50	2.50	0.00

Appendix III.7. The normalized direct relation matrix from the perspective of customers.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	0.00	0.08	0.09	0.08	0.08	0.08	0.08	0.06	0.06	0.07	0.08	0.08	0.08	0.07
A2	0.05	0.00	0.05	0.08	0.06	0.06	0.05	0.05	0.05	0.06	0.08	0.05	0.05	0.05
A3	0.08	0.07	0.00	0.01	0.09	0.06	0.05	0.05	0.03	0.05	0.06	0.06	0.06	0.05
A4	0.07	0.07	0.01	0.00	0.06	0.07	0.05	0.04	0.03	0.06	0.09	0.06	0.06	0.05
A5	0.05	0.05	0.03	0.05	0.00	0.08	0.06	0.07	0.06	0.06	0.07	0.07	0.05	0.06
A6	0.04	0.05	0.02	0.06	0.09	0.00	0.08	0.06	0.05	0.06	0.06	0.05	0.05	0.06
A7	0.05	0.04	0.01	0.03	0.07	0.06	0.00	0.06	0.03	0.06	0.07	0.05	0.06	0.06
A8	0.04	0.03	0.01	0.02	0.06	0.05	0.07	0.00	0.02	0.07	0.06	0.05	0.05	0.04
A9	0.04	0.03	0.01	0.04	0.02	0.02	0.04	0.03	0.00	0.06	0.06	0.05	0.05	0.04
A10	0.04	0.05	0.03	0.06	0.06	0.06	0.06	0.05	0.08	0.00	0.08	0.05	0.05	0.05
A11	0.03	0.02	0.01	0.04	0.06	0.06	0.07	0.06	0.07	0.06	0.00	0.04	0.05	0.03
A12	0.04	0.06	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.04	0.06	0.00	0.06	0.05
A13	0.05	0.05	0.02	0.07	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.05	0.00	0.08
A14	0.05	0.06	0.02	0.07	0.05	0.05	0.05	0.06	0.06	0.06	0.04	0.03	0.05	0.00

Appendix III.8. The normalized direct relation matrix from the perspective of developers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	0.00	0.05	0.02	0.08	0.08	0.02	0.08	0.08	0.08	0.06	0.06	0.07	0.06	0.05	0.08	0.06	0.06
B2	0.02	0.00	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.03	0.06	0.03	0.04	0.04	0.04	0.04	0.04
B3	0.01	0.05	0.00	0.02	0.02	0.01	0.06	0.04	0.04	0.03	0.02	0.03	0.04	0.03	0.02	0.03	0.02
B4	0.06	0.08	0.01	0.00	0.06	0.02	0.07	0.05	0.05	0.03	0.03	0.02	0.04	0.06	0.03	0.05	0.04
B5	0.05	0.03	0.02	0.02	0.00	0.05	0.06	0.04	0.03	0.03	0.02	0.03	0.04	0.04	0.04	0.04	0.04
B6	0.02	0.07	0.02	0.06	0.05	0.00	0.07	0.04	0.05	0.04	0.04	0.04	0.03	0.06	0.02	0.04	0.04
B7	0.03	0.02	0.04	0.02	0.02	0.02	0.00	0.03	0.04	0.04	0.02	0.03	0.04	0.04	0.04	0.04	0.04
B8	0.02	0.02	0.02	0.02	0.02	0.02	0.08	0.00	0.03	0.06	0.03	0.03	0.04	0.04	0.03	0.04	0.03
B9	0.02	0.02	0.02	0.02	0.02	0.02	0.07	0.02	0.00	0.04	0.02	0.03	0.04	0.05	0.03	0.04	0.02
B10	0.02	0.02	0.02	0.02	0.02	0.02	0.07	0.02	0.02	0.00	0.04	0.04	0.02	0.03	0.02	0.03	0.03
B11	0.02	0.04	0.02	0.02	0.02	0.02	0.07	0.03	0.02	0.05	0.00	0.02	0.03	0.02	0.03	0.04	0.03
B12	0.03	0.03	0.02	0.03	0.02	0.02	0.06	0.05	0.04	0.05	0.05	0.00	0.06	0.04	0.04	0.05	0.04
B13	0.02	0.02	0.02	0.02	0.02	0.02	0.07	0.03	0.02	0.03	0.02	0.04	0.00	0.04	0.05	0.04	0.06
B14	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.03	0.03	0.02	0.03	0.02	0.02	0.00	0.04	0.04	0.04
B15	0.06	0.02	0.02	0.05	0.05	0.02	0.02	0.02	0.02	0.03	0.02	0.05	0.03	0.04	0.00	0.06	0.06
B16	0.04	0.04	0.02	0.05	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.06	0.00	0.04
B17	0.02	0.06	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.05	0.05	0.04	0.02	0.04	0.00

Appendix III.9. The total relation matrix from the perspective of customers.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A1	0.15	0.23	0.16	0.23	0.26	0.25	0.26	0.23	0.21	0.25	0.28	0.23	0.24	0.23
A2	0.16	0.11	0.11	0.19	0.2	0.19	0.19	0.18	0.17	0.19	0.23	0.17	0.17	0.17
A3	0.18	0.18	0.06	0.13	0.22	0.19	0.19	0.18	0.15	0.18	0.21	0.18	0.18	0.17
A4	0.17	0.18	0.07	0.12	0.2	0.2	0.19	0.17	0.15	0.19	0.23	0.18	0.18	0.17
A5	0.16	0.16	0.09	0.17	0.14	0.21	0.2	0.2	0.18	0.2	0.22	0.19	0.18	0.18
A6	0.14	0.16	0.08	0.17	0.22	0.13	0.21	0.18	0.16	0.19	0.21	0.17	0.17	0.18
A7	0.14	0.14	0.06	0.14	0.19	0.18	0.12	0.17	0.14	0.18	0.2	0.15	0.17	0.16
A8	0.12	0.12	0.06	0.11	0.17	0.15	0.17	0.1	0.11	0.17	0.18	0.14	0.15	0.13
A9	0.11	0.11	0.05	0.12	0.11	0.11	0.13	0.12	0.08	0.15	0.16	0.13	0.13	0.12
A10	0.14	0.16	0.08	0.17	0.19	0.19	0.19	0.17	0.19	0.13	0.22	0.16	0.17	0.16
A11	0.12	0.11	0.06	0.13	0.17	0.16	0.18	0.16	0.16	0.17	0.12	0.14	0.15	0.13
A12	0.14	0.16	0.08	0.16	0.18	0.18	0.18	0.17	0.17	0.16	0.2	0.11	0.17	0.16
A13	0.16	0.16	0.08	0.19	0.20	0.19	0.20	0.20	0.18	0.21	0.21	0.17	0.13	0.20
A14	0.14	0.16	0.07	0.17	0.17	0.17	0.17	0.17	0.16	0.18	0.17	0.14	0.16	0.11

Appendix III.10. The total relation matrix from the perspective of developers.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
B1	0.06	0.12	0.07	0.14	0.14	0.07	0.19	0.15	0.14	0.13	0.12	0.14	0.14	0.13	0.15	0.15	0.14
B2	0.05	0.04	0.05	0.05	0.05	0.04	0.1	0.07	0.06	0.07	0.09	0.07	0.08	0.08	0.08	0.09	0.08
B3	0.04	0.08	0.02	0.05	0.05	0.03	0.11	0.07	0.07	0.07	0.05	0.06	0.08	0.07	0.06	0.07	0.06
B4	0.1	0.13	0.05	0.05	0.1	0.05	0.15	0.1	0.1	0.08	0.08	0.07	0.1	0.12	0.09	0.11	0.1
B5	0.09	0.07	0.05	0.06	0.04	0.08	0.13	0.08	0.07	0.08	0.06	0.07	0.09	0.09	0.09	0.09	0.09
B6	0.06	0.12	0.05	0.1	0.09	0.03	0.15	0.09	0.1	0.09	0.09	0.09	0.08	0.12	0.07	0.1	0.1
B7	0.06	0.06	0.06	0.05	0.05	0.04	0.06	0.07	0.07	0.08	0.05	0.07	0.08	0.08	0.08	0.08	0.08
B8	0.05	0.06	0.05	0.05	0.05	0.04	0.14	0.04	0.07	0.1	0.06	0.07	0.08	0.08	0.07	0.09	0.07
B9	0.05	0.05	0.04	0.05	0.05	0.04	0.12	0.05	0.03	0.08	0.05	0.06	0.08	0.09	0.07	0.08	0.06
B10	0.05	0.05	0.04	0.05	0.05	0.04	0.12	0.05	0.05	0.04	0.07	0.07	0.06	0.07	0.06	0.07	0.07
B11	0.05	0.07	0.04	0.05	0.05	0.04	0.12	0.06	0.05	0.09	0.03	0.05	0.07	0.06	0.07	0.08	0.07
B12	0.07	0.07	0.05	0.07	0.06	0.05	0.13	0.09	0.08	0.1	0.09	0.05	0.11	0.09	0.09	0.1	0.09
B13	0.05	0.06	0.05	0.05	0.05	0.04	0.13	0.07	0.06	0.07	0.05	0.08	0.04	0.08	0.09	0.09	0.10
B14	0.05	0.05	0.04	0.05	0.05	0.04	0.11	0.06	0.06	0.05	0.06	0.05	0.05	0.04	0.07	0.08	0.08
B15	0.1	0.07	0.05	0.09	0.09	0.05	0.09	0.07	0.06	0.08	0.06	0.09	0.08	0.09	0.05	0.11	0.11
B16	0.07	0.08	0.04	0.08	0.05	0.04	0.08	0.07	0.06	0.06	0.05	0.06	0.07	0.07	0.1	0.05	0.08
B17	0.05	0.1	0.05	0.05	0.05	0.04	0.09	0.07	0.05	0.07	0.06	0.08	0.09	0.08	0.06	0.08	0.04

Appendix IV: Daily Global Solar Radiation at King's Park

Table IV. Daily Global Solar Radiation (MJ/m²) at King's Park of Hong Kong in 2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	7.3	3.3	20.24	4.1	4.13	12.93	12.37	27.51	16.58	13.12	3.21	7.29
2	15.52	3.39	18.01	5.09	9.6	16.43	4.55	23.96	18.55	15.79	5.37	13.89
3	15.15	3.95	17.69	26.02	25.27	11.24	9.14	9.25	24.64	23.05	3.77	11.17
4	16.46	13.79	20.91	27.15	26.59	20.38	4.75	5.33	24.31	16.73	4.27	11.76
5	16.78	10.9	18.34	25.64	25.08	21.65	4.2	8.49	22.05	18.22	3.26	8.15
6	16.2	13.3	13.74	24.27	25.59	9.33	9.37	16.71	22.76	22.31	8.17	13.86
7	10.91	3.8	13.99	24.08	16.73	7.52	10.93	24.81	9.14	19.88	9.42	14.65
8	16.48	7.4	25.87	26.24	12.47	2.06	27.32	8.43	23.21	20.6	6.61	16.1
9	8.64	4.65	25.11	26.95	18.34	5.92	17.1	6.65	23.94	18.85	18.06	16.12
10	11.12	5.57	24.05	26.55	9.52	4.79	28.11	6.99	11.63	15.43	17.14	16.45
11	17.02	20.67	22.61	17.46	2.06	6.53	26.9	8.08	20.67	21.41	15.26	8.91
12	8.93	17.67	23.39	21.69	0.79	11.01	28.05	4.61	20.85	22.1	8.67	12.37
13	8.38	2.11	22.48	13.13	8.06	15.31	23.24	15.09	22.61	17.88	18.3	5.78
14	5.06	18.98	22.25	24.96	9.82	4.28	22.43	22.63	22.93	21.1	10.6	3.39
15	15.42	16.28	21.11	24.98	10.44	11.29	22.09	19.48	22.95	20.69	13.93	4.17
16	11.93	10.1	10.51	11.17	6.4	11.81	22.53	19.41	18.14	13.24	13.53	2.53
17	3.59	2.81	15	14.24	18.49	17.52	23.39	15.07	20.99	9.49	10.32	5.42
18	5.29	6.65	17.72	4.74	20.19	8.6	17.85	10.43	18.25	4.52	17.7	17.21
19	16.14	1.86	15.1	3.87	22.51	11.55	19.98	14.34	15.09	15.75	17.6	16.84
20	16.53	2.79	5.04	17.58	23.61	10.26	19.4	18.28	10.45	14.14	16.42	14.13
21	11.99	2.93	9.12	21.15	23.42	9.54	23.32	17.45	22.78	21.2	6.59	16.2
22	3.81	3.53	7.76	13.49	9.48	16.84	27.32	25.86	20.88	16.87	3.74	17.55
23	9.79	15.39	2.91	21.48	3.85	24.44	27.5	22.9	13.65	14.22	4.12	17.24
24	8.11	16.23	4.9	18.88	5.58	27.81	26.65	17.66	20.59	17.52	3.42	16.89
25	7.43	18.88	5.81	15.69	11.3	25.44	25.98	11.26	20.99	21.1	4.43	17.29
26	11.73	21.55	10.08	12.32	17.05	26.93	24.88	22.57	20.5	20.82	4.27	16.64
27	15.33	22.23	4.97	19.3	3.83	23.34	27.68	25.57	14.11	20.49	3.66	16.72
28	3.97	20.66	3.18	20.07	18.08	27.2	24.95	24.88	15.53	18.97	11.34	16
29	6.63		7.79	22.38	19.39	20.59	21.61	15.97	8.76	18.84	17.05	12.77
30	16.78		17.74	4.84	21.64	7.35	5.43	18.15	2.38	16.54	7.06	15.69
31	3.79		20.18		13.14		24.79	15.08		11.26		16.52

References

Adarsh Nagarajan, R. T., Ingrid Repins, and Peter Hacke. (2019). *Photovoltaic Inverter Reliability Assessment*. https://www.nrel.gov/docs/fy20osti/74462.pdf

Adeh, E. H., Good, S. P., Calaf, M., & Higgins, C. W. (2019). Solar PV power potential is greatest over croplands. *Scientific reports*, *9*(1), 11442.

Aghamolaei, R., Shamsi, M. H., & O'Donnell, J. (2020). Feasibility analysis of community-based PV systems for residential districts: A comparison of on-site centralized and distributed PV installations. *Renewable Energy*, *157*, 793-808. https://doi.org/https://doi.org/10.1016/j.renene.2020.05.024

Ahmadi, S., Nourmohamadzadeh, Z., & Amiri, B. (2023). A hybrid DEMATEL and social network analysis model to identify factors affecting learners' satisfaction with MOOCs. *Heliyon*, *9*(7), e17894. https://doi.org/10.1016/j.heliyon.2023.e17894

Akinci, H., & Özalp, A. Y. (2022). Optimal site selection for solar photovoltaic power plants using geographical information systems and fuzzy logic approach: a case study in Artvin, Turkey. *Arabian Journal of Geosciences*, *15*(9). https://doi.org/10.1007/s12517-022-10129-y

Al Garni, H. Z., & Awasthi, A. (2017). Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. *Applied Energy*, *206*, 1225-1240.

Al Garni, H. Z., & Awasthi, A. (2018). Solar PV power plants site selection: A review. *Advances in Renewable Energies and Power Technologies*, 57-75.

Alam, S. S., Ahmad, M., Othman, A. S., Shaari, Z. B. H., & Masukujjaman, M. (2021). Factors Affecting Photovoltaic Solar Technology Usage Intention among Households in Malaysia: Model Integration and Empirical Validation. *Sustainability*, *13*(4), 1773. https://www.mdpi.com/2071-1050/13/4/1773

Alami Merrouni, A., Elwali Elalaoui, F., Mezrhab, A., Mezrhab, A., & Ghennioui, A. (2018). Large scale PV sites selection by combining GIS and Analytical Hierarchy Process. Case study: Eastern Morocco. *Renewable Energy*, *119*, 863-873. https://doi.org/https://doi.org/10.1016/j.renene.2017.10.044

Alami Merrouni, A., Mezrhab, A., & Mezrhab, A. (2016). PV sites suitability analysis in the Eastern region of Morocco. *Sustainable Energy Technologies and Assessments*, *18*, 6-15. https://doi.org/https://doi.org/10.1016/j.seta.2016.09.006

Aldahmashi, N., Khan, Y., & Alamoud, A. (2021, 20-25 June 2021). Techno-Economic Analysis of Grid-connected Rooftop Solar PV Systems in Saudi Arabia. 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC),

Ali, S., Taweekun, J., Techato, K., Waewsak, J., & Gyawali, S. (2019). GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand. *Renewable Energy*, *132*, 1360-1372.

Ali, S. M., Hossen, M. A., Mahtab, Z., Kabir, G., Paul, S. K., & Adnan, Z. u. H. (2020). Barriers to lean six sigma implementation in the supply chain: An ISM model. *Computers & Industrial Engineering*, *149*, 106843. https://doi.org/https://doi.org/10.1016/j.cie.2020.106843

Alonso, J. C., Dose, J., Fleischer, G., Geraghty, K., Greif, A., Rodrigo, J., & Schmidt, W.-P. (2007). Electrical and electronic components in the automotive sector: Economic and environmental assessment. *The International Journal of Life Cycle Assessment*, *12*, 328-335.

Aly, A., Jensen, S. S., & Pedersen, A. B. (2017). Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis. *Renewable Energy*, *113*, 159-175.

An, J., Hong, T., & Lee, M. (2022). Determining the optimal trading price of electricity for energy consumers and prosumers. *Renewable and Sustainable Energy Reviews*, *154*. https://doi.org/10.1016/j.rser.2021.111851

Arán Carrión, J., Espín Estrella, A., Aznar Dols, F., Zamorano Toro, M., Rodríguez, M., & Ramos Ridao, A. (2008). Environmental decision-support systems for evaluating the carrying capacity of land areas: Optimal site selection for grid-connected photovoltaic power plants. *Renewable and Sustainable Energy Reviews*, *12*(9), 2358-2380. https://doi.org/https://doi.org/10.1016/j.rser.2007.06.011

Arroyo, P., & Carrete, L. (2019). Motivational drivers for the adoption of green energy. *Management Research Review*, *42*(5), 542-567. https://doi.org/10.1108/MRR-02-2018-0070

Asante, D., He, Z., Adjei, N. O., & Asante, B. (2020). Exploring the barriers to renewable energy adoption utilising MULTIMOORA- EDAS method. *Energy Policy*, *142*, 111479. https://doi.org/https://doi.org/10.1016/j.enpol.2020.111479

Ashraf, U., Morelli, T. L., Smith, A. B., & Hernandez, R. R. (2024). Climate-Smart Siting for renewable energy expansion. *iScience*, *27*(10). https://doi.org/10.1016/j.isci.2024.110666

Ashtianipour, Z., & Zandhessami, H. (2015, 2-6 Aug. 2015). An integrated ISM-DEMATEL model for evaluation of technological innovation capabilities' impact on the competitiveness of Small & Medium Size Enterprises (SMEs). 2015 Portland International Conference on Management of Engineering and Technology (PICMET),

Augustine, P., & McGavisk, E. (2016). The next big thing in renewable energy: Shared solar. *The Electricity Journal*, *29*(4), 36-42.

Awad, H., & Gül, M. (2018). Optimisation of community shared solar application in energy efficient communities. *Sustainable Cities and Society*, *43*, 221-237. https://doi.org/https://doi.org/10.1016/j.scs.2018.08.029

Babey, A.-M. (2020). Doing your research project. A guide for first-time researchers. *Higher Education Research & Development*, *39*(4), 852-854. https://doi.org/10.1080/07294360.2019.1675294

Balaman, Ş. Y. (2019). Chapter 5 - Uncertainty Issues in Biomass-Based Production Chains. In Ş. Y. Balaman (Ed.), *Decision-Making for Biomass-Based Production Chains* (pp. 113-142). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-814278-3.00005-4

Balta-Ozkan, N., Yildirim, J., & Connor, P. M. (2015). Regional distribution of photovoltaic deployment in the UK and its determinants: A spatial econometric approach. *Energy Economics*, *51*, 417-429. https://doi.org/10.1016/j.eneco.2015.08.003

Balta-Ozkan, N., Yildirim, J., Connor, P. M., Truckell, I., & Hart, P. (2021). Energy transition at local level: Analyzing the role of peer effects and socio-economic factors on UK solar photovoltaic deployment. *Energy Policy*, *148*. https://doi.org/10.1016/j.enpol.2020.112004

Bandaru, S. H., Becerra, V., Khanna, S., Espargilliere, H., Torres Sevilla, L., Radulovic, J., Hutchinson, D., & Khusainov, R. (2021). A General Framework for Multi-Criteria Based Feasibility Studies for Solar Energy Projects: Application to a Real-World Solar Farm. *Energies*, *14*(8). https://doi.org/10.3390/en14082204

Bashiri, A., & Alizadeh, S. H. (2018). The analysis of demographics, environmental and knowledge factors affecting prospective residential PV system adoption: A study in Tehran. *Renewable and Sustainable Energy Reviews*, *81*, 3131-3139. https://doi.org/10.1016/j.rser.2017.08.093

Batel, S., Devine-Wright, P., & Tangeland, T. (2013). Social acceptance of low carbon energy and associated infrastructures: A critical discussion. *Energy Policy*, *58*, 1-5. https://doi.org/https://doi.org/10.1016/j.enpol.2013.03.018

Bauwens, T., & Devine-Wright, P. (2018). Positive energies? An empirical study of community energy participation and attitudes to renewable energy. *Energy Policy*, *118*, 612-625.
Beck, A. L., Chan, G., & Rai, V. (2020). *Scaling community solar in Texas: Barries, strategies, and roadmap*.
Beikkhakhian, Y., Javanmardi, M., Karbasian, M., & Khayambashi, B. (2015). The application of ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods. *Expert Systems with Applications*, *42*(15), 6224-6236. https://doi.org/https://doi.org/10.1016/j.eswa.2015.02.035
Bell, D., Gray, T., & Haggett, C. (2005). The 'social gap'in wind farm siting decisions: explanations and policy responses. *Environmental politics*, *14*(4), 460-477.
Boon, F. P., & Dieperink, C. (2014). Local civil society based renewable energy organisations in the Netherlands: Exploring the factors that stimulate their emergence and development. *Energy Policy*, *69*, 297-307. https://doi.org/https://doi.org/10.1016/j.enpol.2014.01.046
Bovarnick, B., & Johnson, L. (2017). Research Review on Residential Solar Access: Barriers and Solutions for Low and Moderate Income Communities. In: Connecticut. Retrieved from http://cbey. yale. edu/sites/default/files ….
Boyd, A. D., & Paveglio, T. B. (2015). " Placing" Energy Development in a Local Context: Exploring the Origins of Rural Community Perspectives. *Journal of Rural and Community Development*, *10*(2).
Brummer, V. (2018). Community energy–benefits and barriers: A comparative literature review of Community Energy in the UK, Germany and the USA, the benefits it provides for society and the barriers it faces. *Renewable and Sustainable Energy Reviews*, *94*, 187-196.
Burch, J., Woods, J., Kozubal, E., & Boranian, A. (2012). Zero energy communities with central solar plants using liquid desiccants and local storage. *Energy Procedia*, *30*, 55-64.
Burger, A. (2017). The sun rises on Japan's solar-powered smart communities. *Solar Magazine. Available online at: https://solarmagazine. com/the-sun-rises-on-japans-solar-powered-smart-communities/[Accessed 3 October 2020]*.
Burtt, D., & Dargusch, P. (2015). The cost-effectiveness of household photovoltaic systems in reducing greenhouse gas emissions in Australia: Linking subsidies with emission reductions. *Applied Energy*, *148*, 439-448. https://doi.org/https://doi.org/10.1016/j.apenergy.2015.03.091
Calvert, K., & Mabee, W. (2015). More solar farms or more bioenergy crops? Mapping and assessing potential land-use conflicts among renewable energy technologies in eastern Ontario, Canada. *Applied Geography*, *56*, 209-221.
Carlisle, J. E., Kane, S. L., Solan, D., Bowman, M., & Joe, J. C. (2015). Public attitudes regarding large-scale solar energy development in the US. *Renewable and Sustainable Energy Reviews*, *48*, 835-847.
Cass, N., Walker, G., & Devine-Wright, P. (2010). Good neighbours, public relations and bribes: the politics and perceptions of community benefit provision in renewable energy development in the UK. *Journal of environmental policy & planning*, *12*(3), 255-275.
Chakrabarti, S., & Chakrabarti, S. (2002). Rural electrification programme with solar energy in remote region–a case study in an island. *Energy Policy*, *30*(1), 33-42.
Chan, G., Evans, I., Grimley, M., Ihde, B., & Mazumder, P. (2017). Design choices and equity implications of community shared solar. *The Electricity Journal*, *30*(9), 37-41. https://doi.org/https://doi.org/10.1016/j.tej.2017.10.006

Chan, G., Grimley, M., Arnold, E., Evans, I., Herbers, J., Hoffman, M., Ihde, B., Mazumder, P., Morgan, J., & Neuman, N. (2018). Community shared solar in Minnesota: Learning from the first 300 megawatts.

Chang, B., & Starcher, K. (2019). Evaluation of wind and solar energy investments in Texas. *Renewable Energy*, *132*, 1348-1359. https://doi.org/https://doi.org/10.1016/j.renene.2018.09.037

Chang, C.-T. (2007). Multi-choice goal programming. *Omega*, *35*(4), 389-396.

Chang, V., Goldenberg, C., Hoskins, J., Lassiter, S., Li, Z., Nakatani, E., Oluwafemi, S., & Safford, H. (2017). Solar gardens in the Garden State: community solar recommendations for New Jersey.

Charabi, Y., & Gastli, A. (2011). PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renewable Energy*, *36*(9), 2554-2561. https://doi.org/https://doi.org/10.1016/j.renene.2010.10.037

Chen, X., & Qiao, W. (2023). A hybrid STAMP-fuzzy DEMATEL-ISM approach for analyzing the factors influencing building collapse accidents in China. *Scientific reports*, *13*(1), 19745. https://doi.org/10.1038/s41598-023-46778-6

Choi, Y., Suh, J., & Kim, S.-M. (2019). GIS-Based Solar Radiation Mapping, Site Evaluation, and Potential Assessment: A Review. *Applied Sciences*, *9*(9), 1960. https://www.mdpi.com/2076-3417/9/9/1960

Chuang, H.-M., Lin, C. K., Chen, D.-R., & Chen, Y.-S. (2013). Evolving MCDM applications using hybrid expert-based ISM and DEMATEL models: An example of sustainable ecotourism. *TheScientificWorldJournal*, *2013*, 751728. https://doi.org/10.1155/2013/751728

Cleland, M. (2016). A Matter of Trust: The role of communities in energy decision-making.

CLP, C. P. H. K. L. (2022). *CLP Information Kit*. https://www.clp.com.hk/content/dam/clphk/documents/about-clp-site/media-site/resources-site/publications-site/CLP-Information-Kit-English.pdf

CLP, C. P. H. K. L. (2023). *Electricity Tariff*.

Colak, H. E., Memisoglu, T., & Gercek, Y. (2020). Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey. *Renewable Energy*, *149*, 565-576. https://doi.org/https://doi.org/10.1016/j.renene.2019.12.078

Coruhlu, Y. E., Solgun, N., Baser, V., & Terzi, F. (2022). Revealing the solar energy potential by integration of GIS and AHP in order to compare decisions of the land use on the environmental plans. *Land use policy*, *113*, 105899. https://doi.org/https://doi.org/10.1016/j.landusepol.2021.105899

Coughlin, J., Grove, J., Irvine, L., Jacobs, J. F., Phillips, S. J., Moynihan, L., & Wiedman, J. (2011). Guide to community solar: Utility, private, and non-profit project development.

Craven, C. (2011). *Community solar garden gets first site*. https://www.csbj.com/news/daily/community-solar-garden-gets-first-site/article_6945265c-a9b1-56a2-9d87-a1b9d121f833.html

Creamer, E., Eadson, W., van Veelen, B., Pinker, A., Tingey, M., Braunholtz‐Speight, T., Markantoni, M., Foden, M., & Lacey‐Barnacle, M. (2018). Community energy: Entanglements of community, state, and private sector. *Geography Compass*, *12*(7). https://doi.org/10.1111/gec3.12378

Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of Management Studies*, *47*(6), 1154-1191. https://doi.org/10.1111/j.1467-6486.2009.00880.x

CSD, C. a. S. D. o. H. K. (2023). *Hong Kong Energy Statistics Annual Report*. https://www.censtatd.gov.hk/en/EIndexbySubject.html?pcode=B1100002&scode=90

CSDI, C. S. D. I. (2025). *Common spatial data of Hong Kong* https://portal.csdi.gov.hk/geoportal/#metadataInfoPanel

Dane, F. (1990). *Research Methods*.

Dato, P., Durmaz, T., & Pommeret, A. (2021). Feed-in tariff policy in Hong Kong: Is it efficient? *City and Environment Interactions*, *10*, 100056. https://doi.org/https://doi.org/10.1016/j.cacint.2021.100056

Davtalab, M., & Alesheikh, A. A. (2018). Spatial optimization of biomass power plant site using fuzzy analytic network process. *Clean Technologies and Environmental Policy*, *20*(5), 1033-1046. https://doi.org/10.1007/s10098-018-1531-5

DEED, D. o. E. E. D. o. S. o. A. (2018). *Life cycle cost analysis handbook* https://education.alaska.gov/facilities/publications/LCCAHandbook.pdf

Deshmukh, R., Wu, G. C., Callaway, D. S., & Phadke, A. (2019). Geospatial and techno-economic analysis of wind and solar resources in India. *Renewable Energy*, *134*, 947-960.

Deutsch, N., & Berényi, L. (2020). Economic potentials of community-shared solar plants from the utility-side of the meter – A Hungarian case. *The Electricity Journal*, *33*(8), 106826. https://doi.org/https://doi.org/10.1016/j.tej.2020.106826

DeVar, S. G. (2019). Equitable Community Solar

California & Beyond. *Ecology Law Quarterly*, *46*(4), 1017-1048. https://www.jstor.org/stable/27069897

Deveci, M., Cali, U., & Pamucar, D. (2021). Evaluation of criteria for site selection of solar photovoltaic (PV) projects using fuzzy logarithmic additive estimation of weight coefficients. *Energy Reports*, *7*, 8805-8824. https://doi.org/https://doi.org/10.1016/j.egyr.2021.10.104

Devine-Wright, P. (2009). Rethinking NIMBYism: The Role of Place Attachment and Place Identity in Explaining Place-protective Action. 441 (January), 426–441. In.

Devine-Wright, P., Batel, S., Aas, O., Sovacool, B., Labelle, M. C., & Ruud, A. (2017). A conceptual framework for understanding the social acceptance of energy infrastructure: Insights from energy storage. *Energy Policy*, *107*, 27-31.

Devine-Wright, P., & Wiersma, B. (2020). Understanding community acceptance of a potential offshore wind energy project in different locations: An island-based analysis of 'place-technology fit'. *Energy Policy*, *137*, 111086.

Dijkgraaf, E., van Dorp, T. P., & Maasland, E. (2018). On the effectiveness of feed-in tariffs in the development of solar photovoltaics. *The Energy Journal*, *39*(1).

Domínguez Bravo, J., García Casals, X., & Pinedo Pascua, I. (2007). GIS approach to the definition of capacity and generation ceilings of renewable energy technologies. *Energy Policy*, *35*(10), 4879-4892. https://doi.org/https://doi.org/10.1016/j.enpol.2007.04.025

Doorga, J. R., Rughooputh, S. D., & Boojhawon, R. (2019). Multi-criteria GIS-based modelling technique for identifying potential solar farm sites: A case study in Mauritius. *Renewable Energy*, *133*, 1201-1219.

Drechsler, M., Egerer, J., Lange, M., Masurowski, F., Meyerhoff, J., & Oehlmann, M. (2017). Efficient and equitable spatial allocation of renewable power plants at the country scale. *Nature Energy*, *2*(9), 1-9.

EEB, E. a. E. B., Hong Kong. (2017). *Hong Kong's climate action plan 2030+*. https://www.eeb.gov.hk/en/eeb_index.html

EEB, E. a. E. B., Hong Kong. (2021). *Hong Kong's climate action plan 2050*. https://www.eeb.gov.hk/sites/default/files/pdf/cap_2050_en.pdf

Eldemir, F., & Onden, I. (2016). Geographical information systems and multicriteria decisions integration approach for hospital location selection. *International Journal of Information Technology & Decision Making*, *15*(05), 975-997.

Elevate. (2017). *Community Solar Business Case Tool*. https://www.elevatenp.org/publications/community-solar-business-case-tool/

Elkadeem, M. R., Younes, A., Sharshir, S. W., Campana, P. E., & Wang, S. (2021). Sustainable siting and design optimization of hybrid renewable energy system: A geospatial multi-criteria analysis. *Applied Energy*, *295*, 117071. https://doi.org/https://doi.org/10.1016/j.apenergy.2021.117071

EMSD, E. a. M. S. D. (2018). *Code of practice on working near electricity supply lines*. https://www.emsd.gov.hk/en/electricity_safety/new_edition_cop/new_edition_cop_working_near_esl/index.html

EMSD, E. a. M. S. D. (2019). *Study Report of Photovoltaic (PV) Applications and PV Potential on Building Rooftops in Hong Kong*. https://re.emsd.gov.hk/english/files/2019_Executive_Summary_for_PV_Study_EN.pdf

EMSD, E. a. M. S. D. (2023). *Hong Kong Energy End-use Data 2023*. https://www.emsd.gov.hk/en/energy_efficiency/energy_end_use_data_and_consumption_indicators/hong_kong_energy_end_use_data/data/index.html

EMSD, E. a. M. S. D., Hong Kong. (2023). *List of examples of government-funded solar PV projects*. https://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_ep.html

Energy, H. (2016). *Hybrid optimization model for electric renewables*. https://www.homerenergy.com/

EPA, U. S. E. P. A. (2016). *Community Solar: An Opportunity to Enhance Sustainable Development on Landfills and Other Contaminated Sites*.

Esen, H., Inalli, M., & Esen, M. (2006). Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. *Energy Conversion and Management*, *47*(9-10), 1281-1297.

Esen, H., Inalli, M., & Esen, M. (2007). A techno-economic comparison of ground-coupled and air-coupled heat pump system for space cooling. *Building and environment*, *42*(5), 1955-1965.

Etongo, D., & Naidu, H. (2022). Determinants of household adoption of solar energy technology in Seychelles in a context of 100% access to electricity. *Discover Sustainability*, *3*(1), 38. https://doi.org/10.1007/s43621-022-00108-4

Farooq, U., Rehman, S. K. U., Javed, M. F., Jameel, M., Aslam, F., & Alyousef, R. (2020). Investigating BIM Implementation Barriers and Issues in Pakistan Using ISM Approach. *Applied Sciences*, *10*(20), 7250. https://www.mdpi.com/2076-3417/10/20/7250

Ferreira, E., Sequeira, M. M., & Gouveia, J. P. (2024). Sharing Is Caring: Exploring Distributed Solar Photovoltaics and Local Electricity Consumption through a Renewable Energy Community. *Sustainability*, *16*(7), 2777. https://www.mdpi.com/2071-1050/16/7/2777

Fina, B., & Auer, H. (2020). Economic Viability of Renewable Energy Communities under the Framework of the Renewable Energy Directive Transposed to Austrian Law. *Energies*, *13*(21), 5743. https://www.mdpi.com/1996-1073/13/21/5743

Firozjaei, H. K., Firozjaei, M. K., Nematollahi, O., Kiavarz, M., & Alavipanah, S. K. (2020). On the effect of geographical, topographic and climatic conditions on feed-in tariff optimization for solar photovoltaic electricity generation: A case study in Iran. *Renewable Energy*, *153*, 430-439.

Fleiß, E., Hatzl, S., Seebauer, S., & Posch, A. (2017). Money, not morale: The impact of desires and beliefs on private investment in photovoltaic citizen participation

initiatives. *Journal of Cleaner Production*, *141*, 920-927. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.09.123
Fontaine, A., & Labussière, O. (2018). Community-based solar projects: sun-sharing politics and collective resource construction trials. *Local Environment*, *24*(11), 1015-1034. https://doi.org/10.1080/13549839.2018.1531838
Fontela, E., & Gabus, A. (1976). The DEMATEL observer. In: Dematel.
Freitas, S., Reinhart, C., & Brito, M. (2018). Minimizing storage needs for large scale photovoltaics in the urban environment. *Solar Energy*, *159*, 375-389.
Fuller, S. (2014). Creating a low carbon zone in Brixton, London, UK. In *An Urban Politics of Climate Change* (pp. 199-218). Routledge.
Funkhouser, E., Blackburn, G., Magee, C., & Rai, V. (2015). Business model innovations for deploying distributed generation: The emerging landscape of community solar in the US. *Energy Research & Social Science*, *10*, 90-101.
Gai, D. H. B., Shittu, E., Attanasio, D., Weigelt, C., LeBlanc, S., Dehghanian, P., & Sklar, S. (2021). Examining community solar programs to understand accessibility and investment: Evidence from the US. *Energy Policy*, *159*, 112600.
Galen, B., Naïm, D., Eric, O. S., & Sydney, F. (2022). *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States*. https://emp.lbl.gov/sites/default/files/2_tracking_the_sun_2022_report.pdf
Gamma, K., Stauch, A., & Wüstenhagen, R. (2017). 7th consumer barometer of renewable energy. *University of St. Gallen. Retrieved October*, *16*, 2017.
Giamalaki, M., & Tsoutsos, T. (2019). Sustainable siting of solar power installations in Mediterranean using a GIS/AHP approach. *Renewable Energy*, *141*, 64-75.
Gilman, P. (2014). *System Advisor model (SAM) time step for SAM model simulations*. https://sam.nrel.gov/
Gorroño-Albizu, L., Sperling, K., & Djørup, S. (2019). The past, present and uncertain future of community energy in Denmark: Critically reviewing and conceptualising citizen ownership. *Energy Research & Social Science*, *57*, 101231.
GovHK. (2022). *Renewable Energy Certificates*. https://www.gov.hk/en/residents/environment/sustainable/renewable/certificates.htm
Graebig, M., Bringezu, S., & Fenner, R. (2010). Comparative analysis of environmental impacts of maize–biogas and photovoltaics on a land use basis. *Solar Energy*, *84*(7), 1255-1263.
Guerrero, J., Chapman, A. C., & Verbič, G. (2019). Decentralized P2P Energy Trading Under Network Constraints in a Low-Voltage Network. *IEEE Transactions on Smart Grid*, *10*(5), 5163-5173. https://doi.org/10.1109/TSG.2018.2878445
Günen, M. A. (2021). A comprehensive framework based on GIS-AHP for the installation of solar PV farms in Kahramanmaraş, Turkey. *Renewable Energy*, *178*, 212-225. https://doi.org/https://doi.org/10.1016/j.renene.2021.06.078
Hachem-Vermette, C., Cubi, E., & Bergerson, J. (2016). Energy performance of a solar mixed-use community. *Sustainable Cities and Society*, *27*, 145-151.
Hafiz, F., Rodrigo de Queiroz, A., Fajri, P., & Husain, I. (2019). Energy management and optimal storage sizing for a shared community: A multi-stage stochastic programming approach. *Applied Energy*, *236*, 42-54. https://doi.org/https://doi.org/10.1016/j.apenergy.2018.11.080
He, J. (2022). Identification and Evaluation of Factors Influencing the Quality of Elderly Services Supply Chain Based on DEMATEL-ISM-TOPSIS Method. *International Journal of Information Systems in the Service Sector*, *14*, 1-22. https://doi.org/10.4018/IJISSS.295948

He, Y., Kang, J., Pei, Y., Ran, B., & Song, Y. (2021). Research on influencing factors of fuel consumption on superhighway based on DEMATEL-ISM model. *Energy Policy*, *158*, 112545. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112545

Heinisch, V., Odenberger, M., Göransson, L., & Johnsson, F. (2019). Organizing prosumers into electricity trading communities: Costs to attain electricity transfer limitations and self-sufficiency goals. *International Journal of Energy Research*, *43*(13), 7021-7039. https://doi.org/https://doi.org/10.1002/er.4720

Henni, S., Staudt, P., & Weinhardt, C. (2021). A sharing economy for residential communities with PV-coupled battery storage: Benefits, pricing and participant matching. *Applied Energy*, *301*, 117351. https://doi.org/https://doi.org/10.1016/j.apenergy.2021.117351

Heo, J., Moon, H., Chang, S., Han, S., & Lee, D.-E. (2021). Case Study of Solar Photovoltaic Power-Plant Site Selection for Infrastructure Planning Using a BIM-GIS-Based Approach. *Applied Sciences*, *11*(18). https://doi.org/10.3390/app11188785

Heras-Saizarbitoria, I., Sáez, L., Allur, E., & Morandeira, J. (2018). The emergence of renewable energy cooperatives in Spain: A review. *Renewable and Sustainable Energy Reviews*, *94*, 1036-1043.

Hernandez, R. R., Armstrong, A., Burney, J., Ryan, G., Moore-O'Leary, K., Diédhiou, I., Grodsky, S. M., Saul-Gershenz, L., Davis, R., Macknick, J., Mulvaney, D., Heath, G. A., Easter, S. B., Hoffacker, M. K., Allen, M. F., & Kammen, D. M. (2019). Techno–ecological synergies of solar energy for global sustainability. *Nature Sustainability*, *2*(7), 560-568. https://doi.org/10.1038/s41893-019-0309-z

Hernandez, R. R., Easter, S., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., & Ravi, S. (2014). Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews*, *29*, 766-779.

Hicks, J., & Ison, N. (2018). An exploration of the boundaries of 'community'in community renewable energy projects: Navigating between motivations and context. *Energy Policy*, *113*, 523-534.

Hielscher, S., Seyfang, G., & Smith, A. (2011). *Community innovation for sustainable energy*.

Hinchliffe, J. (2016). *Newstead Aims to Become First Town in Victoria to Go 100 Per Cent Renewable*. https://www.bendigoadvertiser.com.au/story/3728173/newstead-to-go-100-renewable/

Hirsh Bar Gai, D., Shittu, E., Attanasio, D., Weigelt, C., LeBlanc, S., Dehghanian, P., & Sklar, S. (2021). Examining community solar programs to understand accessibility and investment: Evidence from the U.S. *Energy Policy*, *159*, 112600. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112600

HK Electric Company, L. (2023). *Billing, payment & Tariffs*. https://www.hkelectric.com/en/customer-services/billing-payment-and-tariffs/tariffs

HKE, H. E. I. L. (2014). *HK Electric Corporate Information 2014*.

HKE, H. E. I. L. (2021). *HK Electric Corporate Information 2021*. https://www.hkelectric.com/en/our-operations/scheme-of-control/corporate-information-brochure/2021-22

HKMA, H. K. M. A. (2021). *2021 Annual report of Hong Kong Monetary Authority*.

HKO, H. K. O. (2022). *Daily Global Solar Radiation (MJ/m²) at King's Park in Hong Kong in 2022*. https://www.hko.gov.hk/en/index.html

Hoffacker, M. K., Allen, M. F., & Hernandez, R. R. (2017). Land-sparing opportunities for solar energy development in agricultural landscapes: a case study of the Great Central Valley, CA, United States. *Environmental science & technology*, *51*(24), 14472-14482.

Hong, J., Gu, J., Liang, X., Liu, G., & Qiping Shen, G. (2019). Characterizing embodied energy accounting with a multi-dimensional framework: A study of China's building sector. *Journal of Cleaner Production*, *215*, 154-164. https://doi.org/10.1016/j.jclepro.2018.12.300
Hong, J., Shen, Q., & Xue, F. (2016). A multi-regional structural path analysis of the energy supply chain in China's construction industry. *Energy Policy*, *92*, 56-68. https://doi.org/10.1016/j.enpol.2016.01.017
Hong, T., Lee, M., Koo, C., Jeong, K., & Kim, J. (2017). Development of a method for estimating the rooftop solar photovoltaic (PV) potential by analyzing the available rooftop area using Hillshade analysis. *Applied Energy*, *194*, 320-332. https://doi.org/10.1016/j.apenergy.2016.07.001
Horváth, D., & Szabó, R. Z. (2018). Evolution of photovoltaic business models: Overcoming the main barriers of distributed energy deployment. *Renewable and Sustainable Energy Reviews*, *90*, 623-635. https://doi.org/https://doi.org/10.1016/j.rser.2018.03.101
Hosseini, S. M., Paydar, M. M., & Hajiaghaei-Keshteli, M. (2021). Recovery solutions for ecotourism centers during the Covid-19 pandemic: Utilizing Fuzzy DEMATEL and Fuzzy VIKOR methods. *Expert Systems with Applications*, *185*, 115594. https://doi.org/https://doi.org/10.1016/j.eswa.2021.115594
Huang, M. L., Wang, M. H., Lu, S. D., & Lin, Y. T. (2018). Application of an extension method on optimal site selection for PV power systems: A case study in Taiwan. *IEEJ Transactions on Electrical and Electronic Engineering*, *13*(6), 831-839.
Huang, P., Sun, Y., Lovati, M., & Zhang, X. (2021). Solar-photovoltaic-power-sharing-based design optimization of distributed energy storage systems for performance improvements. *Energy*, *222*, 119931. https://doi.org/https://doi.org/10.1016/j.energy.2021.119931
IEA. (2022a). *Trends in PV Applications 2022*.
IEA. (2022b). World Energy Outlook 2022. In: IEA, Paris, France.
IEA, I. E. A. (2024). *Renewables 2023-Analysis and forecast to 2028*. https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
India, T. T. o. (2016). Beas has world's largest rooftop solar plant. *The Times of India*.
IRD, I. R. D. o. H. K. (2023). *Profits tax of buisnesses*. https://www.ird.gov.hk/eng/tax/bus_pft.htm
IREAN, t. I. R. E. A. (2019). *Renewable Power Generation Costs in 2019*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf
IREAN, t. I. R. E. A. (2020). *Renewable Power Generation Costs in 2020*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_Power_Generation_Costs_2020.pdf
IREAN, t. I. R. E. A. (2022). ***Renewable Power Generation Costs in 2021***. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf
Islam, T. (2014). Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data. *Energy Policy*, *65*, 340-350. https://doi.org/https://doi.org/10.1016/j.enpol.2013.10.004

ITC, I. a. T. C. o. H. K. (2022). *Innovation and technology fund for better living*. https://www.itf.gov.hk/en/funding-programmes/facilitating-technology/fbl/index.html

Ivy, Y. (2023). *Powering HK toward greener future*. https://www.hk2050isnow.org/powering-hk-toward-greener-future/

Jadhav, J. R., Mantha, S. S., & Rane, S. B. (2015). Roadmap for Lean implementation in Indian automotive component manufacturing industry: comparative study of UNIDO Model and ISM Model. *Journal of Industrial Engineering International*, *11*(2), 179-198. https://doi.org/10.1007/s40092-014-0074-6

Jansen, B. W., van Stijn, A., Gruis, V., & van Bortel, G. (2020). A circular economy life cycle costing model (CE-LCC) for building components. *Resources, Conservation and Recycling*, *161*, 104857.

Jayant, A., & Singh, P. (2015). Interpretive Structural Modeling (ISM) Approach: A State of the Art Literature Review.

Jayaraman, K., Paramasivan, L., & Kiumarsi, S. (2017). Reasons for low penetration on the purchase of photovoltaic (PV) panel system among Malaysian landed property owners. *Renewable and Sustainable Energy Reviews*, *80*, 562-571. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.213

Jayaweera, N., Jayasinghe, C. L., & Weerasinghe, S. N. (2018). Local factors affecting the spatial diffusion of residential photovoltaic adoption in Sri Lanka. *Energy Policy*, *119*, 59-67. https://doi.org/10.1016/j.enpol.2018.04.017

Jones, K. B., Bennett, E. C., Ji, F. W., & Kazerooni, B. (2017). Beyond Community Solar: Aggregating Local Distributed Resources for Resilience and Sustainability. In *Innovation and Disruption at the Grid's Edge* (pp. 65-81). https://doi.org/10.1016/b978-0-12-811758-3.00004-8

Joshi, G., & Yenneti, K. (2020). Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability? *Energy and Buildings*, *210*. https://doi.org/10.1016/j.enbuild.2019.109736

Karakaya, E., & Sriwannawit, P. (2015). Barriers to the adoption of photovoltaic systems: The state of the art. *Renewable and Sustainable Energy Reviews*, *49*, 60-66. https://doi.org/https://doi.org/10.1016/j.rser.2015.04.058

Kashyap, A., Kumar, C., kumar, V., & Shukla, O. J. (2022). A DEMATEL model for identifying the impediments to the implementation of circularity in the aluminum industry. *Decision Analytics Journal*, *5*, 100134. https://doi.org/https://doi.org/10.1016/j.dajour.2022.100134

Kato, T., Yamawaki, H., & Suzuoki, Y. (2009). A study on dumping power flow fluctuation at grid-connection point of residential micro-grid with clustered photovoltaic power generation systems. 2009 IEEE PES/IAS Conference on Sustainable Alternative Energy (SAE),

Kim, C. H., Kim, M., & Song, Y. J. (2021). Sequence-to-sequence deep learning model for building energy consumption prediction with dynamic simulation modeling. *Journal of Building Engineering*, *43*, 102577.

Kim, S., Lee, Y., & Moon, H.-R. (2018). Siting criteria and feasibility analysis for PV power generation projects using road facilities. *Renewable and Sustainable Energy Reviews*, *81*, 3061-3069. https://doi.org/https://doi.org/10.1016/j.rser.2017.08.067

Klein, S. J., & Coffey, S. (2016). Building a sustainable energy future, one community at a time. *Renewable and Sustainable Energy Reviews*, *60*, 867-880.

Klein, S. J. W., Hargreaves, A., & Coffey, S. (2021). A financial benefit-cost analysis of different community solar approaches in the Northeastern US. *Solar Energy*, *213*, 225-245. https://doi.org/https://doi.org/10.1016/j.solener.2020.11.031

Kocabaldır, C., & Yücel, M. A. (2023). GIS-based multicriteria decision analysis for spatial planning of solar photovoltaic power plants in Çanakkale province, Turkey. *Renewable Energy*, *212*, 455-467. https://doi.org/https://doi.org/10.1016/j.renene.2023.05.075

Koch, J., & Christ, O. (2018). Household participation in an urban photovoltaic project in Switzerland: Exploration of triggers and barriers. *Sustainable Cities and Society*, *37*, 420-426. https://doi.org/https://doi.org/10.1016/j.scs.2017.10.028

Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 722-744.

Kong, W.-H. (2017). *WWF Launches Pioneering "Solarizing Communities" Project in Tai O Rooftop solar provides free electricity and a clean energy alternative WWF urges the government to commit to a feed-in tariff policy to boost renewables*. https://www.wwf.org.hk/en/?17940/Press-Release-WWF-Launches-Pioneering-Solarizing-Communities-Project-in-Tai-O-Rooftop-solar-provides-free-electricity-and-a-clean-energy-alternative-WWF-urges-the-government-to-commit-to-a-feed-in-tariff-policy-to-boost-renewables

Konkle, D., & Specialist, C. (2013). A guidebook for community solar programs in Michigan communities. *Great Lakes Renewable Energy Association*.

Kumar, A., & Dixit, G. (2018). An analysis of barriers affecting the implementation of e-waste management practices in India: A novel ISM-DEMATEL approach. *Sustainable Production and Consumption*, *14*, 36-52.

Kumar Singh, A., Prasath Kumar, V. R., & Krishnaraj, L. (2022). Emerging technology trends in the C&I rooftop solar market in India: Case study on datacentre – Retrofit with BIPV by U-Solar. *Solar Energy*, *238*, 203-215. https://doi.org/https://doi.org/10.1016/j.solener.2022.04.033

Kurokawa, K., & Ikki, O. (2001). The Japanese experiences with national PV system programmes. *Solar Energy*, *70*(6), 457-466.

Kusakana, K. (2020). Optimal peer-to-peer energy management between grid-connected prosumers with battery storage and photovoltaic systems. *Journal of Energy Storage*, *32*, 101717. https://doi.org/https://doi.org/10.1016/j.est.2020.101717

Kwan, C. L. (2012). Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. *Energy Policy*, *47*, 332-344. https://doi.org/https://doi.org/10.1016/j.enpol.2012.04.074

Lage, M., Castro, R., Manzolini, G., Casalicchio, V., & Sousa, T. (2024). Techno-economic analysis of self-consumption schemes and energy communities in Italy and Portugal. *Solar Energy*, *270*, 112407. https://doi.org/https://doi.org/10.1016/j.solener.2024.112407

Lai, C. S., & McCulloch, M. D. (2017). Levelized cost of electricity for solar photovoltaic and electrical energy storage. *Applied Energy*, *190*, 191-203. https://doi.org/https://doi.org/10.1016/j.apenergy.2016.12.153

Lee, H.-J., Huh, S.-Y., & Yoo, S.-H. (2018). Social Preferences for Small-Scale Solar Photovoltaic Power Plants in South Korea: A Choice Experiment Study. *Sustainability*, *10*(10). https://doi.org/10.3390/su10103589

Lee, S., Shenoy, P., Ramamritham, K., & Irwin, D. (2021). AutoShare: Virtual community solar and storage for energy sharing. *Energy Informatics*, *4*(1). https://doi.org/10.1186/s42162-021-00144-w

Li, H., & Jie, Z. (2020). *Distributed Solar Energy Sharing within Connected Communities: A Coalition Game Approach* 2019 IEEE Power & Energy Society General Meeting (PESGM), Atlanta, GA, USA.

Li, H. X., Zhang, Y., Edwards, D., & Hosseini, M. R. (2019). Improving the energy production of roof-top solar PV systems through roof design. *Building Simulation*, *13*(2), 475-487. https://doi.org/10.1007/s12273-019-0585-6

Li, L. W., Birmele, J., Schaich, H., & Konold, W. (2013). Transitioning to community-owned renewable energy: Lessons from Germany. *Procedia Environmental Sciences*, *17*, 719-728.

Li, Q., Duan, H., Xie, M., Kang, P., Ma, Y., Zhong, R., Gao, T., Zhong, W., Wen, B., Bai, F., & Vuppaladadiyam, A. K. (2021). Life cycle assessment and life cycle cost analysis of a 40 MW wind farm with consideration of the infrastructure. *Renewable and Sustainable Energy Reviews*, *138*, 110499. https://doi.org/https://doi.org/10.1016/j.rser.2020.110499

Liang, H., Shen, J., Yip, H.-L., Fang, M. M., & Dong, L. (2024). Unleashing the green potential: Assessing Hong Kong's building solar PV capacity. *Applied Energy*, *369*, 123567. https://doi.org/https://doi.org/10.1016/j.apenergy.2024.123567

Lo, K. (2017). Renewable Energy Development in Hong Kong: Potential, Progress, and Barriers. *Current Sustainable/Renewable Energy Reports*, *4*(2), 50-55. https://doi.org/10.1007/s40518-017-0068-2

Lo, K., Mah, D. N.-Y., Wang, G., Leung, M. K. H., Lo, A. Y., & Hills, P. (2018). Barriers to adopting solar photovoltaic systems in Hong Kong. *Energy & Environment*, *29*(5), 649-663. https://doi.org/10.1177/0958305x18757402

Long, C., Wu, J., Zhou, Y., & Jenkins, N. (2018). Peer-to-peer energy sharing through a two-stage aggregated battery control in a community Microgrid. *Applied Energy*, *226*, 261-276. https://doi.org/https://doi.org/10.1016/j.apenergy.2018.05.097

López Prol, J., & Steininger, K. W. (2020). Photovoltaic self-consumption is now profitable in Spain: Effects of the new regulation on prosumers' internal rate of return. *Energy Policy*, *146*, 111793. https://doi.org/https://doi.org/10.1016/j.enpol.2020.111793

Lowitzsch, J., Hoicka, C. E., & van Tulder, F. J. (2020). Renewable energy communities under the 2019 European Clean Energy Package–Governance model for the energy clusters of the future? *Renewable and Sustainable Energy Reviews*, *122*, 109489.

Lu, L. (2013). *Study on the Development Potential and Energy Incentives of Rooftop Solar Photovoltaic Applications in Hong Kong*.

Lüthi, S., & Wüstenhagen, R. (2012). The price of policy risk — Empirical insights from choice experiments with European photovoltaic project developers. *Energy Economics*, *34*(4), 1001-1011. https://doi.org/10.1016/j.eneco.2011.08.007

Mackenzie, W., & Research, G. (2018). *The Vision for U.S. Community Solar: A Roadmap to 2030 and Beyond was prepared by on behalf of Vote Solar*. https://votesolar.org/wp-content/uploads/2021/05/FULL_REPORT__The_Vision_for_US_Community_Solar_072518.pdf

Mah, D. N.-y. (2019). Community solar energy initiatives in urban energy transitions: A comparative study of Foshan, China and Seoul, South Korea. *Energy Research & Social Science*, *50*, 129-142. https://doi.org/10.1016/j.erss.2018.11.011

Mah, D. N.-y., Cheung, D. M.-w., Leung, M. K. H., Wang, M. Y., Wong, M. W.-m., Lo, K., & Cheung, A. T. F. (2021). Policy mixes and the policy learning process of energy transitions: Insights from the feed-in tariff policy and urban community solar in Hong Kong. *Energy Policy*, *157*. https://doi.org/10.1016/j.enpol.2021.112214

Mah, D. N.-y., Wang, G., Lo, K., Leung, M. K. H., Hills, P., & Lo, A. Y. (2018). Barriers and policy enablers for solar photovoltaics (PV) in cities: Perspectives of potential adopters in

Hong Kong. *Renewable and Sustainable Energy Reviews*, *92*, 921-936. https://doi.org/10.1016/j.rser.2018.04.041

Majumdar, A., Garg, H., & Jain, R. (2021). Managing the barriers of Industry 4.0 adoption and implementation in textile and clothing industry: Interpretive structural model and triple helix framework. *Computers in Industry*, *125*, 103372.

Majumdar, D., & Pasqualetti, M. J. (2019). Analysis of land availability for utility-scale power plants and assessment of solar photovoltaic development in the state of Arizona, USA. *Renewable Energy*, *134*, 1213-1231.

Mansó Borràs, I., Neves, D., & Gomes, R. (2023). Using urban building energy modeling data to assess energy communities' potential. *Energy and Buildings*, *282*, 112791. https://doi.org/https://doi.org/10.1016/j.enbuild.2023.112791

McAdam, D., & Boudet, H. (2012). *Putting Social Movements in Their Place: From Copernicus to Ptolemy and (hopefully) back again; 2. Comparing communities' at risk'for mobilization; 3. Explaining variation in the level of opposition to energy projects; 4. Does opposition matter?: mobilization and project outcome; 5. From not my back yard to not in anyone's back yard: the emergence of regional movements against liquefied natural gas; 6. Back to the future: returning to a Copernican approach to the study of contention*. Cambridge University Press.

Mehta, P., & Tiefenbeck, V. (2022). Solar PV sharing in urban energy communities: Impact of community configurations on profitability, autonomy and the electric grid. *Sustainable Cities and Society*, *87*. https://doi.org/10.1016/j.scs.2022.104178

Mermoud, A. (2012). PVSYST photovoltaic software. *The University of Geneva: Geneva, Switzerland*.

Michaud, G. (2020). Perspectives on community solar policy adoption across the United States. *Renewable Energy Focus*, *33*, 1-15. https://doi.org/https://doi.org/10.1016/j.ref.2020.01.001

Middlemiss, L., & Parrish, B. D. (2010). Building capacity for low-carbon communities: The role of grassroots initiatives. *Energy Policy*, *38*(12), 7559-7566.

Mirosław-Świątek, D., Popielski, P., Śliwiński, P., Cwalina, T., & Skutnik, Z. (2021). Analysis of factors influencing levee safety using the DEMATEL method. *PLOS ONE*, *16*(9), e0255755. https://doi.org/10.1371/journal.pone.0255755

Mirzania, P., Balta-Ozkan, N., & Ford, A. (2020). An innovative viable model for community-owned solar PV projects without FIT: Comprehensive techno-economic assessment. *Energy Policy*, *146*. https://doi.org/10.1016/j.enpol.2020.111727

Mitigation, C. C. (2011). IPCC special report on renewable energy sources and climate change mitigation. *Renewable Energy*, *20*(11).

Moradi, S., Yousefi, H., Noorollahi, Y., & Rosso, D. (2020). Multi-criteria decision support system for wind farm site selection and sensitivity analysis: Case study of Alborz Province, Iran. *Energy Strategy Reviews*, *29*, 100478. https://doi.org/https://doi.org/10.1016/j.esr.2020.100478

Mousavizade, F., & Shakibazad, M. (2019). Identifying and ranking CSFs for KM implementation in urban water and sewage companies using ISM-DEMATEL technique. *Journal of knowledge management*, *23*(1), 200-218.

Mundaca, L., & Samahita, M. (2020). What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. *Energy Research & Social Science*, *60*, 101319. https://doi.org/https://doi.org/10.1016/j.erss.2019.101319

Munday, M., Bristow, G., & Cowell, R. (2011). Wind farms in rural areas: How far do community benefits from wind farms represent a local economic development opportunity? *Journal of Rural Studies*, *27*(1), 1-12.

Nadizadeh Shorabeh, S., Argany, M., Rabiei, J., Karimi Firozjaei, H., & Nematollahi, O. (2021). Potential assessment of multi-renewable energy farms establishment using spatial multi-criteria decision analysis: A case study and mapping in Iran. *Journal of Cleaner Production*, *295*, 126318. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.126318

NERL. (2016). *Community solar scenario tool*. https://www.nrel.gov/

NERL, t. N. R. E. L. (2018). *Lifetime of PV Panels*. https://www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html

Net, H. R. (2006). *List of examples of solar PV projects*. https://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_ep.html

NIST, N. I. o. S. a. T. (1995). NIST Handbook 135 Life-Cycle Costing Manual For The Federal Energy Management Program. In.

Noll, D., Dawes, C., & Rai, V. (2014). Solar community organizations and active peer effects in the adoption of residential PV. *Energy Policy*, *67*, 330-343.

Nonhebel, S. (2005). Renewable energy and food supply: will there be enough land? *Renewable and Sustainable Energy Reviews*, *9*(2), 191-201.

O'Neil, S. G. (2021). Community obstacles to large scale solar: NIMBY and renewables. *Journal of Environmental Studies and Sciences*, *11*(1), 85-92. https://doi.org/10.1007/s13412-020-00644-3

Oluoch, S., Lal, P., Bevacqua, A., & Wolde, B. (2021). Consumer willingness to pay for community solar in New Jersey. *The Electricity Journal*, *34*(8), 107006. https://doi.org/https://doi.org/10.1016/j.tej.2021.107006

Oozeki, T., Yamada, T., Otani, K., Takashima, T., & Kato, K. (2010). An analysis of reliability in the early stages of photovoltaic systems in Japan. *Progress in Photovoltaics: Research and applications*, *18*(5), 363-370.

Oryani, B., Koo, Y., Rezania, S., & Shafiee, A. (2021). Barriers to renewable energy technologies penetration: Perspective in Iran. *Renewable Energy*, *174*, 971-983. https://doi.org/https://doi.org/10.1016/j.renene.2021.04.052

Ou, L., Chen, Y., Zhang, J., & Ma, C. (2022). Dematel-ISM-Based Study of the Impact of Safety Factors on Urban Rail Tunnel Construction Projects. *Comput Intell Neurosci*, *2022*, 2222556. https://doi.org/10.1155/2022/2222556

Ouyang, X., & Lin, B. (2014). Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. *Energy Policy*, *70*, 64-73. https://doi.org/https://doi.org/10.1016/j.enpol.2014.03.030

Ozcan, O., & Ersoz, F. (2019). Project and cost-based evaluation of solar energy performance in three different geographical regions of Turkey: Investment analysis application. *Engineering Science and Technology, an International Journal*, *22*(4), 1098-1106. https://doi.org/10.1016/j.jestch.2019.04.001

Palm, A. (2017). Peer effects in residential solar photovoltaics adoption—A mixed methods study of Swedish users. *Energy Research & Social Science*, *26*, 1-10. https://doi.org/https://doi.org/10.1016/j.erss.2017.01.008

Palm, J. (2018). Household installation of solar panels – Motives and barriers in a 10-year perspective. *Energy Policy*, *113*, 1-8. https://doi.org/https://doi.org/10.1016/j.enpol.2017.10.047

Palmer, D., Gottschalg, R., & Betts, T. (2019). The future scope of large-scale solar in the UK: Site suitability and target analysis. *Renewable Energy*, *133*, 1136-1146.

Panchenko, V. (2021). Photovoltaic thermal module with paraboloid type solar concentrators. *International Journal of Energy Optimization and Engineering (IJEOE)*, *10*(2), 1-23.

Parag, Y., & Sovacool, B. K. (2016). Electricity market design for the prosumer era. *Nature Energy*, *1*(4), 16032. https://doi.org/10.1038/nenergy.2016.32

Peleckis, K. (2021). Application of the DEMATEL Model for Assessing IT Sector's Sustainability. *Sustainability*, *13*(24), 13866. https://www.mdpi.com/2071-1050/13/24/13866

Peng, J., & Lu, L. (2013). Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits. *Renewable and Sustainable Energy Reviews*, *27*, 149-162. https://doi.org/https://doi.org/10.1016/j.rser.2013.06.030

Perger, T. (2020, 16-18 Sept. 2020). Fair Energy Sharing in Local Communities: Dynamic Participation of Prosumers. 2020 17th International Conference on the European Energy Market (EEM),

Peters, M., Fudge, S., High-Pippert, A., Carragher, V., & Hoffman, S. M. (2018). Community solar initiatives in the United States of America: Comparisons with – and lessons for – the UK and other European countries. *Energy Policy*, *121*, 355-364. https://doi.org/https://doi.org/10.1016/j.enpol.2018.06.022

Pillot, B., Muselli, M., Poggi, P., & Dias, J. B. (2015). Satellite-based assessment and in situ validation of solar irradiation maps in the Republic of Djibouti. *Solar Energy*, *120*, 603-619. https://doi.org/https://doi.org/10.1016/j.solener.2015.08.015

Pojadas, D. J., & Abundo, M. L. S. (2022). A spatial cost-benefit-externality modelling framework for siting of variable renewable energy farms: A case in Bohol, Philippines. *Renewable Energy*, *181*, 1177-1187. https://doi.org/https://doi.org/10.1016/j.renene.2021.09.114

Prehoda, E., Winkler, R., & Schelly, C. (2019). Putting research to action: Integrating collaborative governance and community-engaged research for community solar. *Social Sciences*, *8*(1), 11.

Qiu, T., Wang, L., Lu, Y., Zhang, M., Qin, W., Wang, S., & Wang, L. (2022). Potential assessment of photovoltaic power generation in China. *Renewable and Sustainable Energy Reviews*, *154*. https://doi.org/10.1016/j.rser.2021.111900

Qureshi, T. M., Ullah, K., & Arentsen, M. J. (2017). Factors responsible for solar PV adoption at household level: A case of Lahore, Pakistan. *Renewable and Sustainable Energy Reviews*, *78*, 754-763.

R, V., & Vinodh, S. (2021). Development of a structural model based on ISM for analysis of barriers to integration of leanwith industry 4.0. *The TQM Journal*, *33*(6), 1201-1221. https://doi.org/10.1108/TQM-07-2020-0151

Rai, V., & Beck, A. L. (2015). Public perceptions and information gaps in solar energy in Texas. *Environmental Research Letters*, *10*(7), 074011. https://doi.org/10.1088/1748-9326/10/7/074011

Rai, V., Reeves, D. C., & Margolis, R. (2016). Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renewable Energy*, *89*, 498-505. https://doi.org/https://doi.org/10.1016/j.renene.2015.11.080

Rajesh, A., Nikhil, D., & Vivek, S. (2013). Interpretive Structural Modelling (ISM) approach : An Overview. *Research Journal of Management Sciences*, *2*(2), 3-8.

Ramos, A., Berzosa, J., Espí, J., Clarens, F., & Rouboa, A. (2020). Life cycle costing for plasma gasification of municipal solid waste: A socio-economic approach. *Energy Conversion and Management*, *209*, 112508.

Realini, A., Cereghetti, N., & Chianese, D. (2003). Mean time before failure of photovoltaic modules. *Final Report (MTBF Project), Federal Office for Education and Science Tech. Rep., BBW*, *99*.

Reindl, K., & Palm, J. (2021). Installing PV: Barriers and enablers experienced by non-residential property owners. *Renewable and Sustainable Energy Reviews*, *141*, 110829. https://doi.org/https://doi.org/10.1016/j.rser.2021.110829

REN21. (2022). *Renewables 2022 Global Status Report*.

REN21. (2023). *Renewables 2023 Global Status Report*. https://www.ren21.net/gsr-2023/

REN21. (2024). ***Renewables 2024 Global Status Report***. https://www.ren21.net/gsr-2024/

Richter, J. (2008). *Financial analysis of residential PV and solar water heating systems in the US* Murdoch University].

Roddis, P., Carver, S., Dallimer, M., Norman, P., & Ziv, G. (2018). The role of community acceptance in planning outcomes for onshore wind and solar farms: An energy justice analysis. *Applied Energy*, *226*, 353-364.

Rogers, E. M. (1995). Diffusion of Innovations: modifications of a model for telecommunications. *Die diffusion von innovationen in der telekommunikation*, 25-38.

Rogers, J. C., Simmons, E. A., Convery, I., & Weatherall, A. (2012). Social impacts of community renewable energy projects: findings from a woodfuel case study. *Energy Policy*, *42*, 239-247. https://doi.org/https://doi.org/10.1016/j.enpol.2011.11.081

Rudge, K. (2021). The potential for community solar in Connecticut: A geospatial analysis of solar canopy siting on parking lots. *Solar Energy*, *230*, 635-644.

Ruggiero, S., Martiskainen, M., & Onkila, T. (2018). Understanding the scaling-up of community energy niches through strategic niche management theory: Insights from Finland. *Journal of Cleaner Production*, *170*, 581-590.

Saaty, T. L. (1986). Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, *32*(7), 841-855. https://doi.org/10.1287/mnsc.32.7.841

Saeidi, R., Noorollahi, Y., Aghaz, J., & Chang, S. (2023). FUZZY-TOPSIS method for defining optimal parameters and finding suitable sites for PV power plants. *Energy*, *282*, 128556. https://doi.org/https://doi.org/10.1016/j.energy.2023.128556

Sahu, G. P., Singh, P., & Dwivedi, P. (2021). Adoption of solar energy in India: A study through interpretive structural modelling. *World Journal of Science, Technology and Sustainable Development*, *18*(4), 457-473.

San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. *Renewable Energy*, *36*(2), 498-502. https://doi.org/https://doi.org/10.1016/j.renene.2010.07.031

Sánchez-Lozano, J. M., Antunes, C. H., García-Cascales, M. S., & Dias, L. C. (2014). GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain. *Renewable Energy*, *66*, 478-494.

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & Socorro García-Cascales, M. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. *Renewable and Sustainable Energy Reviews*, *24*, 544-556. https://doi.org/https://doi.org/10.1016/j.rser.2013.03.019

Sardianou, E., & Genoudi, P. (2013). Which factors affect the willingness of consumers to adopt renewable energies? *Renewable Energy*, *57*, 1-4. https://doi.org/https://doi.org/10.1016/j.renene.2013.01.031

Saunders, R. W., Gross, R. J. K., & Wade, J. (2012). Can premium tariffs for micro-generation and small scale renewable heat help the fuel poor, and if so, how? Case studies of innovative finance for community energy schemes in the UK. *Energy Policy*, *42*, 78-88. https://doi.org/https://doi.org/10.1016/j.enpol.2011.11.045

Sayed, M. A., Ahmed, M. M., Azlan, W., & Kin, L. W. (2024). Peer to peer solar energy sharing system for rural communities. *Cleaner Energy Systems*, *7*, 100102. https://doi.org/https://doi.org/10.1016/j.cles.2023.100102

Schelly, C. (2014). Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Research & Social Science*, *2*, 183-191. https://doi.org/https://doi.org/10.1016/j.erss.2014.01.001

Schulte, E., Scheller, F., Sloot, D., & Bruckner, T. (2022). A meta-analysis of residential PV adoption: The important role of perceived benefits, intentions and antecedents in solar energy acceptance. *Energy Research & Social Science*, *84*, 102339.

Schunder, T., Yin, D., Bagchi-Sen, S., & Rajan, K. (2020). A spatial analysis of the development potential of rooftop and community solar energy. *Remote Sensing Applications: Society and Environment*, *19*, 100355.

SES, S. E. S. (2015). *SES Solar Co-operative Ltd.* https://environmentalsociety.ca/wp-content/uploads/2015/10/Updated-Oct-2015-Solar-Co-op-Info-1.pdf

Seyfang, G., Park, J. J., & Smith, A. (2013). A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy*, *61*, 977-989.

Seyfang, G., & Smith, A. (2007). Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environmental politics*, *16*(4), 584-603. https://doi.org/10.1080/09644010701419121

SG, T. S. G. (2013). *Influencing behaviours - moving beyond the individual: ISM user guide*. https://www.hutton.ac.uk/sites/default/files/files/29_Influencing%20behaviours%20and%20moving%20beyond%20the%20individual.pdf

Shahedi, A., Nazari-Shirkouhi, S., Bozorgi-Amiri, A., Amirkhalili, Y. S., & Shahedi, M. (2023). Application of hybrid ISM-DEMATEL approach for analyzing the barriers of automotive remanufacturing: a real-world case study. *Journal of Remanufacturing*, *13*(1), 67-98. https://doi.org/10.1007/s13243-022-00121-w

Shakeel, S. R., Yousaf, H., Irfan, M., & Rajala, A. (2023). Solar PV adoption at household level: Insights based on a systematic literature review. *Energy Strategy Reviews*, *50*, 101178. https://doi.org/https://doi.org/10.1016/j.esr.2023.101178

Shakeri, H., & Khalilzadeh, M. (2020). Analysis of factors affecting project communications with a hybrid DEMATEL-ISM approach (A case study in Iran). *Heliyon*, *6*(8), e04430.

Shakouri, M., Lee, H. W., & Kim, Y.-W. (2017). A probabilistic portfolio-based model for financial valuation of community solar. *Applied Energy*, *191*, 709-726.

Sharma, D., Mehra, R., & Raj, B. (2021). Comparative analysis of photovoltaic technologies for high efficiency solar cell design. *Superlattices and Microstructures*, *153*. https://doi.org/10.1016/j.spmi.2021.106861

Shiraishi, K., Shirley, R. G., & Kammen, D. M. (2019). Geospatial multi-criteria analysis for identifying high priority clean energy investment opportunities: A case study on land-use conflict in Bangladesh. *Applied Energy*, *235*, 1457-1467.

Siegrist, C. R., Barth, B., Campbell, B., Krishnamoorthy, B., & Taylor, M. (2013). Utility community solar handbook: Understanding and supporting utility program development. *Solar Electric Power Association: Washington, DC, USA*, 1-25.

Simon, P., Fraunhofer, I., & Werner, W. (2024). *Photovoltaics Report*. https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html

Simsek, E., Williams, M. J., & Pilon, L. (2021). Effect of dew and rain on photovoltaic solar cell performances. *Solar Energy Materials and Solar Cells*, *222*. https://doi.org/10.1016/j.solmat.2020.110908

Sindhu, S. (2022). Cause-related marketing—an interpretive structural model approach. *Journal of Nonprofit & Public Sector Marketing*, *34*(1), 102-128.

Sindhu, S., Nehra, V., & Luthra, S. (2017). Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India. *Renewable and Sustainable Energy Reviews*, *73*, 496-511.

Singh, S., & Gupta, A. (2021). An ISM modeling for factors affecting the purchase of green products. *Journal of Modelling in Management*, *16*(1), 103-123. https://doi.org/10.1108/JM2-05-2019-0099

Skoczek, A., Sample, T., & Dunlop, E. D. (2009). The results of performance measurements of field‐aged crystalline silicon photovoltaic modules. *Progress in Photovoltaics: Research and applications*, *17*(4), 227-240.

Soeiro, S., & Ferreira Dias, M. (2020). Community renewable energy: Benefits and drivers. *Energy Reports*, *6*, 134-140. https://doi.org/https://doi.org/10.1016/j.egyr.2020.11.087

Solangi, K. H., Saidur, R., Luhur, M. R., Aman, M. M., Badarudin, A., Kazi, S. N., Lwin, T. N. W., Rahim, N. A., & Islam, M. R. (2015). Social acceptance of solar energy in Malaysia: users' perspective. *Clean Technologies and Environmental Policy*, *17*(7), 1975-1986. https://doi.org/10.1007/s10098-015-0920-2

Solargis. (2024). *Solar resource maps & GIS data*. https://solargis.com/resources/free-maps-and-gis-data?locality=china

Song, X., Zhang, J., Zhan, C., Xuan, Y., Ye, M., & Xu, C. (2015). Global sensitivity analysis in hydrological modeling: Review of concepts, methods, theoretical framework, and applications. *Journal of Hydrology*, *523*, 739-757. https://doi.org/https://doi.org/10.1016/j.jhydrol.2015.02.013

Sorooshian, S., Tavana, M., & Ribeiro-Navarrete, S. (2023). From classical interpretive structural modeling to total interpretive structural modeling and beyond: A half-century of business research. *Journal of Business Research*, *157*, 113642. https://doi.org/https://doi.org/10.1016/j.jbusres.2022.113642

Sovacool, B. K., Hess, D. J., Cantoni, R., Lee, D., Claire Brisbois, M., Jakob Walnum, H., Freng Dale, R., Johnsen Rygg, B., Korsnes, M., Goswami, A., Kedia, S., & Goel, S. (2022). Conflicted transitions: Exploring the actors, tactics, and outcomes of social opposition against energy infrastructure. *Global Environmental Change*, *73*, 102473. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2022.102473

Stack, V., & Narine, L. L. (2022). Sustainability at Auburn University: Assessing Rooftop Solar Energy Potential for Electricity Generation with Remote Sensing and GIS in a Southern US Campus. *Sustainability*, *14*(2), 626.

Stagl, S. (2006). Multicriteria evaluation and public participation: the case of UK energy policy. *Land use policy*, *23*(1), 53-62.

Standard, T. (2022). *Jockey Club SolarCare Programme connects NGOs with green experts to light up communities via innovative technology*. https://www.thestandard.com.hk/breaking-news/section/4/194752/Jockey-Club-SolarCare-Programme-connects-NGOs-with-green-experts-to-light-up-communities-via-innovative-technology

Stauch, A., & Gamma, K. (2020). Cash vs. solar power: An experimental investigation of the remuneration-related design of community solar offerings. *Energy Policy*, *138*, 111216. https://doi.org/https://doi.org/10.1016/j.enpol.2019.111216

Stauch, A., & Vuichard, P. (2019). Community solar as an innovative business model for building-integrated photovoltaics: An experimental analysis with Swiss electricity consumers. *Energy and Buildings*, *204*, 109526.

Steele, K., Carmel, Y., Cross, J., & Wilcox, C. (2009). Uses and misuses of multicriteria decision analysis (MCDA) in environmental decision making. *Risk Analysis: An International Journal*, *29*(1), 26-33.

Sütterlin, B., & Siegrist, M. (2017). Public acceptance of renewable energy technologies from an abstract versus concrete perspective and the positive imagery of solar power. *Energy Policy*, *106*, 356-366.

Swain, M. M. C. (2019). *Managing stakeholder conflicts over energy infrastructure: case studies from New England's energy transition* Massachusetts Institute of Technology].

Sward, J. A., Nilson, R. S., Katkar, V. V., Stedman, R. C., Kay, D. L., Ifft, J. E., & Zhang, K. M. (2021). Integrating social considerations in multicriteria decision analysis for utility-scale solar photovoltaic siting. *Applied Energy*, *288*, 116543. https://doi.org/https://doi.org/10.1016/j.apenergy.2021.116543

Sward, J. A., Siff, J., Gu, J., & Zhang, K. M. (2019). Strategic planning for utility-scale solar photovoltaic development–Historical peak events revisited. *Applied Energy*, *250*, 1292-1301.

Taha, Z., & Rostam, S. (2011). A fuzzy AHP–ANN-based decision support system for machine tool selection in a flexible manufacturing cell. *The International Journal of Advanced Manufacturing Technology*, *57*(5-8), 719-733. https://doi.org/10.1007/s00170-011-3323-5

Tan, Z., Li, D., & Xu, T. (2022). The future adoption of community shared solar: An unlabeled choice experiment in Guangdong, China. *Journal of Cleaner Production*, *378*. https://doi.org/10.1016/j.jclepro.2022.134417

Thakur, P., & Wilson, V. H. (2022). Analysis of barriers affecting the adoption of community solar from consumer's perspective: A hybrid ISM-DEMATEL approach. *Energy & Environment*. https://doi.org/10.1177/0958305x221122930

Thapar, S., Sharma, S., & Verma, A. (2017). Local community as shareholders in clean energy projects: Innovative strategy for accelerating renewable energy deployment in India. *Renewable Energy*, *101*, 873-885.

Topkaya, S. O. (2012). A discussion on recent developments in Turkey's emerging solar power market. *Renewable and Sustainable Energy Reviews*, *16*(6), 3754-3765. https://doi.org/https://doi.org/10.1016/j.rser.2012.03.019

Trivedi, A., Jakhar, S. K., & Sinha, D. (2021). Analyzing barriers to inland waterways as a sustainable transportation mode in India: a dematel-ISM based approach. *Journal of Cleaner Production*, *295*, 126301.

Tsai, S.-B. (2018). Using the DEMATEL model to explore the job satisfaction of research and development professionals in china's photovoltaic cell industry. *Renewable and Sustainable Energy Reviews*, *81*, 62-68. https://doi.org/https://doi.org/10.1016/j.rser.2017.07.014

Tseng, M.-L., Ardaniah, V., Sujanto, R. Y., Fujii, M., & Lim, M. K. (2021). Multicriteria assessment of renewable energy sources under uncertainty: Barriers to adoption. *Technological Forecasting and Social Change*, *171*, 120937. https://doi.org/https://doi.org/10.1016/j.techfore.2021.120937

Turney, D., & Fthenakis, V. (2011). Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, *15*(6), 3261-3270.

Vakili, S., Schönborn, A., & Ölçer, A. I. (2022). Techno-economic feasibility of photovoltaic, wind and hybrid electrification systems for stand-alone and grid-connected shipyard electrification in Italy. *Journal of Cleaner Production*, *366*, 132945. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.132945

van der Schoor, T., & Scholtens, B. (2019). The power of friends and neighbors: a review of community energy research. *Current opinion in environmental sustainability*, *39*, 71-80.

Van Opstal, W., & Smeets, A. (2022). Market-Specific Barriers and Enablers for Organizational Investments in Solar PV—Lessons from Flanders. *Sustainability*, *14*(20), 13069. https://www.mdpi.com/2071-1050/14/20/13069

Van Opstal, W., & Smeets, A. (2023). When do circular business models resolve barriers to residential solar PV adoption? Evidence from survey data in flanders. *Energy Policy*, *182*, 113761. https://doi.org/https://doi.org/10.1016/j.enpol.2023.113761

Vasseur, V., & Kemp, R. (2015). The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renewable and Sustainable Energy Reviews*, *41*, 483-494. https://doi.org/https://doi.org/10.1016/j.rser.2014.08.020

Vignesh, R., Jarett, Z., Eric, O. S., David, F., Jal, D., Michael, W., Paul, B., & Robert, M. (2022). *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022*. https://www.nrel.gov/docs/fy22osti/83586.pdf

Vihalemm, T., & Keller, M. (2016). Consumers, citizens or citizen-consumers? Domestic users in the process of Estonian electricity market liberalization. *Energy Research & Social Science*, *13*, 38-48. https://doi.org/https://doi.org/10.1016/j.erss.2015.12.004

WAI, M. K. (2014). *Study on the development potential and energy incentives of rooftop solar photovoltaic applications in the Polytechnic University Campus* https://theses.lib.polyu.edu.hk//bitstream/200/7638/1/b27606156.pdf

Walker, B. J. A., Wiersma, B., & Bailey, E. (2014). Community benefits, framing and the social acceptance of offshore wind farms: An experimental study in England. *Energy Research & Social Science*, *3*, 46-54. https://doi.org/https://doi.org/10.1016/j.erss.2014.07.003

Walker, G. (2008). What are the barriers and incentives for community-owned means of energy production and use? *Energy Policy*, *36*(12), 4401-4405.

Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy*, *36*(2), 497-500.

Walker, G., Devine-Wright, P., Hunter, S., High, H., & Evans, B. (2010). Trust and community: Exploring the meanings, contexts and dynamics of community renewable energy. *Energy Policy*, *38*(6), 2655-2663.

Wanderer, T., & Herle, S. (2013). Using a web-based SDSS for siting solar power plants. EnviroInfo,

Wang, L., Kisi, O., Zounemat-Kermani, M., Salazar, G. A., Zhu, Z., & Gong, W. (2016). Solar radiation prediction using different techniques: model evaluation and comparison. *Renewable and Sustainable Energy Reviews*, *61*, 384-397. https://doi.org/https://doi.org/10.1016/j.rser.2016.04.024

Wang, W.-C., Lin, Y.-H., Lin, C.-L., Chung, C.-H., & Lee, M.-T. (2012). DEMATEL-based model to improve the performance in a matrix organization. *Expert Systems with Applications*, *39*(5), 4978-4986. https://doi.org/https://doi.org/10.1016/j.eswa.2011.10.016

Warfield, J. N. (1973). Binary matrices in system modeling. *IEEE Transactions on Systems, Man, and Cybernetics*(5), 441-449.

Warren, C. R., & McFadyen, M. (2010). Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland. *Land use policy*, *27*(2), 204-213.

Watson, J. J., & Hudson, M. D. (2015). Regional Scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation. *Landscape and urban planning*, *138*, 20-31.

Wei, C. K., & Saad, A. Y. (2020). The Potential of Solar Energy for Domestic and Commercial Buildings in Malaysia. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *75*(3), 91-98. https://doi.org/10.37934/arfmts.75.3.9198

Wolske, K. S. (2020). More alike than different: Profiles of high-income and low-income rooftop solar adopters in the United States. *Energy Research & Social Science*, *63*, 101399. https://doi.org/https://doi.org/10.1016/j.erss.2019.101399

Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683-2691. https://doi.org/https://doi.org/10.1016/j.enpol.2006.12.001

Xue, Y., Lindkvist, C. M., & Temeljotov-Salaj, A. (2021). Barriers and potential solutions to the diffusion of solar photovoltaics from the public-private-people partnership perspective–Case study of Norway. *Renewable and Sustainable Energy Reviews*, *137*, 110636.

Yan, J., Yang, Y., Elia Campana, P., & He, J. (2019). City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China. *Nature Energy*, *4*(8), 709-717. https://doi.org/10.1038/s41560-019-0441-z

Yang, H., Wang, M., & Peng, J. (2020). *Actual Performances of PV Panels in the Local Environment*.

Yin, R. (1984). *Case Study Research: Design and Methods*. Beverly Hills, CA. Sage Publications.

Yin, S.-H., Wang, C.-C., Teng, L.-Y., & Hsing, Y. M. (2012). Application of DEMATEL, ISM, and ANP for key success factor (KSF) complexity analysis in R&D alliance. *Scientific Research and Essays*, *7*(19), 1872-1890.

Young, J., & Brans, M. (2017). Analysis of factors affecting a shift in a local energy system towards 100% renewable energy community. *Journal of Cleaner Production*, *169*, 117-124. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.08.023

Yousefi, H., Hafeznia, H., & Yousefi-Sahzabi, A. (2018). Spatial Site Selection for Solar Power Plants Using a GIS-Based Boolean-Fuzzy Logic Model: A Case Study of Markazi Province, Iran. *Energies*, *11*(7), 1648. https://www.mdpi.com/1996-1073/11/7/1648

Yuan, X., Zhang, M., Wang, Q., Wang, Y., & Zuo, J. (2017). Evolution analysis of environmental standards: Effectiveness on air pollutant emissions reduction. *Journal of Cleaner Production*, *149*, 511-520. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.02.127

Yuan, X., Zuo, J., & Ma, C. (2011). Social acceptance of solar energy technologies in China—End users' perspective. *Energy Policy*, *39*(3), 1031-1036. https://doi.org/https://doi.org/10.1016/j.enpol.2011.01.003

Zepter, J. M., Lüth, A., Crespo del Granado, P., & Egging, R. (2019). Prosumer integration in wholesale electricity markets: Synergies of peer-to-peer trade and residential storage. *Energy and Buildings*, *184*, 163-176. https://doi.org/https://doi.org/10.1016/j.enbuild.2018.12.003

Zhang, R., & Lee, M. (2023). Optimization of Feed-in Tariff mechanism for residential and industrial photovoltaic adoption in Hong Kong. *Journal of Cleaner Production*, *406*, 137043. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.137043

Zhang, R., Lee, M., & Huang, L. (2023). Grid parity analysis of photovoltaic systems considering feed-in tariff and renewable energy certificate schemes in Hong Kong. *Renewable and Sustainable Energy Reviews*, *181*, 113326. https://doi.org/https://doi.org/10.1016/j.rser.2023.113326

Zhang, R., Lee, M., Zhao, D., Kang, H., & Hong, T. (2023). Peer-to-peer trading price and strategy optimization considering different electricity market types, tariff systems, and pricing models. *Energy and Buildings*, *300*, 113645. https://doi.org/https://doi.org/10.1016/j.enbuild.2023.113645

Zhang, S. (2016). Innovative business models and financing mechanisms for distributed solar PV (DSPV) deployment in China. *Energy Policy*, *95*, 458-467. https://doi.org/https://doi.org/10.1016/j.enpol.2016.01.022

Zhou, D., Shah, T., Jebran, K., Ali, S., & Ali, A. (2017). Acceptance and willingness to pay for solar home system: Survey evidence from northern area of Pakistan. *Energy Reports*, *3*, 54-60.